II-VI INFRARED ... the world leader in CO_2 laser optics

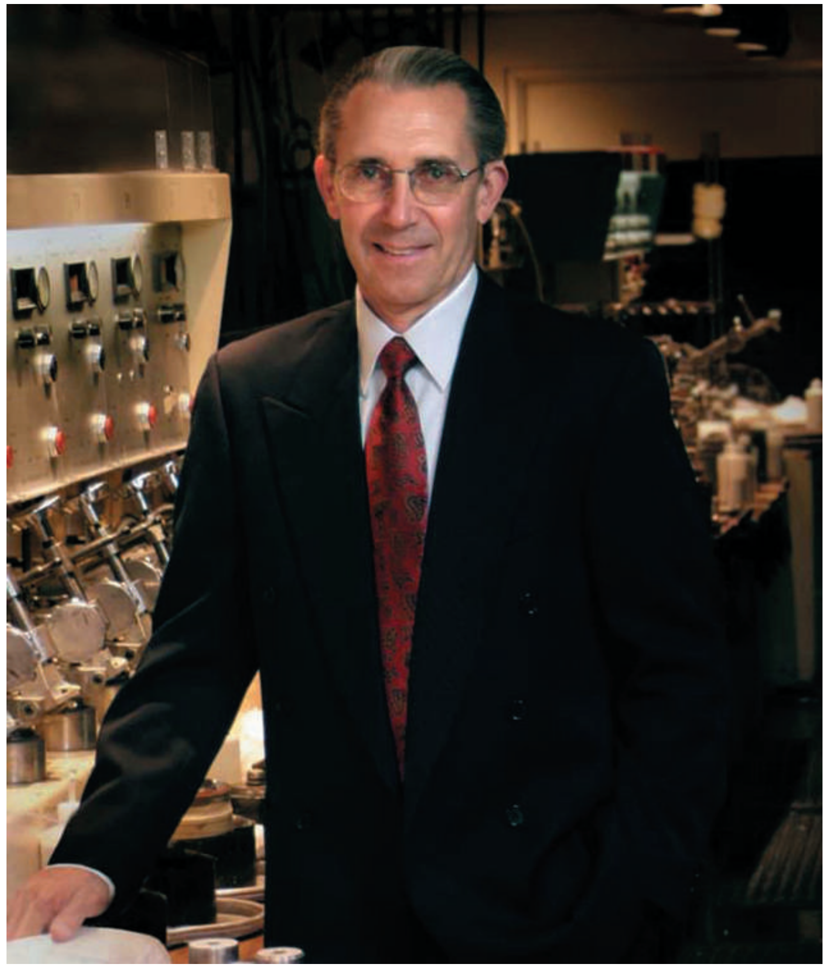
OPTICS CATALOG AND REFERENCE GUIDE

www.iiviinfrared.com

Chemical Code Key

- Al — Aluminum
- CdTe — Cadmium telluride
- Cu — Copper
- GaAs — Gallium arsenide
- Ge — Germanium
- Mo — Molybdenum
- Si — Silicon
- ZnSe — Zinc selenide
- ZnS — Zinc sulfide
- ZnS MS — Zinc sulfide MultiSpectral

Please see page 114 for other abbreviations.



Dr. Carl J. Johnson, II-VI Incorporated's founder and chairman of the board

II-VI INCORPORATED'S HISTORY

In 1971, II-VI Incorporated began by exclusively producing the highest-quality materials available for manufacturing high-power industrial CO_2 laser optics. Today, we have diversified into numerous business units for near-infrared optics, YAG components, and telecommunications components (VLOC); defense and aerospace optics (Exotic Electro-Optics); selenium and tellurium metals and products (PRM); thermoelectric cooling devices (Marlow Industries); silicon carbide (II-VI WBG); and advanced materials development (II-VI AMDC).

As II-VI Incorporated continues to grow, we focus on the company's original, industry-leading products: infrared materials and CO_2 laser optics. And thanks to decades of innovation in ZnSe materials processing, thin-film coating, precision diamond turning, and finished optics fabrication, II-VI Infrared is the world leader in CO_2 laser optics. From developing original equipment optics for the world's top laser manufacturers, to producing replacement laser optics for end users, our company delivers an unbeatable combination of innovation, quality, and experience. II-VI Infrared also delivers the largest vertically integrated CO_2 laser optics manufacturing process — from raw materials to finished coated products — in the world.

II-VI Infrared's products range from replacement CO_2 laser optics and nozzles to lenses, partial reflectors, windows, beamsplitters, mirrors, beam expanders, reflective phase retarders, scanning-laser system optics, diamond-turned custom optics, and more. Our products and reputation make us the number-one supplier to original equipment manufacturers of CO_2 laser systems worldwide, while our capabilities are without rival in the industry.

Our diamond turning facility is among the largest and most advanced in the world, offering services such as flycutting and multiple-axis turning, as well as fast- and slow-tool servos for custom optics. Single-point diamond turning is used in finishing transmissive optics and mirrors in a variety of metals and IR materials.

Major investments in computer design programs, evaporation equipment, clean rooms, and testing facilities enable us to offer a broad range of IR thin-film coatings. II-VI Infrared is known for designing and producing consistently low-absorption coatings for high-power CO_2 laser optics. Additionally, our talented and experienced engineering team, using optical design software and CAD systems, designs and builds standard and custom optics as well as specialized mounts, components, and electro-optic assemblies.

Our quality assurance program includes comprehensive testing, documentation, and statistical analysis to ensure that each optic and component performs to customer requirements.

This catalog provides a comprehensive overview of our capabilities, products, and services. For additional information, contact a II-VI Infrared sales and support representative.

Francis J. Kramer, II-VI Incorporated's chief executive officer and president

HOW DID II-VI GET ITS NAME?

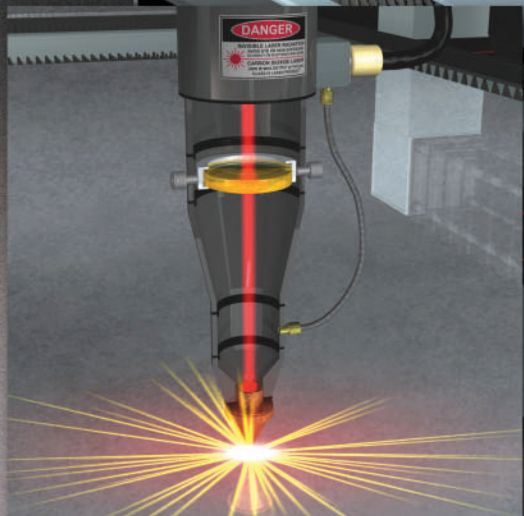
II-VI Infrared. The name is synonymous with the world's greatest CO_2 laser optics and infrared optical materials. But what, exactly, does the name mean?

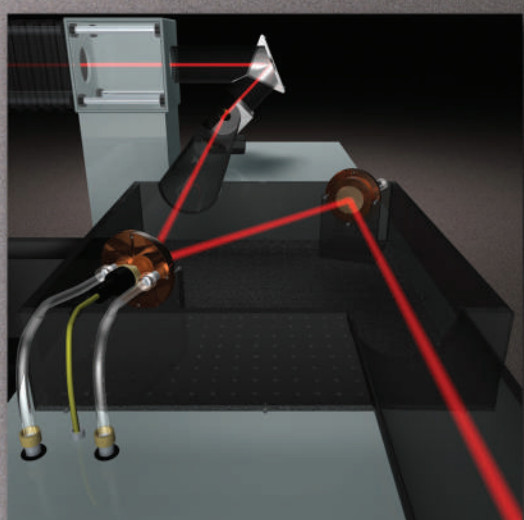
The Roman numerals "II-VI" refer to Column II and Column VI of the Periodic Table of Elements. By chemically combining elements from Column II and Column VI, we produce the infrared optical crystalline compounds zinc selenide, zinc sulfide, and zinc sulfide MultiSpectral. These compounds, and others created from Column II and Column VI elements, are commonly referred to as "II-VI materials." When we were founded in 1971, company founder, Dr. Carl J. Johnson, paid homage to our II-VI materials heritage and called our new company "II-VI Incorporated."

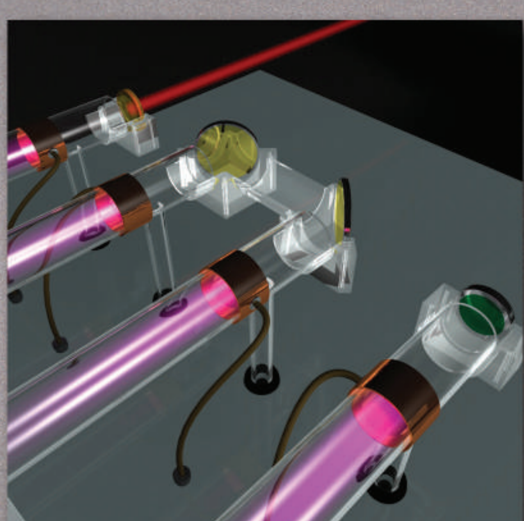
In the ensuing years, as our infrared optics manufacturing capabilities expanded into precision diamond turning and world-class thin-film coatings, our corporation grew as well. Through strategic acquisitions, II-VI Incorporated expanded far beyond infrared optical materials and finished optics products, building a portfolio of companies that share in our materials heritage yet bring a vastly diversified range of products to market, including gamma-ray detectors, thermoelectric coolers, and silicon carbide substrates.

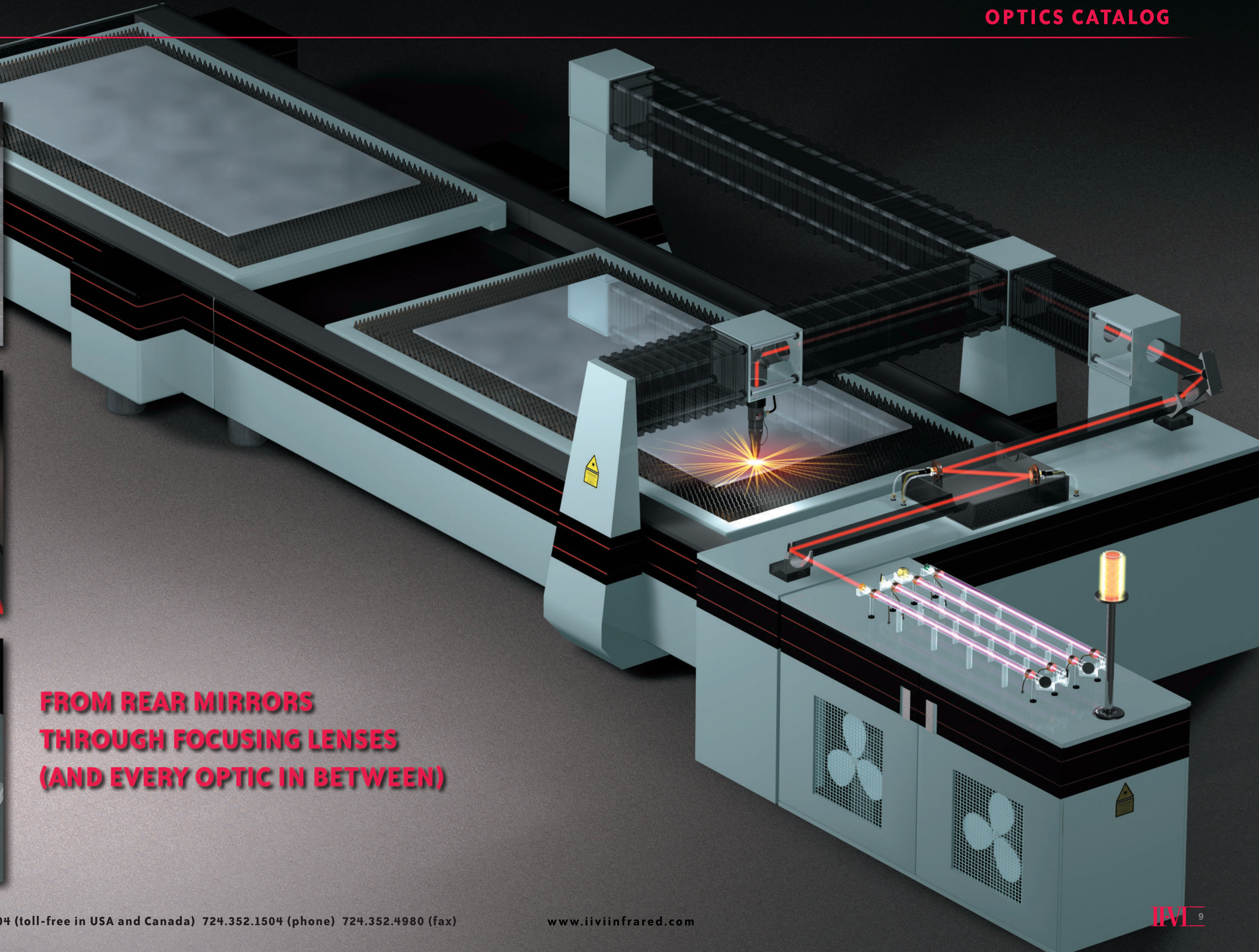
In recognizing that "II-VI Incorporated" represents far more today than when originally founded, we recently christened our core optical materials and finished optics business unit "II-VI Infrared." This differentiates it from the corporate whole, and reflects upon our 36-year heritage of producing the world's finest infrared and CO_2 laser optics.

To learn more, visit our website at www.iiviinfrared.com.









FROM REAR MIRRORS THROUGH FOCUSING LENSES (AND EVERY OPTIC IN BETWEEN)

CAPABILITIES

CRYSTAL GROWTH

II-VI Incorporated was founded in 1971 to supply better materials to infrared optics producers. Initially starting with cadmium telluride, II-VI gravitated to producing zinc selenide and zinc sulfide during the 1980s.

II-VI produces zinc selenide and zinc sulfide by using a process called chemical vapor deposition (CVD). In specially designed furnaces, zinc vapors are reacted with hydrogen selenide or hydrogen sulfide gas to produce zinc selenide or zinc sulfide, respectively. The reaction deposits the material in crystalline form on the deposition plates. Following the removal from the furnace, material is cut, polished, and tested for optical quality. The material is then used to produce optics or sold as sheet stock or optic blanks.

A chemical vapor deposition (CVD) furnace

Products Offered

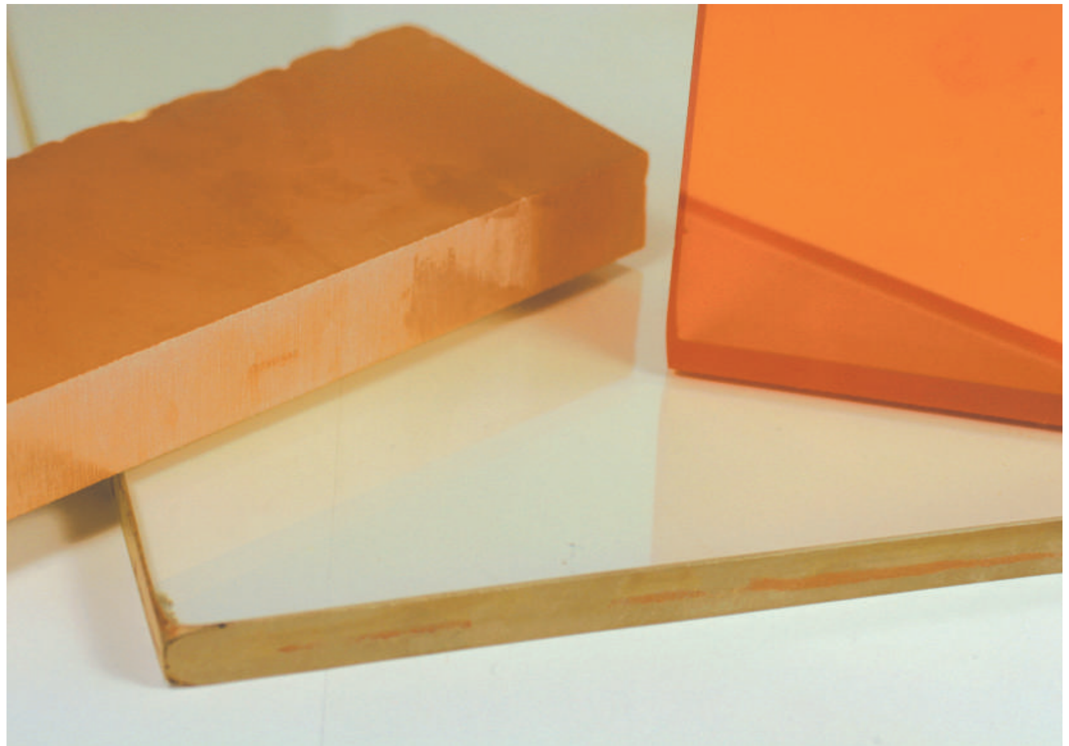
II-VI Infrared produces the following infrared materials (pictured below):

- Zinc selenide
- Zinc sulfide regular grade
- Zinc sulfide MultiSpectral grade

Zinc sulfide MultiSpectral grade is regular grade material treated after growth using a hot isostatic press process to remove growth voids and defects. The result is a product that is useful within the infrared and visible spectrums.

II-VI offers a wide variety of standard sizes and thicknesses for sheet stock and optic blanks, and produces custom sizes and thicknesses upon request.

After chemical vapor deposition, zinc selenide material undergoes the blanking and grinding process to remove what II-VI calls "alligator skin."



II-VI Infrared's three materials fabricated at our Saxonburg plant, from left to right: zinc sulfide, zinc sulfide MultiSpectral, and zinc selenide.

OPTICS FABRICATION

Finished optics manufacturing requires unique techniques coupled with precision-machining and fabrication. II-VI's Saxonburg plant has provided optical fabrication capabilities to our customers since 1971. On average, our operators have 15 years of optical fabrication experience. Although we specialize in build-to-print work, our state-of-the-art equipment enables production ranging from prototypes to OEM products.

Our production facilities in Saxonburg, Singapore, and Suzhou are custom designed for grinding and polishing infrared optics.

The finished products produced in our facilities include windows, lenses, prisms, modulators, waveplates, mirrors, beamsplitters, and cylinders. In addition to finished optics, we also produce generated, core-drilled, and sufficient material to yield (SMTY) blanks.

The blanking and grinding department is capable of shaping and machining varieties of optical materials and geometries. To achieve our customer's requirements, II-VI's skilled technicians utilize computer numeric controlled (CNC) shaping and precision-curve generating equipment.

Polishing is performed on numerous materials and configurations. Opticians utilize the following methods to polish optics: CNC high-speed polishing, double-sided polishing, conventional-spindle polishing, and cylinder polishing.

Typical polishing specifications utilized by the optical fabrication department include:

- Diameters: 4 to 200 mm typical, larger available upon request
- Thickness: 0.5 to 50 mm
- Angles: < 5 arc seconds
- Surface Accuracy: to 1⁄20 wave
- Parallelism: to 2 arc seconds

II-VI can also polish optical material to precise customer specifications. Materials fabricated at our facilities include:

- Zinc selenide (ZnSe)
- Zinc sulfide (ZnS)
- Zinc sulfide MultiSpectral (ZnS MS)
- Germanium (Ge)
- Gallium arsenide (GaAs)
- Silicon (Si)
- Cadmium telluride (CdTe)
- Molybdenum (Mo)

A II-VI Infrared optician operating a CNC polishing machine.

A II-VI Infrared optician evaluates a zinc selenide lens during the polishing process.

DIAMOND TURNING

We established the II-VI diamond turning facility in 1988, with a Pneumo MSG500 flycutter purchase. Today, we are an industry leader in diamond-turned components for commercial, military, and aerospace customers. Our facility offers:

- Single- and dual-axis flycutting
- Two-axis turning
- Slow- and fast-tool servos for non-rotationally symmetric geometries
- High-purity aluminum plated (Alumiplate™) mirrors
- Prototype to production quantities
- Thermal cycling
- Dedicated cleaning
- 14,000 ft^2 facility
- 24/7 operation

Diamond Turning Advantages

- Diamond turning can produce complex geometries not possible using conventional optical polishing techniques.
- Deterministic process achieves high degrees of accuracy and repeatability.
- Certain materials that are difficult to polish are easily diamond-machined.
- Optical and mechanical interfaces of bolt-together assemblies are generated and controlled throughout the diamond turning process (i.e., scan lens housings and off-axis parabolas).
- New servo system designs enable the manufacture of non-rotationally symmetric geometries.

A II-VI diamond turning technician cuts spherical parts on a two-axis lathe.

Zinc selenide (ZnSe) aspheric lens

High-Volume Flycutting

II-VI uses single-point diamond flycutting machines with CNC controllers capable of producing high-volume plano (flat) geometries. We can produce surface finishes on OFHC copper of less than 50 Angstroms RMS, surface finishes on 6061 aluminum of less than 60 Angstroms RMS, and figure accuracies of λ/4 peak-to-valley at 0.6328µm on both materials.

Products include:
- Laser beam delivery mirrors
- Laser cavity mirrors
- Steering and head mirrors for military/aerospace
- Variable radius mirrors (VRMs)
- Faceted lenses and mirrors for laser beam integration
- Pyramidal polygons for laser scanning
- Components for space and cryogenic applications

Two-Axis Turning

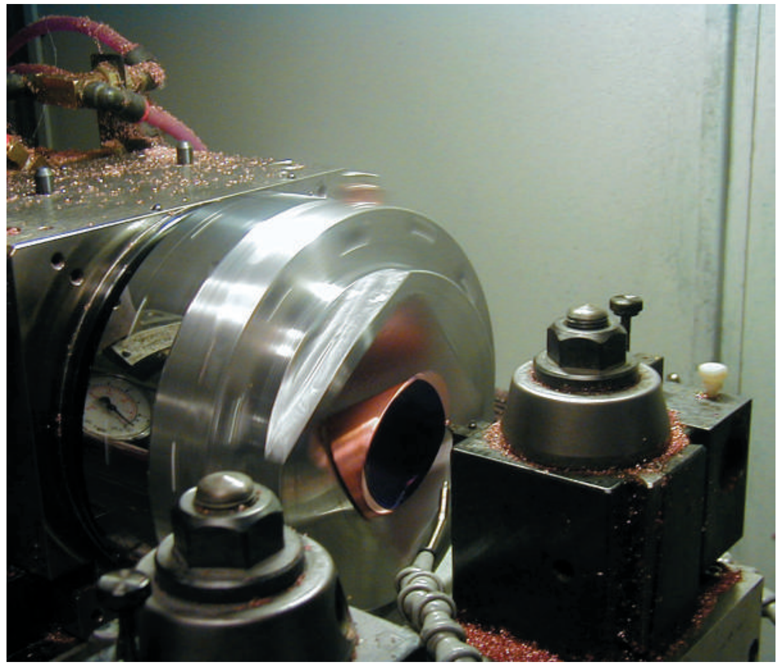
Our two-axis lathes are CNC controlled with positional resolutions as low as 16 pm. Our largest format lathe is the Nanoform 700, which is capable of producing on-axis parts up to 700 mm in diameter and weighing up to 200 pounds. Our Nanoform 250 Ultra machines are capable of surface finishes less than 20 Angstroms RMS and figure accuracies of λ/6 peak-to-valley at 0.6328µm.

Products include:
- Parabolic beam-focusing optics
- Spherical mirrors for laser cavities
- Aspheric focusing lenses
- Telecentric lenses for micro-via drilling
- Reflective beam expanders
- Cylindrical optics
- Custom aerospace components
- Reflective telescopes and seeker/sensor optics
- Components for space and cryogenic applications

Free-Form Turning

Non-rotationally symmetric geometries have become more common since the development of slow-tool servo (STS) and fast-tool servo (FTS) technologies. Both require adding a high-resolution encoder to the spindle of a standard diamond turning lathe for precise angular position data. With STS, the entire Z-axis moves back and forth throughout each spindle revolution. STS programs are defined in three dimensions X, Z, and C (linear, linear, and rotational) and the stroke length is limited only by the travel of the slide. It is ideal for producing large toroidal and off-axis parabolic geometries. The FTS is a piezo-electric actuated diamond tool that mounts to a standard diamond turning lathe. The stroke of the FTS is calculated in real time as a function of the X and C (linear and rotational) positions. It has a very high frequency response and 70µm of travel, which is ideal for producing faceted and stepped geometries.

Products include:
- Faceted beam integrators (reflective and transmissive)
- Optical arrays
- Long-working-distance parabolas
- Toroidal optics
- Free-form phase correction optics
- Cylindrical optics



A long-working-distance parabolic mirror is cut with II-VI Infrared's slow-tool servo.

THIN-FILM COATING

II-VI is the recognized leader in designing and producing consistently low-absorption coatings for high-power CO_2 laser optics. Our thin-film coating facility completes our vertically integrated component capability to allow optical fabrication, diamond turning, and coating to be performed at the same location. Having a combined 170 years of experience, the II-VI coating department staff offers a broad coating range for CO_2 laser and infrared imaging applications.

The Quality Difference

- Custom-designed, state-of-the-art coating equipment in our high-volume infrared coating shops in Saxonburg and Singapore provide maximum OEM production capacity
- Recognized as a quality supplier for coat-only services, custom thin-film designs, and military/aerospace defense services
- Manufactures to the customers' highest quality standards in performance, testing, and cosmetic requirements
- Prototype coating designs, custom optical tooling, cleaning services
- Automated computer and electronic controls for consistent and repeatable process monitoring
- Clean room manufacturing (class 1,000 to 10,000), 12,000 sq. ft. area
- Established practice in "Make It the Same," to ensure a consistent quality product regardless of where it is manufactured

II-VI provides a broad coating range for laser and infrared imaging applications:

- Coatings on optics up to 16" in diameter
- Coatings for wavelengths from the visible to infrared (0.45 to 25 µm)
- Custom coating designs
- High-efficiency broadband anti-reflective coatings
- High-damage threshold low-absorption laser coatings
- Very high-reflectivity mirror coatings
- Broadband beamsplitter coatings
- Substrates: zinc selenide, zinc sulfide, zinc sulfide MultiSpectral, germanium, gallium arsenide, silicon, copper, aluminum, amtir, fused silica, silicon carbide, beryllium, molybdenum, and other infrared transmitting materials
- Optical tooling designs to hold most complex optical shapes and fixtures
- MilSpec testing capabilities with additional internal stringent testing to meet most durability requirements
- Customized coatings to meet customer needs and demands

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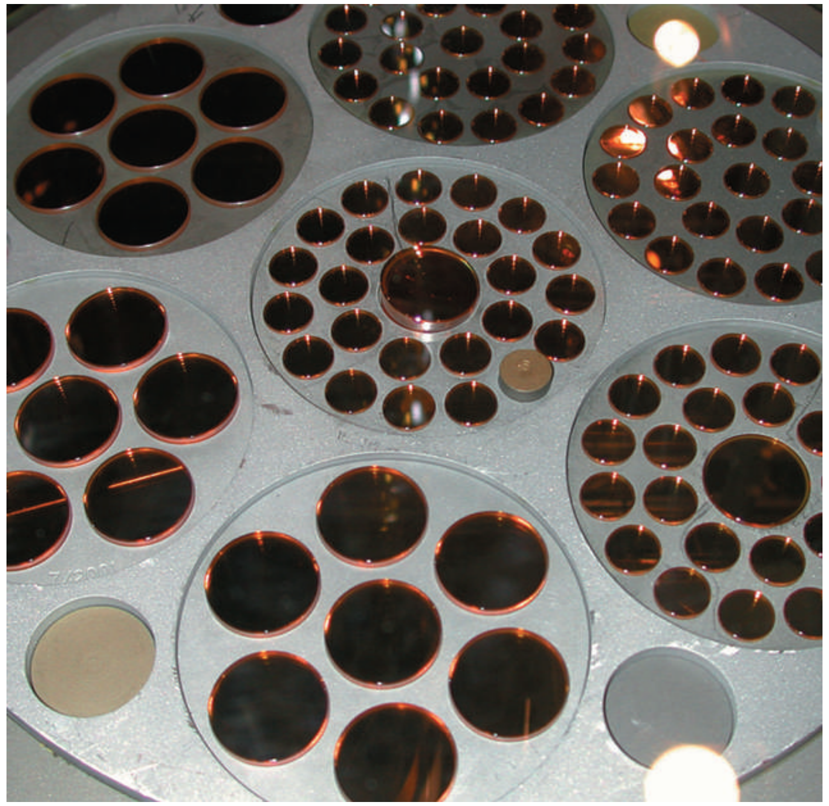
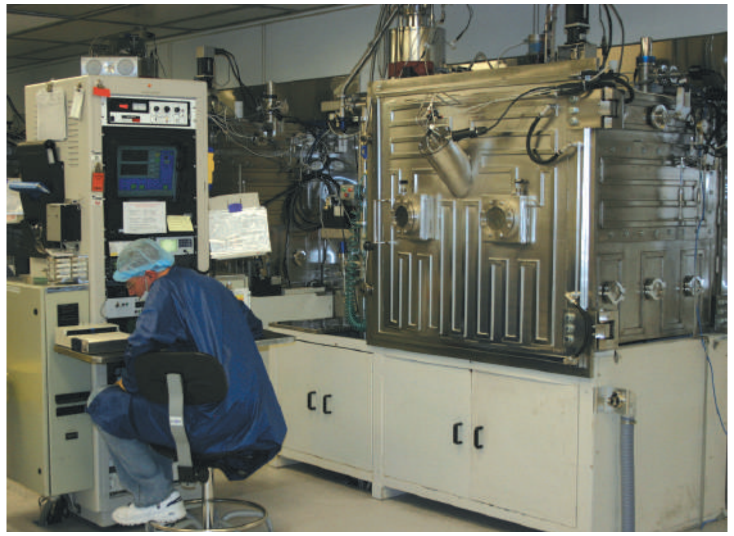


A coating tool with ZnSe lenses.



A coating technician monitors the coating process.

THIN-FILM COATING

(Continued from page 16.)

Beam Delivery Coatings

We offer both high-reflective and transmission type coatings for all beam delivery applications.

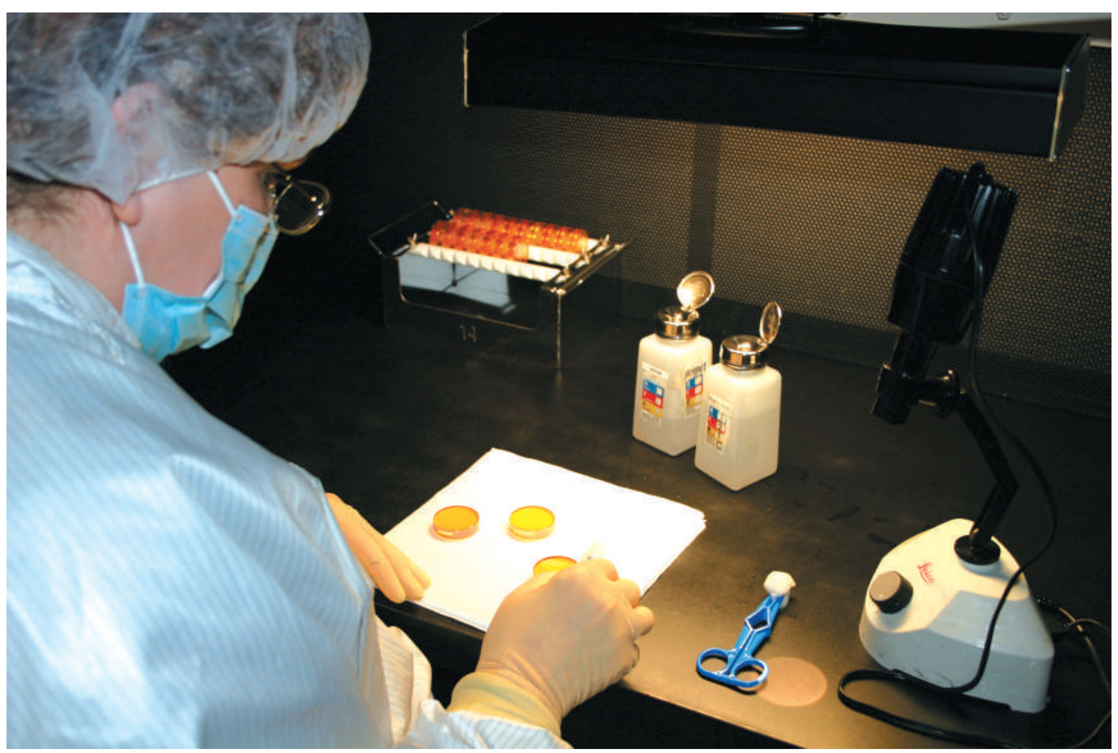
Reflective Coatings

- MMR: our highest-reflection bend mirror coatings
- ATFR: minimizes laser feedback
- RPR: controls polarization and provides precision phase shift
  - o 90°
  - o 45°
  - o 22.5°
- TRZ: maintains incident polarization

Transmissive Coatings

Our AR coatings provide consistently low absorption and reflection to meet the high-power CO_2 laser application needs demanded by OEM and aftermarket users.

- AR coatings available
  - o CO_2 (CW)
  - o CO_2 pulsed
  - o Dual wavelength
  - o Dichroic
  - o Ultra-low absorption MP-5®
- Other custom wavelengths
  - o Thin-Film Polarizer (TFP)
  - o Dichroic beamsplitters
  - o Other beamsplitters



A II-VI Infrared cleaning technician inspects parts before the coating process.

Coating chambers at our Saxonburg facility.

Resonator Coatings

Substrates: ZnSe, Ge, GaAs

Partial Reflectors

Our consistent, low-absorbing coatings offer a wide wavelength range and reflection values for 0.25 to 10 inch part diameters. These parts are available in OEM volumes to custom one of a kind.

- 5 to 98% reflective (standard)
  - o CW
  - o Pulsed
  - o Ultra-low absorption MP-5®
  - o Band-selective*

Rear Mirrors

Our all-dielectric coatings for high reflection, low absorption with controlled transmission are used in laser power monitoring.

- 99 to 99.85% R (partial)
  - o ZnSe, Ge, GaAs

II-VI also offers coatings for low-absorption total reflectors.

- Total reflective coating
  - o MMR and MMR-A (total)
    - Si, Cu
- Band-selective coating*
  - o Stable resonator
    - ZnSe, Ge, GaAs
  - o Unstable
    - Si, Cu

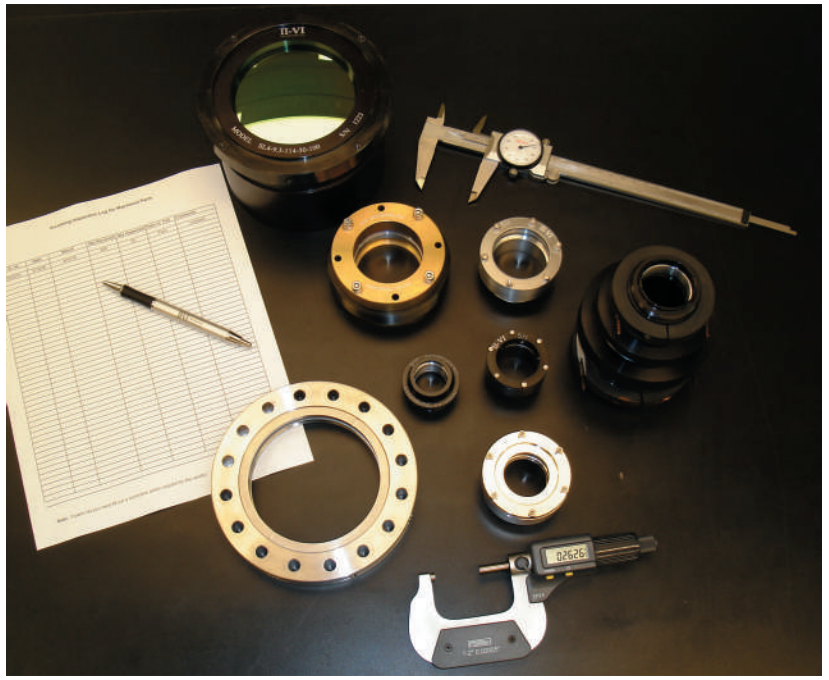
Fold Mirrors

Our low-absorption-coated intercavity mirrors are used to increase laser power or if desired, as polarization locking mirrors.

- MMR/MMR-A
- PLM
- EG

** Specialized coatings designed to help force the laser cavity to lase at a desired wavelength band. Reflection and wavelength values are available in a wide range.*

OPTICAL ASSEMBLY



II-VI's optical assembly capability allows customers to minimize optic handling, thereby reducing risks such as damage and contamination. We offer these vertically integrated capabilities:

- Pro/ENGINEER® 3D modeling
- Precision machine shop work
- Plating processes
- Diamond turning
- Helium leak testing
- Laminar flow hood
- Optical testing and alignment

II-VI will design and manufacture custom prototypes or high-volume production quantities. Our engineers can design unique mounts and assemblies or build to original equipment manufacturer (OEM) specifications. This latter ability reduces the work needed at the customer's facility to assemble the optical component for use.

Special facilities, manufacturing, procedures, and technician training programs are essential to the repeatability and precision required in the optical and electro-optical components and device assembly. At II-VI, various stages of optics assembly and mounting are performed in Class 10,000 clean rooms and on Class 1,000 Laminar Flow benches.

By designing and producing optical assemblies, II-VI helps the customer:

- Achieve consistent product quality by reducing the risks associated with handling optics and lowering the potential for distorting the optic
- Verify product quality by undertaking optical testing of the mounted component

OPTICAL DESIGN & ENGINEERING

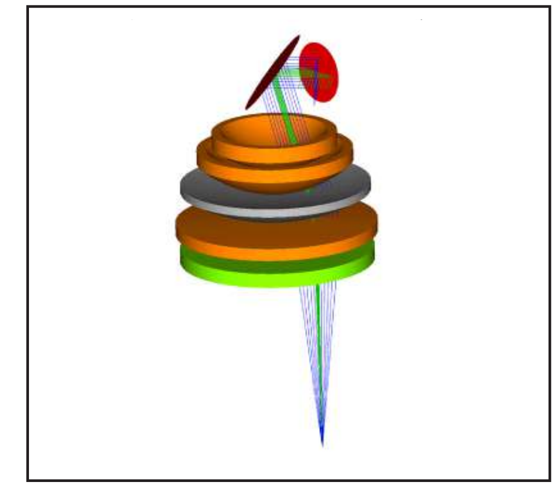
II-VI Infrared's manufacturing capabilities are based on an optics foundry concept. Our aim is to provide consistent product quality the OEM laser builders require.

Our optical design and engineering group supports our customers in:

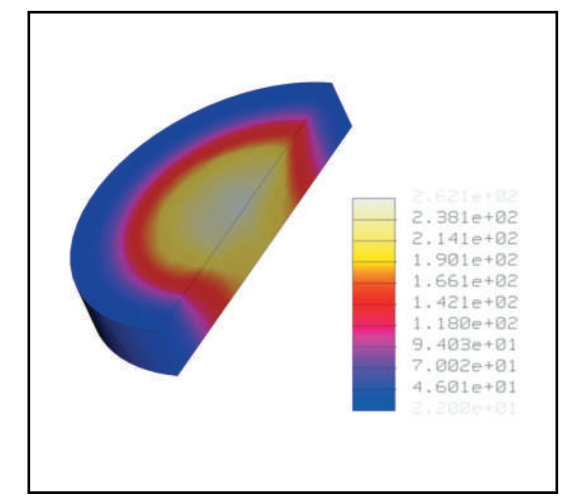
- Developing new products and creating solutions for market applications
- Defining their product needs so the component we deliver will work in its given applications
- Reducing customer risk by drawing from our extensive experience for supplying CO_2 laser components
- Interpreting common electronic drawing formats and optical design prescriptions in Code V™, Zemax®, and OSLO®

By using design capabilities to verify the customer product design, II-VI Infrared produces the internal documentation, tooling, and processes to make a component. Designs received from all over the world are communicated to the shop floor in consistent formats that are familiar to our opticians and quality personnel.

A II-VI Infrared engineer working with CAD software Pro/ENGINEER® to render a 3D model of one of II-VI's optical assemblies.



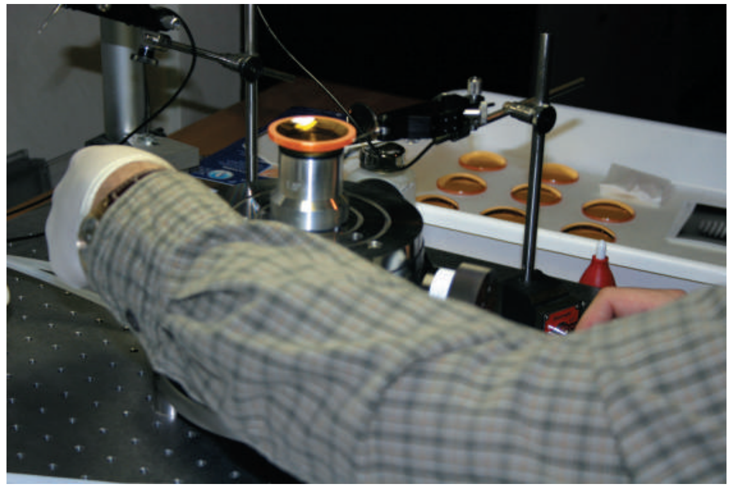
A four-element scan lens with debris window (in green) showing galvo mirror locations and the ray trace using OSLO® lens design software.



A heat transfer analysis performed on a zinc sulfide lens, using the finite element analysis software package, Pro/MECHANICA®.

QUALITY ASSURANCE

The quality assurance program at II-VI includes thorough testing, documentation, and statistical analysis to ensure that each optic and component performs to established standards. Dimensional and surface testing equipment, both optical and mechanical, coupled with spectrophotometers and precision reflectivity and transmission test systems, guarantee consistent quality. The material absorption is measured by custom designed laser calorimeters.



A quality assurance metrology technician checks for edge thickness variation on ZnSe lenses before the parts are inspected.

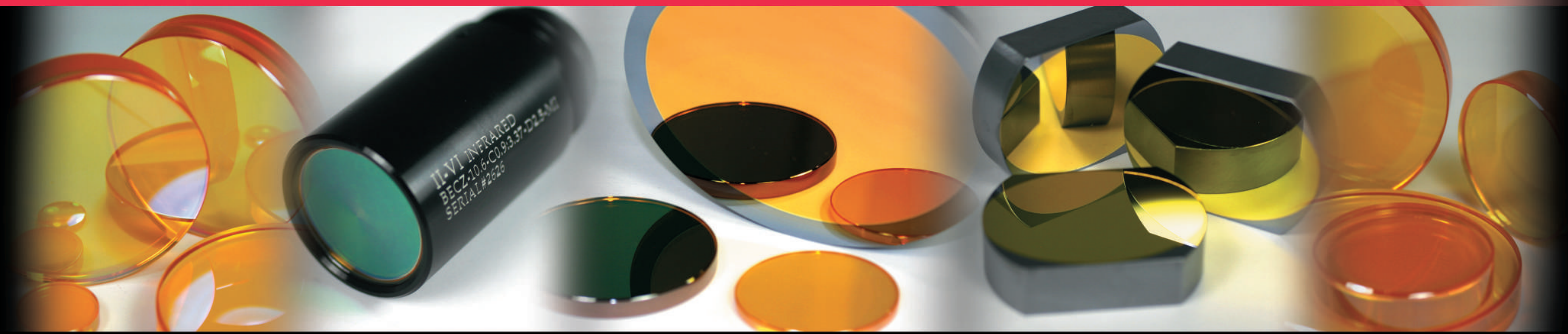
Our quality assurance inspectors clean and inspect every part before shipping our products to our customers.

INTERNATIONAL SALES & SUPPORT

The sales and technical support staff at our headquarters in Saxonburg is complemented by a highly qualified international distributor network. Our worldwide organization provides optical design services for custom IR systems. Our engineers can help with specifications and optics selection for virtually any laser or beam delivery system. Every order is reviewed by our technical experts to ensure that the optics specified match our customers' needs.

A II-VI Infrared sales representative is always willing to assist and help with any order.

PRODUCTS



MATERIAL OVERVIEW

II-VI Incorporated was founded in 1971 to supply better materials to infrared optics producers. Initially starting with cadmium telluride, II-VI gravitated to producing zinc selenide and zinc sulfide during the 1980s. II-VI's vertical integration, from materials growth through precision optics manufacturing, positions the company as the leader in CO_2 laser optics.

Today, II-VI Infrared is the world's leading producer of ZnSe material. Our ZnS and ZnS MultiSpectral materials are used in a growing number of infrared systems both domestic and abroad.

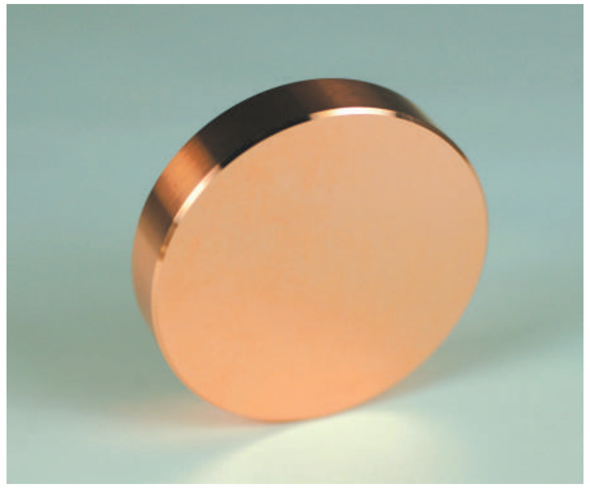
Common Transmissive Substrates

	Optical Properties			Thermal Properties		Mechanical Properties			
Material	Bulk Absorption Coefficient @ 10.6μm (/cm)	Refractive Index @ 10.6μm (unitless)	Temp. Change of Refractive Index @ 10.6μm ($x10^{-6}$/°C)	Thermal Conductivity @ 20°C (W/cm/°C)	Linear Expansion Coefficient @ 20°C ($x10^{-6}$/°C)	Young's Modulus ($x10^6$ psi)	Rupture Modulus ($x10^3$ psi)	Hardness (Knoop)	Mass Density (g/cm^3)
Amtir-1	0.02	2.495	77	0.0025	13.0	3.20	2.5	170	4.40
CaF_2	2x10*	1.4289*	-11.5*	0.10	18.9	11.0	5.4	158	3.18
CdTe	0.0018	2.674	107	0.062	5.9	5.40	3.2	45	5.85
CVD Diamond	0.10	2.375	9.6	12-20	1.0	152.3	36.3	10,000	3.51
Fused Silica	~0.0001*	1.45*	10*	0.014	0.55	10.6	7.3	600	2.20
GaAs	0.01	3.275	149	0.48	5.6	12.04	20.0	750	5.31
Ge	0.03	4.003	408	0.59	6.0	14.50	13.5	692	5.32
KCl	0.00014	1.455	-33	0.065	36.0	4.35	0.64	7.2-9.3	1.98
NaCl	0.00045	1.491	-22	0.065	44.0	5.80	4.1	18.2	2.16
Si	1.5	3.418	160	1.56	2.56	19.00	17.0	1150	2.33
ZnSe	0.0005	2.403	61	0.18	7.57	9.75	8.0	105-120	5.27
ZnS	0.24	2.192	41	0.167	6.8	10.80	15.0	210-240	4.08
ZnS MS	<0.0005*	2.287*	~42*	0.272	6.5	12.40	10.0	150-160	4.09

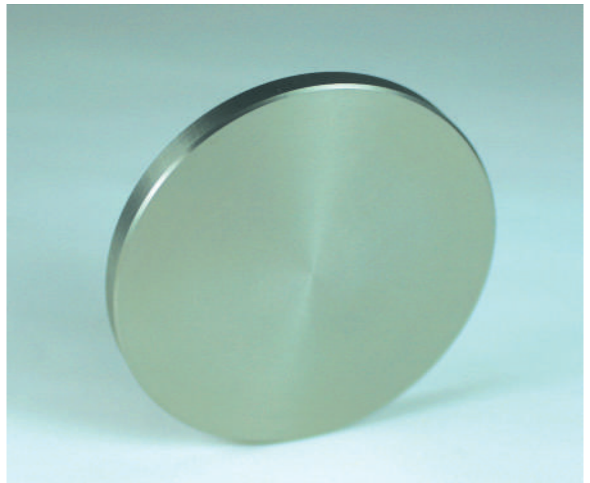
* Values @ 1.07μm

Common Metallic Substrates

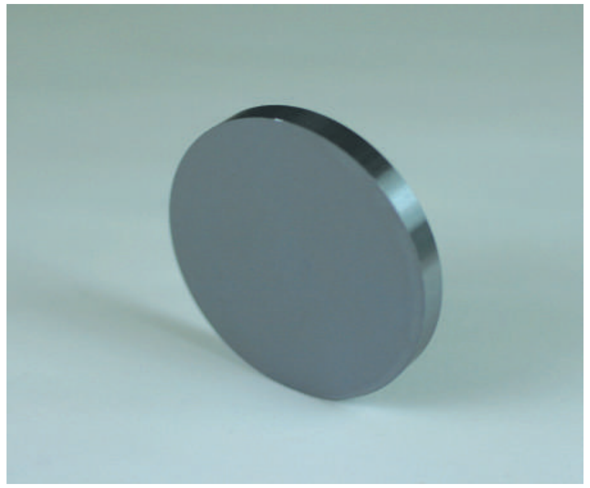
	Thermal Properties			Mechanical Properties		
Material	Specific Heat (J/g/°C)	Thermal Conductivity @ 20°C (W/cm/°C)	Expansion Coefficient @ 20°C ($x10^{-6}$/°C)	Young's Modulus ($x10^6$ psi)	Hardness (Mohs)	Mass Density (g/cm^3)
Cu	0.385	3.90	16.7	17	3	8.96
Mo	0.250	1.33	5.4	47	6	10.2
Si	0.716	1.56	2.6	29	7	2.32
Al	0.900	1.67	22.5	10	2.75	2.7



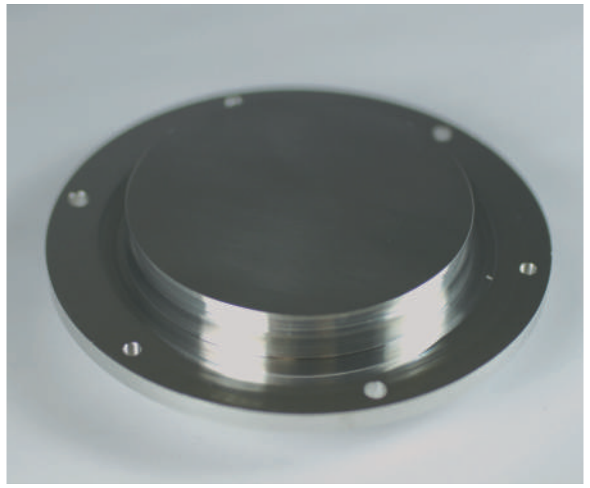
Copper substrate



Molybdenum substrate



Silicon substrate



Aluminum substrate

MATERIAL

Zinc Selenide (ZnSe)

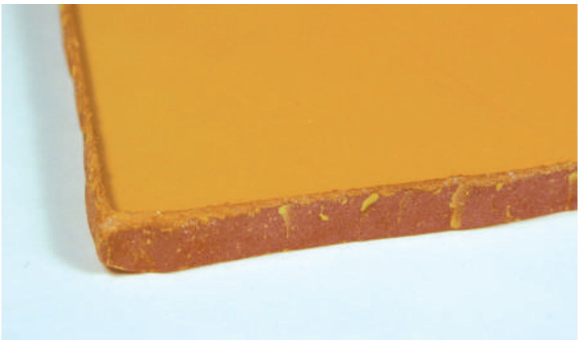
Thermo-Optic Coefficient @ Various Wavelengths
dn/dT (10^{-5}°C^{-1})

Temp °C	Wavelength 0.632µm	1.15µm	3.39µm	10.6µm
-180	7.6	5.4	5.0	4.9
-160	8.2	5.7	5.2	5.1
-140	8.7	6.0	5.4	5.4
-120	9.1	6.3	5.6	5.5
-100	9.4	6.5	5.8	5.7
-80	9.7	6.6	5.9	5.8
-60	10.0	6.7	6.0	5.9
-40	10.2	6.8	6.1	6.0
-20	10.3	6.9	6.1	6.0
0	10.5	7.0	6.2	6.1
20	10.6	7.0	6.2	6.1
40	10.7	7.0	6.2	6.1
60	10.8	7.1	6.3	6.1
80	10.9	7.1	6.3	6.2
100	11.0	7.2	6.3	6.2
120	11.1	7.2	6.4	6.3
140	11.3	7.3	6.4	6.3
160	11.5	7.4	6.5	6.4
180	11.8	7.6	6.6	6.6
200	12.1	7.8	6.7	6.7
σ[a]	0.1	0.1	0.1	0.1

[a]Standard deviation from a third degree polynomial fit

A.Feldman et al, "Optical Materials Characterization Final Technical Report Feb. 1, 1978 - Sept. 30, 1978," National Bureau of Standards Technical Note 933, Pages 53 and 54.

Prism grade zinc selenide



ZnSe is a preferred material for lenses, windows, output couplers, and beam expanders for its low absorptivity at infrared wavelengths and its visible transmission. For high-power applications, it's critical that the material bulk absorption and internal defect structure be carefully controlled, that minimum-damage polishing technology be employed, and the highest quality optical thin-film coatings be used. The material absorption is verified by CO_2 laser vacuum calorimetry. Our quality assurance department provides testing and specific optics certification on request.

ZnSe optics are routinely polished from 5 to 300 mm in diameter. Sizes greater than 300 mm diameter and 25 mm thick are manufactured to customer requirements.

ZnSe is non-hygroscopic and chemically stable, unless treated with strong acids. It's safe to use in most industrial, field, and laboratory environments.

Prism Grade Zinc Selenide

II-VI Infrared has the capability to grow prism grade ZnSe up to 2.50" thick. Prism grade ZnSe exhibits minimal refractive index variations within the material on planes perpendicular to the growth direction as well as in other directions. Index variations will test to less than 3 ppm at 0.6328 microns regardless of orientation. Prism grade ZnSe is commonly used in thermal imaging systems. Call our technical sales staff to discuss your specific requirements for material greater than 2.50" thick.

- Refractive index variation less than 3 ppm @ 0.6328µm in all directions
- Consistent optical performance independent of orientation
- Thickness to 2.50"

ZINC SELENIDE

Material Properties

Optical Properties

Bulk Absorption Coefficient @ 10.6µm	≤ 0.0005 cm^{-1}
Temperature Change of Refractive Index @ 10.6µm	61 x 10^{-6}/°C
Refractive Index Inhomogeneity @ 0.6328µm	< 3 x 10^{-6}

Thermal Properties

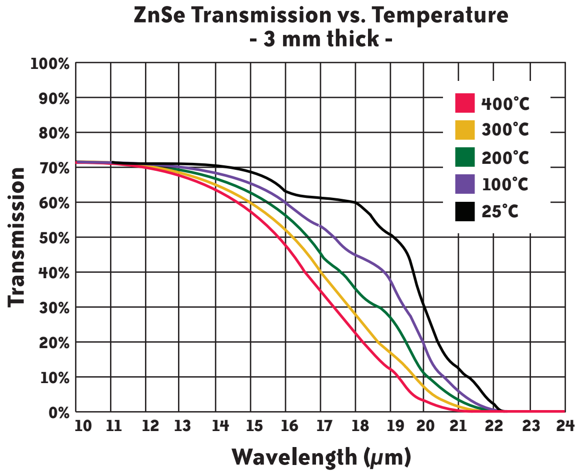
Thermal Conductivity @ 20° C	0.18 W/cm/°C
Specific Heat	0.356 J/g/°C
Linear Expansion Coefficient @ 20° C	7.57 x 10^{-6}/°C

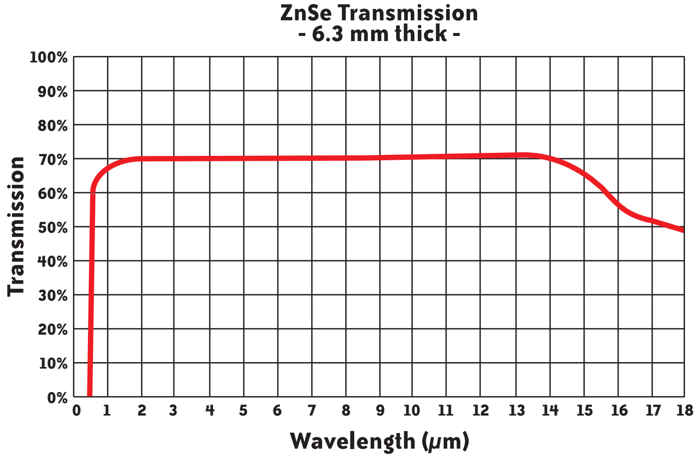
Mechanical Properties

Young's Modulus	67.2 GPa (9.75 x 10^6 psi)
Rupture Modulus	55.1 MPa (8,000 psi)
Knoop Hardness	105-120 kg/mm^2
Density	5.27 g/cm^3
Poisson's Ratio	0.28

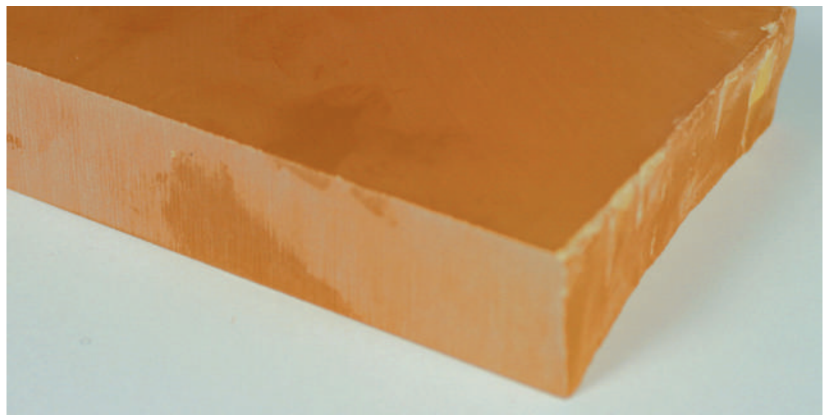
Refractive Indices

Wavelength (µm)	Index	Wavelength (µm)	Index	Wavelength (µm)	Index	Wavelength (µm)	Index
0.54	2.6754	1.8	2.4496	7.4	2.4201	13.0	2.3850
0.58	2.6312	2.2	2.4437	7.8	2.4183	13.4	2.3816
0.62	2.5994	2.6	2.4401	8.2	2.4163	13.8	2.3781
0.66	2.5755	3.0	2.4376	8.6	2.4143	14.2	2.3744
0.70	2.5568	3.4	2.4356	9.0	2.4122	14.6	2.3705
0.74	2.5418	3.8	2.4339	9.4	2.4100	15.0	2.3665
0.78	2.5295	4.2	2.4324	9.8	2.4077	15.4	2.3623
0.82	2.5193	4.6	2.4309	10.2	2.4053	15.8	2.3579
0.86	2.5107	5.0	2.4295	10.6	2.4028	16.2	2.3534
0.90	2.5034	5.4	2.4281	11.0	2.4001	16.6	2.3487
0.94	2.4971	5.8	2.4266	11.4	2.3974	17.0	2.3448
0.98	2.4916	6.2	2.4251	11.8	2.3945	17.4	2.3387
1.0	2.4892	6.6	2.4235	12.2	2.3915	17.8	2.3333
1.4	2.4609	7.0	2.4218	12.6	2.3883	18.2	2.3278



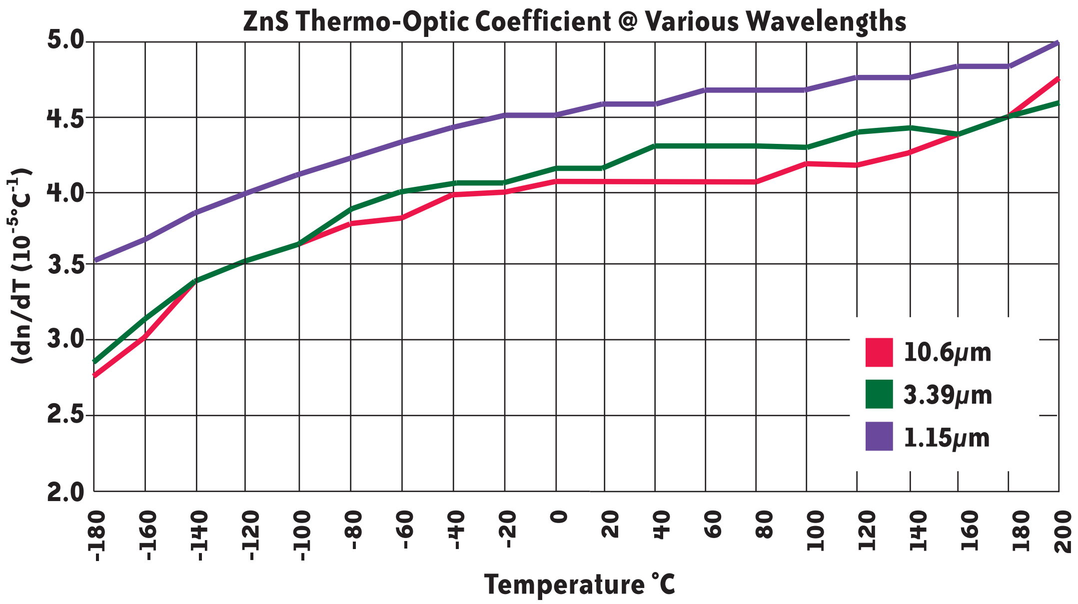


MATERIAL
Zinc Sulfide (ZnS)



ZnS grown by chemical vapor deposition (CVD) at II-VI Infrared exhibits exceptional fracture strength and hardness leading to its frequent choice for military applications or other harsh environments. This material is often used in the 8 to 12 µm region. Its high resistance to rain erosion, high-speed dust, and particulate abrasion, makes it especially suitable for exterior IR windows on aircraft frames.

ZnS has a lower cost relative to ZnSe and ZnS MS, and has potential wherever a tough and strong IR transmitting material is required.



888.558.1504 (toll-free in USA and Canada) 724.352.1504 (phone) 724.352.4980 (fax)

ZINC SULFIDE

Material Properties

Optical Properties

Bulk Absorption Coefficient @ 10.6µm	≤ 0.24 cm^{-1}
Temperature Change of Refractive Index @ 10.6µm	41 x 10^{-6}/°C
Refractive Index Inhomogeneity @ 10.6µm	< 100 x 10^{-6}

Thermal Properties

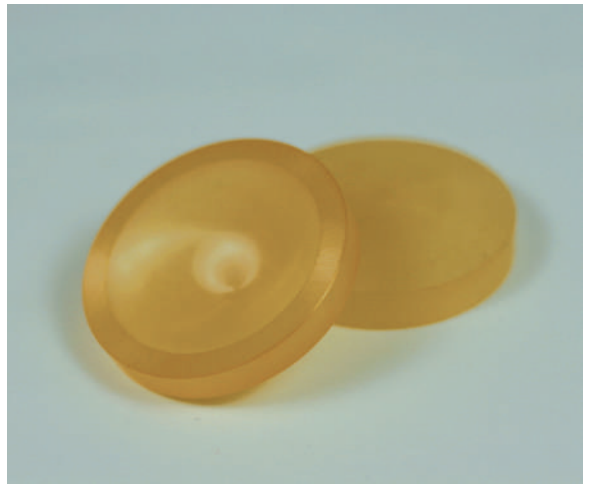
Thermal Conductivity @ 20° C	0.167 W/cm/°C
Specific Heat	0.469 J/g/°C
Linear Expansion Coefficient @ 20° C	6.8 x10^{-6}/°C

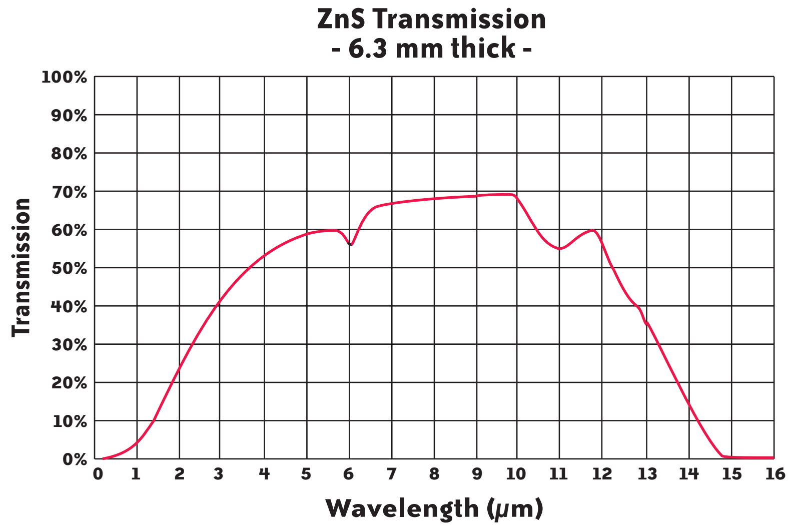
Mechanical Properties

Young's Modulus	74.5 GPa (10.8 x 10^6 psi)
Rupture Modulus	103.4 MPa (15,000 psi)
Knoop Hardness	210-240 kg/mm^2
Density	4.08 g/cm^3
Poisson's Ratio	0.27

Refractive Indices

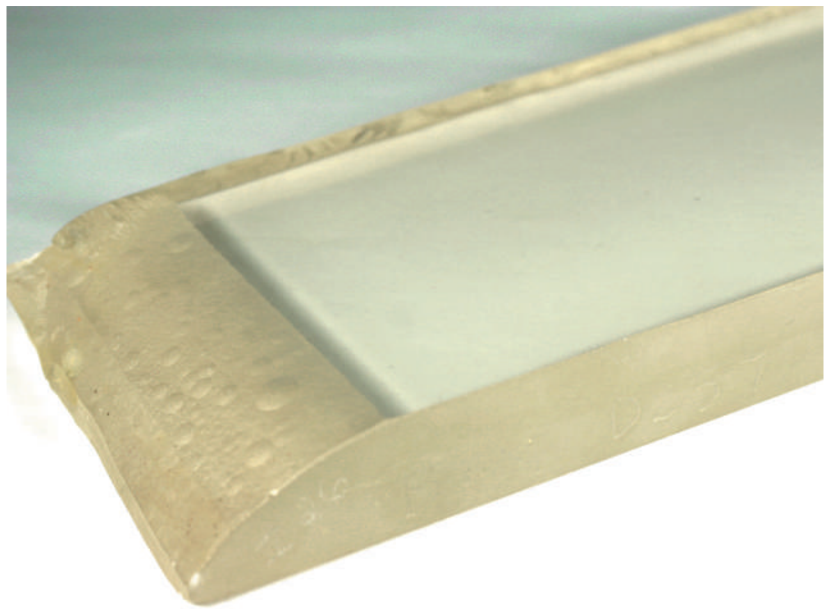
Wavelength (µm)	Index	Wavelength (µm)	Index	Wavelength (µm)	Index	Wavelength (µm)	Index
0.42	2.516	1.0	2.292	7.0	2.232	13.0	2.152
0.46	2.458	1.4	2.275	7.4	2.228	13.4	2.143
0.50	2.419	1.8	2.267	7.8	2.225	13.8	2.135
0.54	2.391	2.2	2.263	8.2	2.221	14.2	2.126
0.58	2.371	2.6	2.260	8.6	2.217	14.6	2.116
0.62	2.355	3.0	2.257	9.0	2.212	15.0	2.106
0.66	2.342	3.4	2.255	9.4	2.208	15.4	2.095
0.70	2.332	3.8	2.253	9.8	2.203	15.8	2.084
0.74	2.323	4.2	2.251	10.2	2.198	16.2	2.072
0.78	2.316	4.6	2.248	10.6	2.192	16.6	2.059
0.82	2.310	5.0	2.246	11.0	2.186	17.0	2.045
0.86	2.305	5.4	2.244	11.4	2.180	17.4	2.030
0.90	2.301	5.8	2.241	11.8	2.173	17.8	2.015
0.94	2.297	6.2	2.238	12.2	2.167	18.2	1.998
0.98	2.294	6.6	2.235	12.6	2.159		





MATERIAL

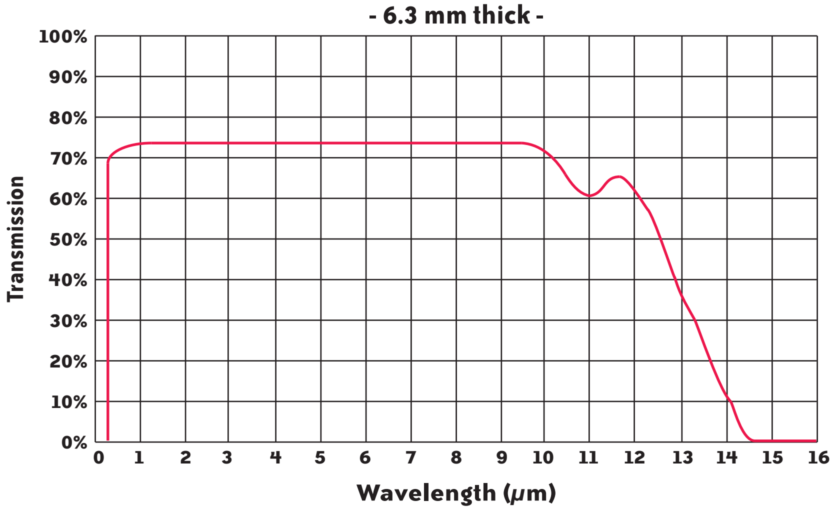
Zinc Sulfide MultiSpectral (ZnS MS)



ZnS MultiSpectral is II-VI Infrared's zinc sulfide material treated by a hot isostatic press (HIP) process. Under intense heat and pressure, defects within the crystalline lattice are virtually eliminated, leaving a water-clear material with minimal scatter and high transmission characteristics from 0.4 to 12 µm. This material is particularly well suited for high-performance common aperture systems that must perform across a broad wavelength spectrum.

II-VI Infrared's extensive capabilities, equipment, and experience enable us to offer ZnS MS material to exacting specifications of dimensional shape and tolerances. ZnS MS material is also available in random sizes and shapes for use as evaporative source material.

ZnS MultiSpectral Transmission
- 6.3 mm thick -



ZINC SULFIDE MULTISPECTRAL

Material Properties

Optical Properties

Bulk Absorption Coefficient @ 10.6µm	≤ 0.20 cm^{-1}
Temperature Change of Refractive Index @ 0.6328µm	54 x 10^{-6}/°C
Refractive Index Inhomogeneity @ 0.6328µm	< 20 x 10^{-6}

Thermal Properties

Thermal Conductivity @ 20 °C	0.27 W/cm/°C
Specific Heat	0.527 J/g/°C
Linear Expansion Coefficient @ 20 °C	6.5 x10^{-6}/°C

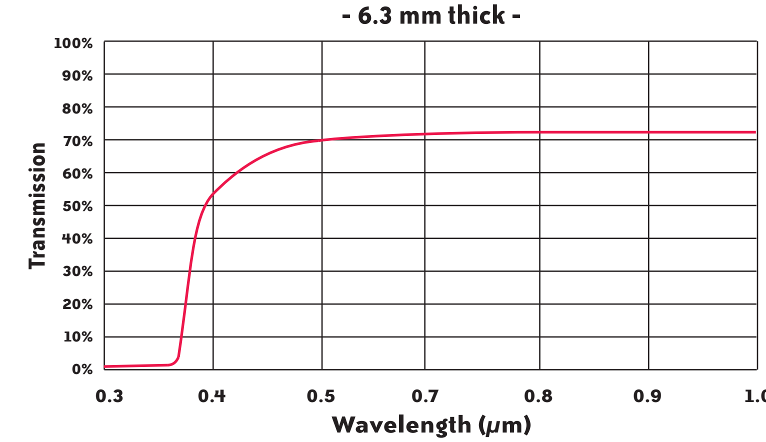
Mechanical Properties

Young's Modulus	85.5 GPa (12.4 x 10^6 psi)
Rupture Modulus	68.9 MPa (10,000 psi)
Knoop Hardness	150-160 kg/mm^2
Density	4.09 g/cm^3
Poisson's Ratio	0.27

Refractive Indices

Wavelength (µm)	Index	Wavelength (µm)	Index
0.4047	2.54515	1.1287	2.28485
0.4358	2.48918	1.5296	2.27191
0.4678	2.44915	2.0581	2.26442
0.4800	2.43691	3.000	2.25772
0.5086	2.41279	3.500	2.25498
0.5461	2.38838	4.000	2.25231
0.5876	2.36789	4.500	2.24955
0.6438	2.34731	5.000	2.24661
0.6678	2.34033	8.000	2.22334
0.7065	2.33073	9.000	2.21290
0.7800	2.31669	10.000	2.20084
0.7948	2.31438	11.250	2.18317
0.8521	2.30659	12.000	2.17101
0.9843	2.30183	13.000	2.15252
1.0140	2.29165		

ZnS MultiSpectral Transmission
- 6.3 mm thick -



MATERIAL BLANKS

Optical Fabrication Options

II-VI offers its infrared materials to customers who have their own optical manufacturing capability. Our ZnSe, ZnS, and ZnS MS are offered in a variety of shapes and configurations.

Sheet Material

Materials can be ordered in sheet form by specifying the material's length x width x thickness. The material will be supplied to minimum +0.200" of the specified length and width. The thickness provided will be minimum +0.010" over specified thickness (Figure 1).

Sufficient Material To Yield (SMTY)

Material ordered in this manner will be provided in irregularly shaped configurations that have been measured with templates to ensure they will yield a predetermined quantity of specific diameters. The thickness provided will be minimum +0.010" over specified thickness. It is important to take into account material removal amounts before specifying a SMTY thickness (Figure 2).

Core-Drilled Blanks

Core-drilled blanks are initially machined with the closest oversized diameter core-drill tool that's at least 0.080" greater than the core-drilled blank diameter required by the customer. Core-drilled blanks have no bevels, edge chips will not exceed 0.030". The thickness provided will be minimum +0.010" over specified thickness(Figure 3 on page 35).

Edged Blanks

Circular, square or rectangular parts are specified with standard dimensional tolerances of +0.000"/-0.005". The thickness provided will be minimum +0.010" over specified thickness. Bevels are specified, also (Figure 4 on page 35).

Generated Curved Lens Blanks

Blanks can be ordered with curves generated and edges beveled. Standard thickness tolerance is +/-0.010". Tolerances on radii depend upon the curve steepness in relation to diameter (Figure 5 on page 35).

Note: Customer may discuss tighter than the above stated tolerances and specifications with our technical sales staff.

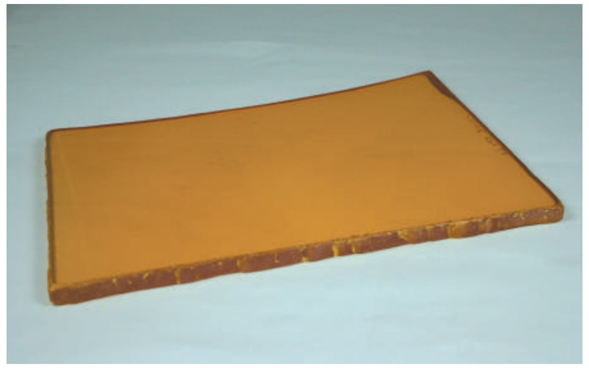


Figure 1 Zinc selenide sheet material

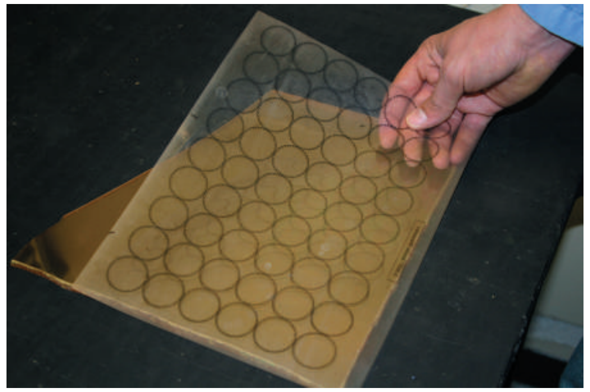


Figure 2 SMTY material being measured with a template

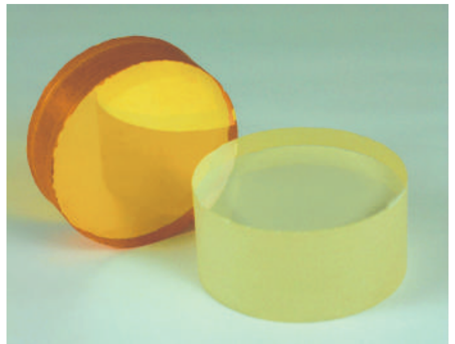


Figure 3 Core-drilled blanks

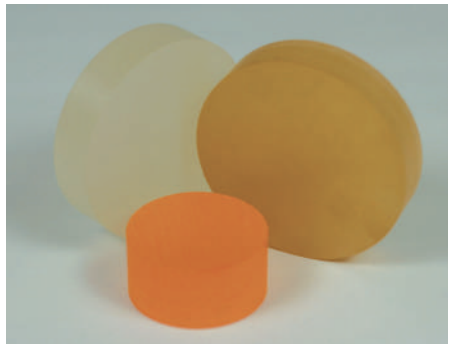


Figure 4 Edged blanks

Figure 5 Generated curved lens blanks

Surface Finishes

II-VI Infrared offers the following surface finishes on ZnSe, ZnS, and ZnS MS blanks. Core-drilled blanks may contain any of the standard surface finishes unless otherwise specified.

- **As Generated (AG)**
  Machined with a 220 grit wheel; produces a dull fine ground finish with generator marks visible to the unaided eye. Requires additional grinding prior to further processing for an optical finish.
- **Fine Ground (FG)**
  Mechanically lapped using a 15µm aluminum oxide slurry; produces a dull fine-ground finish free of scratches as viewed by the unaided eye.
- **View Polished (VP)**
  Multi-stage mechanically polished to a transparent finish as viewed by the unaided eye; requires further processing for an optical finish. Used for inspection of internal quality cosmetics to guarantee the visual quality of the material. Edges are beveled and free of chips as viewed by the unaided eye.

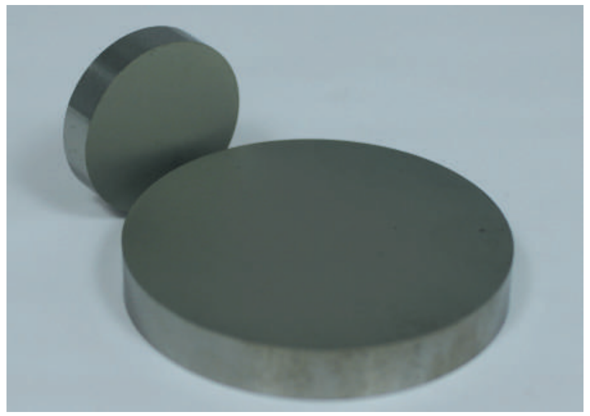
Note: All ZnSe and ZnS MultiSpectral materials are view polished to inspect internal quality, regardless of surface finish.

MATERIAL
Germanium (Ge)

Germanium is a versatile infrared material commonly used in imaging systems and instruments in the 2 to 12 µm spectral region. It is used as a substrate for lenses, windows, and output couplers for low-power CW as well as pulsed TEA, CO_2 lasers. The lowest absorbing Ge optics are limited to a throughput power range of 50 to 100 watts before thermal lensing or thermal runaway. These problems are minimized by properly heatsinking the optic and carefully cleaning contaminated optical surfaces.

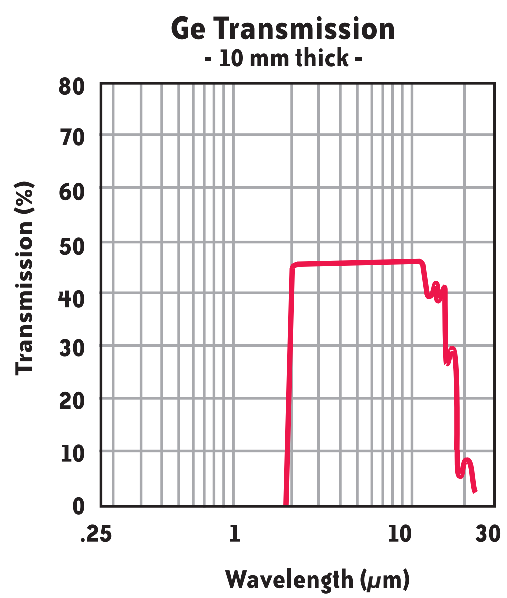
Ge is non-hygroscopic and non-toxic, has good thermal conductivity, excellent surface hardness, and good strength. II-VI carefully monitors the 10.6µm Ge absorptivity for use in laser applications to assure that thermal runaway and fracture do not occur.

One ideal laser application for Ge is a > 99% reflecting back mirror for a CO_2 laser with built-in power meters. A high-reflecting, low-absorption dielectric coating is on one side and an AR coating on the other. The laser operates on the feedback from the high-reflecting side, but enough power leaks through for monitoring by a power meter. II-VI supplies these optics for a number of commercial laser applications.



Material Properties

Optical Properties	
Bulk Absorption Coefficient @ 10.6µm	≤ 0.03 cm^{-1}
Temperature Change of Refractive Index @ 10.6µm	408 x 10^{-6}/°C
Thermal Properties	
Thermal Conductivity @ 20° C	0.59 W/cm/°C
Specific Heat	0.31 J/g/°C
Linear Expansion Coefficient @ 20° C	5.7 x 10^{-6}/°C
Mechanical Properties	
Young's Modulus	100 GPa (14.0 x 10^6 psi)
Rupture Modulus	93 MPa (13,500 psi)
Knoop Hardness	692 kg/mm^2
Density	5.32 g/cm^3
Poisson's Ratio	0.27



Refractive Indices

Wavelength (µm)	Index	Wavelength (µm)	Index	Wavelength (µm)	Index	Wavelength (µm)	Index
2.2	4.0879	5.0	4.0160	7.8	4.0061	10.6	4.0028
2.4	4.0732	5.2	4.0149	8.0	4.0057	10.8	4.0026
2.6	4.0599	5.4	4.0139	8.2	4.0053	11.0	4.0025
2.8	4.0523	5.6	4.0128	8.4	4.0049	11.2	4.0024
3.0	4.0451	5.8	4.0118	8.6	4.0044	11.4	4.0023
3.2	4.0399	6.0	4.0107	8.8	4.0042	11.6	4.0023
3.4	4.0311	6.2	4.0097	9.0	4.0040	11.8	4.0022
3.6	4.0289	6.4	4.0092	9.2	4.0038	12.0	4.0021
3.8	4.0267	6.6	4.0087	9.4	4.0036	12.2	4.0020
4.0	4.0245	6.8	4.0083	9.6	4.0034	12.4	4.0020
4.2	4.0223	7.0	4.0079	9.8	4.0033	12.6	4.0019
4.4	4.0205	7.2	4.0074	10.0	4.0031	12.8	4.0019
4.6	4.0189	7.4	4.0070	10.2	4.0030	13.0	4.0018
4.8	4.0172	7.6	4.0066	10.4	4.0029		

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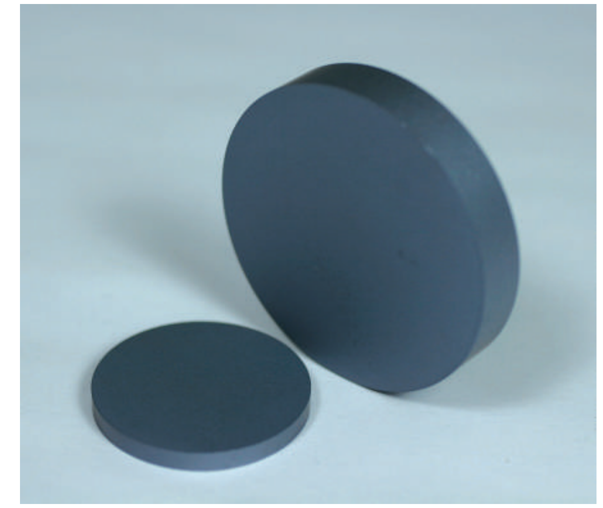
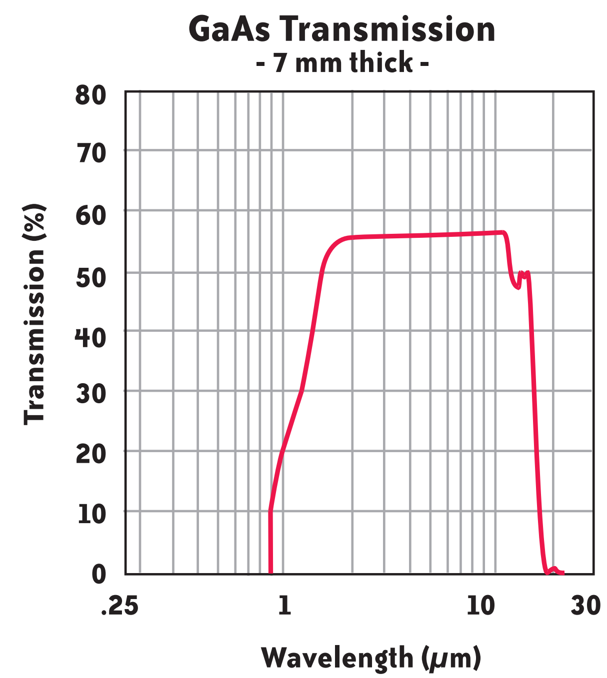


MATERIAL
Gallium Arsenide (GaAs)

Semi-insulating GaAs provides an alternative to ZnSe in medium and high-power CW CO_2 laser systems for lenses and rear mirrors. GaAs is particularly useful in applications where toughness and durability are important. Its hardness and strength make GaAs a good choice where dust or abrasive particles tend to build up or bombard the optical surface. Softer substrates allow particles to embed in the optic even when the best coatings are used.

GaAs is manufactured for semiconductor applications rather than optical applications, so careful material screening is vital in producing quality GaAs optics. At II-VI, we utilize laser vacuum calorimetry and other techniques to screen out materials with voids, inclusions, or other defects which cause inferior optical performance.

GaAs optics are limited by crystal growth technology to diameters typically less than 10 cm. The material is non-hygroscopic, safe to use in laboratory and field applications, and chemically stable except when contacted with strong acids.



Material Properties

Optical Properties	
Bulk Absorption Coefficient @ 10.6µm	≤ 0.01 cm^{-1}
Temperature Change of Refractive Index @ 10.6µm	149 x 10^{-6}/°C
Thermal Properties	
Thermal Conductivity @ 20° C	0.48 W/cm/°C
Specific Heat	0.325 J/g/°C
Linear Expansion Coefficient @ 20° C	5.7 x 10^{-6}/°C
Mechanical Properties	
Young's Modulus	83 GPa (12.04 x 10^6 psi)
Rupture Modulus	138 MPa (20,000 psi)
Knoop Hardness	750 kg/mm^2
Density	5.37 g/cm^3
Poisson's Ratio	0.31

Refractive Indices

Wavelength (µm)	Index	Wavelength (µm)	Index	Wavelength (µm)	Index	Wavelength (µm)	Index
2.6	3.3239	5.4	3.2991	8.2	3.2868	11.0	3.2725
2.8	3.3204	5.6	3.2982	8.4	3.2859	11.2	3.2713
3.0	3.3169	5.8	3.2972	8.6	3.2849	11.4	3.2701
3.2	3.3149	6.0	3.2963	8.8	3.2840	11.6	3.2690
3.4	3.3129	6.2	3.2955	9.0	3.2830	11.8	3.2678
3.6	3.3109	6.4	3.2947	9.2	3.2818	12.0	3.2666
3.8	3.3089	6.6	3.2939	9.4	3.2806	12.2	3.2651
4.0	3.3069	6.8	3.2931	9.6	3.2794	12.4	3.2635
4.2	3.3057	7.0	3.2923	9.8	3.2782	12.6	3.2620
4.4	3.3045	7.2	3.2914	10.0	3.2770	12.8	3.2604
4.6	3.3034	7.4	3.2905	10.2	3.2761	13.0	3.2589
4.8	3.3022	7.6	3.2896	10.4	3.2752	13.2	3.2573
5.0	3.3010	7.8	3.2887	10.6	3.2743	13.4	3.2557
5.2	3.3001	8.0	3.2878	10.8	3.2734	13.6	3.2541

PLANO-CONVEX LENSES

Specifications	Standards
Effective Focal Length (EFL) Tolerance	±2%
Dimensional Tolerance	Diameter: +0.000"/-0.005" Thickness: ±0.010"
Edge Thickness Variation (ETV)	≤ 0.002"
Clear Aperture (polished)	90% of diameter
Surface Figure at 0.63µm	Plano: 1 fringe Power, ½ fringe Irregularity Radius: Power and irregularity vary depending upon radius
Scratch-Dig	20-10
AR Coating Reflectivity per Surface at 10.6µm	≤ 0.20%

Part #	Description	Diameter inches	Diameter (mm)	Focal Length inches	Working Distance inches	Edge Thickness inches	Edge Thickness (mm)
123265	ZnSe	0.50	12.7	1.0	-	0.060	1.52
379095	ZnSe	0.75	19.05	1.0	-	0.085	2.16
104370	ZnSe	1.0	25.4	2.5	-	0.085	2.16
614868	ZnSe	1.0	25.4	5.0	-	0.102	2.59
949585	ZnSe	1.0	25.4	10.0	-	0.111	2.82
696289	ZnSe	1.1	27.94	2.5	-	0.085	2.16
561067	ZnSe	1.1	27.94	5.0	-	0.160	4.06
774048	ZnSe	1.1	27.94	7.5	-	0.106	2.69
982910	ZnSe	1.1	27.94	10.0	-	0.109	2.77
803557	GaAs	1.5	38.1	2.5	-	0.0799	2.03
101766	ZnSe	1.5	38.1	2.5	-	0.300	2.62
975597	GaAs	1.5	38.1	3.5	-	0.354	8.99
441406	ZnSe	1.5	38.1	3.75	-	0.086	2.18
941031	ZnSe	1.5	38.1	-	5.0	0.280	7.11
578662	ZnSe	1.5	38.1	5.0	-	0.300	7.62
464497	ZnSe	1.5	38.1	-	7.5	0.280	7.11
306068	ZnSe	1.5	38.1	7.5	-	0.300	7.62
892020	ZnSe	2.0	50.8	7.5	-	0.310	7.87
232771	ZnSe	2.0	50.8	7.5	-	0.380	9.65
236670	ZnSe	2.5	63.5	10.0	-	0.390	9.90

Contact a II-VI sales representative for exact specifications.

Plano-convex lenses, the most economical transmissive focusing elements available, are ideally suited for laser heat treating, welding, cutting, and infrared radiation collection where spot size or image quality is not critical. They are also the economical choice in high f-number, diffraction limited systems where lens shape has virtually no effect on system performance.

For proper performance with a plano-convex lens, the curved surface should face toward the incoming collimated beam or the longer conjugate distance (the object and image distances together are referred to as the conjugate distance).

Besides the plano-convex, meniscus, and aspheric lens shapes offered in this catalog, II-VI routinely fabricates biconvex and negative focal length lenses upon request.

MENISCUS LENSES

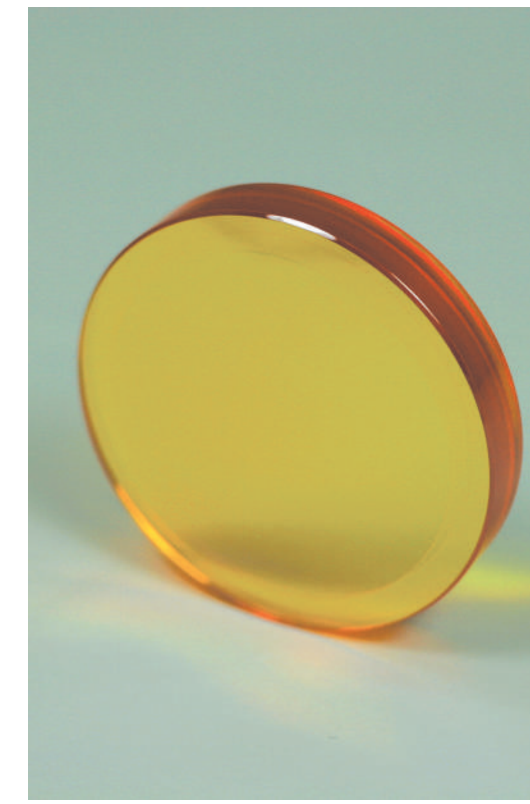
Specifications	Standards
Effective Focal Length (EFL) Tolerance	±2%
Dimensional Tolerance	Diameter: +0.000"/-0.005" Thickness: ±0.010"
Edge Thickness Variation (ETV)	≤ 0.002"
Clear Aperture (polished)	90% of diameter
Surface Figure (power/irregularity) at 0.63µm	Varies depending upon radius
Scratch-Dig	20-10
AR Coating Reflectivity per Surface at 10.6µm	≤ 0.20%

Part #	Description	Diameter inches	Diameter (mm)	Focal Length inches	Edge Thickness inches	Edge Thickness (mm)
247275	ZnSe	0.5	12.7	1.5	0.060	1.52
994141	ZnSe	1.0	25.4	1.0	0.085	2.16
350342	ZnSe	1.0	25.4	2.5	0.085	2.16
376587	ZnSe	1.0	25.4	5.0	0.085	2.16
566650	ZnSe	1.1	27.94	1.5	0.085	2.16
932739	ZnSe	1.1	27.94	2.5	0.085	2.16
801758	ZnSe	1.1	27.94	5.0	0.085	2.16
285767	ZnSe	1.5	38.1	2.5	0.085	2.16
507790	ZnSe	1.5	38.1	5.0	0.236	5.99
406294	ZnSe	1.5	38.1	5.0	0.290	7.37
767963	ZnSe	1.5	38.1	5.0	0.354	8.99
452726	ZnSe	1.5	38.1	7.5	0.125	3.18
784964	ZnSe	1.5	38.1	7.5	0.236	5.99
702232	ZnSe	1.5	38.1	7.5	0.290	7.37
570721	ZnSe	1.5	38.1	7.5	0.354	8.99
935669	ZnSe	2.0	50.8	5.0	0.100	2.54
695399	ZnSe	2.0	50.8	7.5	0.380	9.65
296875	ZnSe	2.0	50.8	10.0	0.100	2.54
490154	ZnSe	2.5	63.5	5.0	0.160	4.06
596352	ZnSe	2.5	63.5	7.5	0.160	4.06
286449	ZnSe	2.5	63.5	10.0	0.160	4.06

Contact a II-VI sales representative for exact specifications.

Meniscus lenses are designed to minimize spherical aberration, producing a minimum focal spot size for incoming collimated light.

In addition to the standard focal lengths listed below, II-VI maintains an extensive inventory of test plates and tooling, resulting in no additional tooling charges for focal length fabrication.



MP-5®

ULTRA-LOW ABSORPTION LENSES

THE BEST ... NOW EVEN BETTER. II-VI Infrared's MP-5 is an ultra-low absorbing lens that ships directly from the factory as a standard OEM CO_2 laser component. Its superior features include a patented coating design enabling lower thermal distortion, visible transmission for reduced set-up time, and easy detection of thermally induced stress. The MP-5 is backed by over a decade of proven performance, and this ultra-low absorbing lens is designed, produced, and supported by II-VI Infrared, the world leader in CO_2 laser optics.

A specially coated zinc selenide (ZnSe) focusing lens, the MP-5 is available in both 1.5" and 2.0" diameters, and ships in standard replacement lens configurations for most popular OEM laser models.

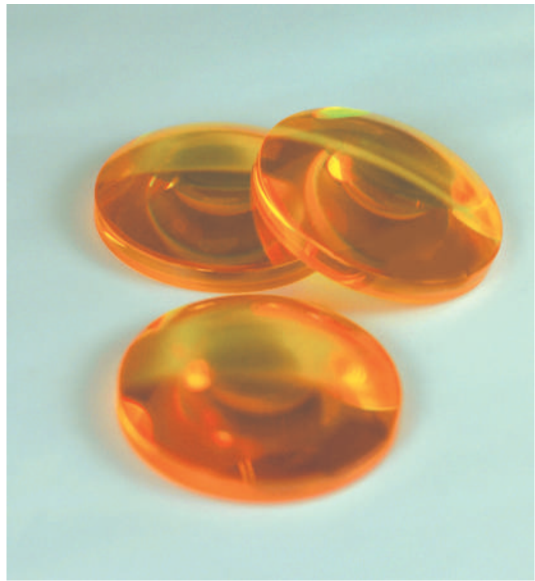
Specifications	Standards
Absorption	≤ 0.13% < 0.10% (typical)
Dimensional Tolerance	Diameter: +0.000"/-0.005" Thickness: ±0.010"
Edge Thickness Variation (ETV)	≤ 0.0005"
Clear Aperture (polished)	90% of lens diameter
Scratch-Dig	40-20

Part #	Description	Diameter inches	Diameter (mm)	Focal Length inches	Edge Thickness inches	Edge Thickness (mm)
794914	ZnSe PO/CX*	1.5	38.1	5.2	0.280	7.11
204518	ZnSe PO/CX*	1.5	38.1	7.7	0.280	7.11
106106	ZnSe PO/CX*	1.5	38.1	5.0	0.300	7.62
383862	ZnSe PO/CX*	1.5	38.1	7.5	0.300	7.62
635061	ZnSe PO/CX*	2.0	50.8	7.5	0.310	7.88
392125	ZnSe PO/CX*	2.0	50.8	7.5	0.380	9.65
528717	ZnSe Meniscus	1.5	38.1	5.0	0.236	5.99
312503	ZnSe Meniscus	1.5	38.1	5.0	0.290	7.37
123397	ZnSe Meniscus	1.5	38.1	5.0	0.354	8.99
714512	ZnSe Meniscus	1.5	38.1	7.5	0.236	5.99
474644	ZnSe Meniscus	1.5	38.1	7.5	0.290	7.37
602033	ZnSe Meniscus	1.5	38.1	7.5	0.354	8.99

**PO/CX is plano convex*
Contact a II-VI sales representative for exact specifications.

ASPHERIC LENSES

Aspheric lenses are commonly used in applications requiring the smallest spot size, such as ceramic drilling. They are designed to be diffraction limited and usually achieve a smaller spot size than either the plano-convex or positive meniscus lens. Aspheric lenses provide the highest power density at the workpiece as compared to plano-convex and positive mensicus lenses with equivalent focal lengths.



Specifications	Standards
Effective Focal Length (EFL) Tolerance	±2%
Dimensional Tolerance	Diameter: +0.000"/-0.005" Thickness: ±0.003"
Edge Thickness Variation (ETV)	≤ 0.0005"
Clear Aperture (polished)	90% of diameter
Surface Figure (power/irregularity) at 0.63μm	Varies depending upon radius
Scratch-Dig	40-20
AR Coating Reflectivity per Surface at 10.6μm	≤ 0.20%

Part #	Description	Diameter inches	Diameter (mm)	Focal Length inches
796278	ZnSe	1.1	27.94	1.5
942147	ZnSe	1.1	27.94	1.5
684500	ZnSe	1.1	27.94	2.5
679268	ZnSe	1.5	38.10	1.5
739932	ZnSe	1.5	38.10	5.0

Contact a II-VI sales representative for exact specifications.

COLLIMATING OPTICS

Reflective and transmissive collimating optics are used in beam delivery systems to maintain beam collimation between the laser resonator and the focusing optics. Reflective collimators typically use Cu total reflectors, while transmissive collimators typically use ZnSe lenses.

Part #	Description*	Diameter inches	Diameter (mm)	Focal Length (m)	Edge Thickness inches	Edge Thickness (mm)	Coating @ 10.6μm
LENSES							
200375	ZnSe PO/CX	1.5	38.1	0.71	0.236	6	AR/AR
439481	ZnSe PO/CX	1.5	38.1	0.82	0.236	6	AR/AR
686863	ZnSe PO/CX	1.5	38.1	0.99	0.236	6	AR/AR
316607	ZnSe PO/CX	1.5	38.1	1.23	0.236	6	AR/AR
827456	ZnSe PO/CX	1.5	38.1	2.50	0.236	6	AR/AR
890070	ZnSe PO/CX	1.5	38.1	7.82	0.119	3.02	AR/AR
702155	ZnSe PO/CX	1.5	38.1	9.50	0.158	4.01	AR/AR
607060	ZnSe PO/CX	1.5	38.1	11.00	0.158	4.01	AR/AR
448393	ZnSe PO/CX	1.5	38.1	15.00	0.158	4.01	AR/AR
945433	ZnSe PO/CX	1.5	38.1	15.00	0.120	3.05	AR/AR
434440	ZnSe PO/CX	2.0	50.8	4.00	0.236	6	AR/AR
687918	ZnSe PO/CX	2.0	50.8	12.00	0.236	6	AR/AR

Part #	Description	Diameter inches	Diameter (mm)	Radius of Curvature** (m)	Edge Thickness inches	Edge Thickness (mm)	Coating @ 10.6μm
MIRRORS							
754229	Cu Reflector	1.496	38	15.00 CC	0.236	6	MMR
798182	Cu Reflector	1.969	50	1.68 CC	0.394	10	MMR
612872	Cu Reflector-WC***	1.969	50	1.87 CC	1.25	31.75	EG
156390	Cu Reflector	1.969	50	2.44 CC	0.375	9.53	EG
881808	Cu Reflector-WC***	1.969	50	3.05 CC	1.25	31.75	EG
403522	Cu Reflector	1.969	50	3.25 CC	0.394	10	MMR
387566	Cu Reflector-WC***	1.969	50	3.61 CC	1.25	31.75	EG
798981	Cu Reflector-WC***	1.969	50	3.68 CC	1.25	31.75	EG
907296	Cu Reflector-WC***	1.969	50	3.72 CC	1.25	31.75	EG
549593	Cu Reflector-WC***	2.25	57.15	1.87 CC	1.25	31.75	EG
234345	Cu Reflector-WC***	2.25	57.15	2.09 CC	1.25	31.75	EG
862041	Cu Reflector	1.969	50	1.0 CX	0.394	10	MMR
534484	Cu Reflector-WC***	1.969	50	1.20 CX	1.25	31.75	EG
662344	Cu Reflector	1.969	50	2.25 CX	0.394	10	MMR
709199	Cu Reflector-WC***	1.969	50	2.34 CX	1.25	31.75	EG
571612	Cu Reflector-WC***	1.969	50	3.0 CX	1.25	31.75	EG
238861	Cu Reflector-WC***	2.25	57.15	1.33 CX	1.25	31.75	EG
764252	Cu Reflector-WC***	2.25	57.15	1.37 CX	1.25	31.75	EG

**PO is plano, CX is convex*
***CC is concave, CX is convex*
****Cu Reflector-WC: water cooled copper reflector*

Plano-convex lenses

Copper total reflector

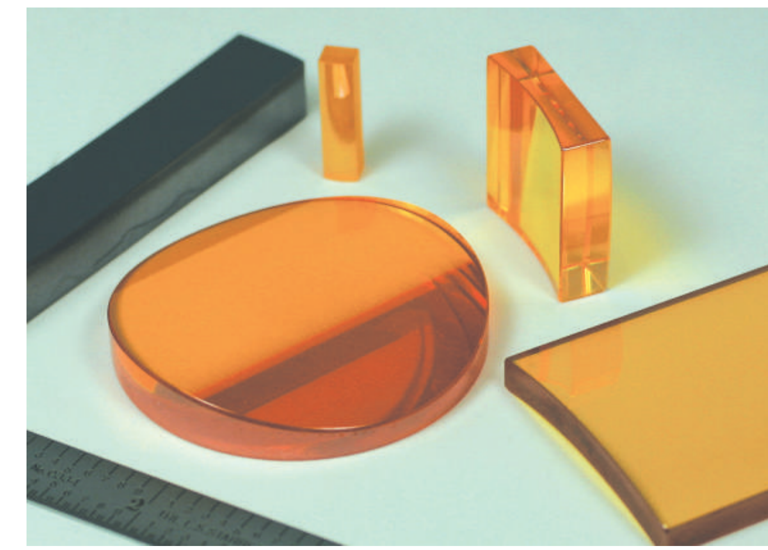
Please see Lenses (page 38) and Mirrors (page 56) sections for standard specifications. Contact a II-VI sales representative for exact specifications.

CYLINDER LENSES

As the name suggests, cylindrical lenses are either round or rectangular objects with cylindrically shaped surfaces. They differ from spherical lenses in that they focus a beam to a focal line rather than a focal point.

Transmission is improved by applying an anti-reflection coating on both sides, and multilayer coatings are available for various areas of the light spectrum. Cylindrical lenses can be made from ZnSe, Ge, Si, and other IR materials.

Applications include laser scanners, laser diode systems, spectrophotometers, projectors, and optical data storage and retrieval systems.



CUSTOM DESIGNS

Besides the plano-convex, meniscus, and aspheric lens shapes offered in this catalog, II-VI routinely fabricates biconvex and negative focal length lenses upon request. Our in-house optical engineers can design the component or optical system which provides the exact performance you require. Please contact our sales and engineering staff for a quotation.

SCANNING LASER SYSTEMS
OPTICS AND COMPONENTS

F-θ scan lenses play a major role in today's leading-edge laser applications. II-VI manufactures scan lenses for CO_2 laser systems that are used for marking, engraving, via hole drilling, and more.

In a typical scan lens configuration, the F-θ lens is used with one or two axis galvo mirrors that enable the laser beam's fast positioning and precision focusing.

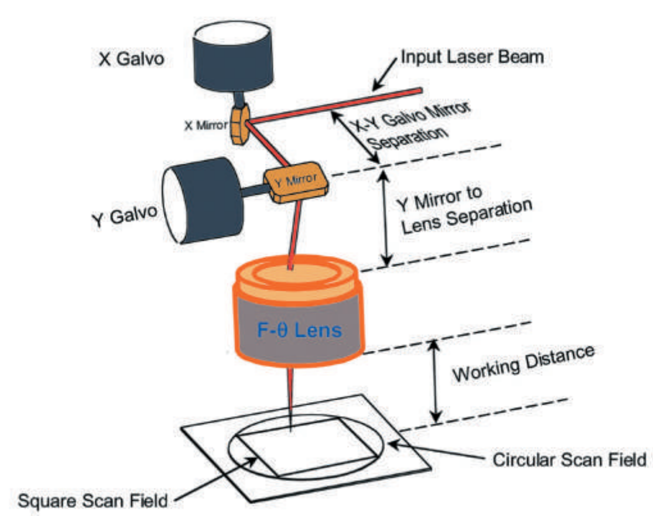
While standard focusing lenses deliver a focused spot to only one point, scan lenses deliver a focused spot to many points on a scan field or workpiece. They require special considerations in their design and use.

Scan lens applications include:
- Marking
- Engraving
- Rapid prototyping
- Drilling circuit board via holes
- Cutting cloth
- Cutting paper

Our II-VI scan lenses feature:
- The finest optical materials in the world
- Special housing designs to optimize performance
- Wavelength options from 9.2 to 10.6 µm
- Via hole drilling diameters from 75 to 300 µm
- Designs featuring one to five optical elements
- Optional protection windows
- Low-loss AR coatings
- Precision optical elements

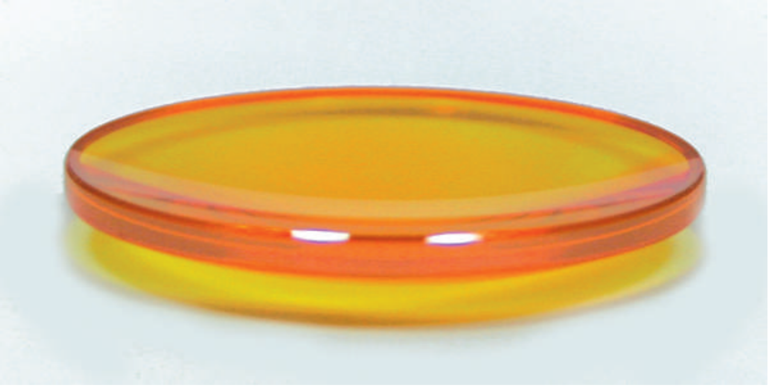
Contact a II-VI sales representative to discuss your scanning laser optics needs.

Scanning Laser System Components



X Galvo	A motor for positioning the X mirror.
Y Galvo	A motor for positioning the Y mirror.
X Mirror	The first mirror in the beam path.
Y Mirror	The second mirror in the beam path.
X-Y Galvo Mirror Separation	The distance between the centers of the two mirrors. It is usually set by the galvo manufacturer.
F-Theta Lens	A singlet, doublet, or triplet lens assembly that provides precision focusing of the laser beam onto the workpiece.
Y Mirror to Lens Separation	The distance between the center of the Y mirror (second mirror in the beam path) and the top edge of the lens housing. It is determined by the user.
Working Distance	The distance from the edge of the lens housing to the workpiece.
Scan Field	The area that can be processed by the galvos and scan lens system. It is usually square, but can be circular or rectangular.

SCAN LENSES
SINGLET (MARKING)



Our single element scan lenses are optimized for wide angles and long focal lengths, making them ideal for applications where large scan fields are required.

Singlet lenses ship unmounted or mounted, and custom mounts are available upon request. Contact a II-VI sales representative for more information.

Part #	Material	Lens CA (mm)	Scan Field (mm)	Focal Length (mm)	Lens Diameter (mm)	Working Distance* (mm)
SL1-10.6-25-88-127-U	ZnSe	25	88	127	28	134
SL1-10.6-25-60-89.5-U	ZnSe	25	60	89.5	28	96
SL1-10.6-36-40-100-U	ZnSe	36	40	100	40	103
SL1-10.6-36-70-100-U	ZnSe	36	70	100	40	106
SL1-10.6-43-40-55-U	ZnSe	43	40	55	48	59
SL1-10.6-43-70-105-U	ZnSe	43	70	105	48	110
SL1-10.6-43-100-150-U	ZnSe	43	100	150	48	159
SL1-10.6-43-140-200-U	ZnSe	43	140	200	48	209
SL1-10.6-43-250-360-U-A	ZnSe	43	250	360	48	379
SL1-10.6-57-120-175-U	ZnSe	57	120	175	64	187
SL1-10.6-57-110-208-U-A	ZnSe	57	110	208	64	217
SL1-10.6-64-140-200	ZnSe	64	140	200	68	215
SL1-10.6-74-140-200-U	ZnSe	74	140	200	75	211
SL1-10.6-40-80-100-U-A	Ge	40	80	100	43	106
SL1-10.6-40-120-200-U-A	Ge	40	120	200	43	217

**Working distance for scan lenses is specific to the input beam parameters and galvo systems. Each model listed above has a detailed specification sheet available upon request. Please contact a II-VI sales representative for more information.*

SCAN LENSES
DOUBLET (MARKING/DRILLING)

Multi-element lenses are available for the most demanding applications. These lenses may contain two to five elements, depending on the desired focal length and scan field. In addition, they can be telecentric if minimum spot distortion is desired.

Performance is further enhanced, and aberrations minimized, by using aspheric designs that are machined in our precision diamond turning facility.

Most designs are mounted in simple barrel mounts; however, the housings can be modified to accommodate special requirements.

Part #	Material	Lens CA (mm)	Scan Field (mm)	Focal Length (mm)	Working Distance* (mm)
SL2-10.6-47-50-100	ZnSe	47	50	100	108
SL2-10.6-50-29-45	ZnSe	50	29	45	56
SL2-10.6-54-70-122	ZnSe	54	70	122	131
SL2-10.6-54-110-170	ZnSe	54	110	170	193
SL2-10.6-54-140-220	ZnSe	54	140	220	246
SL2-10.6-58-104-200	ZnSe	58	104	200	217
SL2-10.6-60-64-125	ZnSe	60	64	125	133
SL2-10.6-64-350-500	ZnSe	64	350	500	545
SL2-10.6-74-100-160	ZnSe, Ge	74	100	160	195
SL2-10.6-80-175-250	ZnSe, Ge	80	175	250	280
SL2-10.6-82-210-300	ZnSe	82	210	300	333

**Working distance for scan lenses is specific to the input beam parameters and galvo systems. Each model listed above has a detailed specification sheet available upon request. Please contact a II-VI sales representative for more information.*

SCAN LENSES
TRIPLET (VIA HOLE DRILLING)

For applications such as marking and engraving, a single scan lens — designed to provide a flat field — yields satisfactory results.

However, other scanning laser system applications, such as electronics micro via drilling, require greater precision. To minimize spot distortion and drill angle, telecentric multi-element lenses take a laser beam from varying input angles and focus the perpendicular beam onto the work surface, regardless of the beam's position in the scan field.

Part #	Material	Lens CA (mm)	Scan Field (mm)	Focal Length (mm)	Working Distance* (mm)	Spot Size (μm)
SL3-9.4-70-40-80-DW	ZnSe	70	40	80	98	100
SL3-9.3-105-50-100-DW-A	ZnSe	105	50	100	120	85
SL3-9.3-108-50-95-DW	Ge, ZnSe	108	50	95	95	65
SL3-9.4-108-50-100-DW	Ge, ZnSe	108	50	100	103	70
SL3-9.4-114-50-85-DW	Ge, ZnSe	114	50	85	85	50
SL3-9.4-115-60-105-DW	ZnSe	115	60	105	133	92
SL3-9.3-128-60-100-DW	ZnSe	128	60	100	111	87

**Working distance for scan lenses is specific to the input beam parameters and galvo systems. Each model listed above has a detailed specification sheet available upon request. Please contact a II-VI sales representative for more information.*

MATERIALS
LENSES
WINDOWS
RESONATOR OPTICS
MIRRORS
PHASE RETARDERS

AR COATED WINDOWS

Specifications	Standards
Dimensional Tolerance	Diameter: +0.000"/-0.005" Thickness: +0.005"/-0.010"
Edge Thickness Variation (ETV)	≤ 3 arc minutes
Clear Aperture (polished)	90% of diameter
Surface Figure (power/irregularity) at 0.63μm	1 fringe/½ fringe
Scratch-Dig	20-10
AR Coating Reflectivity per surface at 10.6μm	< 0.20%

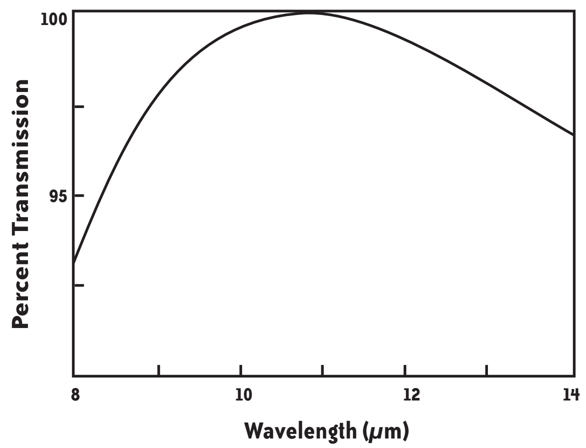
Part #	Description	Diameter inches	Diameter (mm)	Thickness inches	Thickness (mm)
185217	ZnSe	0.25	6.35	0.080	2.03
568604	ZnSe	0.375	9.53	0.080	2.03
162879	ZnSe	0.50	12.7	0.080	2.03
457172	ZnSe	0.75	19.05	0.080	2.03
735199	ZnSe	1.0	25.4	0.080	2.03
617035	ZnSe	1.0	25.4	0.120	3.05
834076	ZnSe	1.1	27.94	0.120	3.05
184651	ZnSe	1.5	38.1	0.120	3.05
883636	ZnSe	2.0	50.8	0.200	5.08
243559	ZnSe	2.5	63.5	0.250	6.35
616847	ZnSe	3.0	76.2	0.250	6.35

AR coated windows are available in other substrates and as uncoated windows. We also offer AR coatings at other wavelengths or wavelength bands. Contact a II-VI sales representative for exact specifications.

Windows are frequently used in optical systems to separate the environment in one part of the system from another, such as to seal vacuum or high-pressure cells. Because the infrared transmitting material has a high index of refraction, an anti-reflection coating is typically applied to windows to minimize losses due to reflections.

For guidelines about calculating the proper thickness for a window to withstand a given pressure, see our Pressure Loading tutorial section, pages 100 to 101.

Below is the typical transmission of an AR coated ZnSe window at 0° incidence:

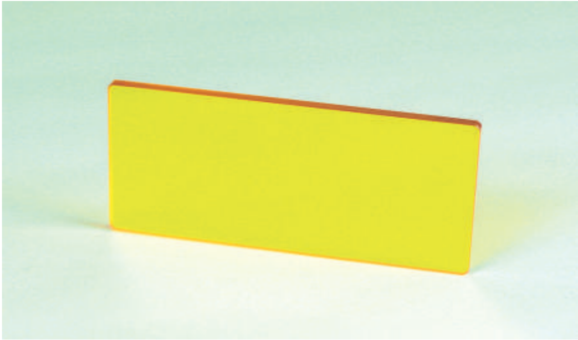


BREWSTER WINDOWS

Rectangular Brewster windows are uncoated substrates used in an optical system at Brewster's Angle, the angle at which p-reflectance drops to zero. This can be calculated from:

$$\Theta_B = \tan^{-1}(n)$$

where Θ_B is Brewster's Angle and n is the material's index of refraction. When used in a laser cavity, a Brewster Window creates polarized laser output.



Fixed beam polarization is often required so that optical components in the system perform consistently as designed. Since many optics and coatings are polarization sensitive, a laser with a time varying polarization state can cause fluctuations in system performance.

While virtually all of the p-component of polarization is transmitted by a Brewster Window, most of the s-component is reflected. For ZnSe, 50% of the incident s-polarized light is reflected per surface. Ge, with a higher index of refraction, has an approximately 87% fresnel reflection of the s-polarization component at 10.6μm.

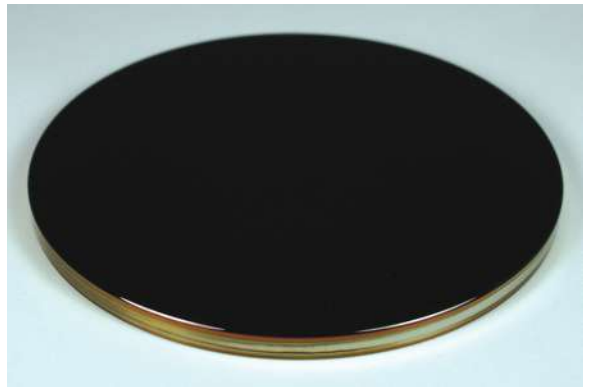
Specifications		Standards
Dimensional Tolerances	Width Length Thickness	+0.000"/-0.005" +0.000"/-0.005" +0.005"/-0.010"
Parallelism	Plano	≤ 3 arc minutes
Clear Aperture (polished)		90% of diameter
Surface Figure at 0.63μm	Width Length	Power: 1 fringe per inch; Irregularity: ½ fringe per inch Power: 1 fringe per inch; Irregularity: ½ fringe per inch
Scratch-Dig		20-10
Brewster Angle at 10.6μm	ZnSe Ge	67.4° 76.0°

Part #	Description	Width inches	Width (mm)	Length inches	Length (mm)	Thickness inches	Thickness (mm)
746216	ZnSe	0.40	10.16	1.04	26.4	0.080	2.03
282837	ZnSe	0.50	12.7	1.30	33.0	0.080	2.03
154022	ZnSe	0.60	15.24	1.56	39.6	0.080	2.03
749878	ZnSe	0.70	17.78	1.82	46.2	0.080	2.03
768646	ZnSe	0.80	20.32	2.08	52.8	0.120	3.05
761688	ZnSe	0.90	22.86	2.34	59.4	0.120	3.05
134369	ZnSe	1.00	25.4	2.60	66.0	0.120	3.05
723434	ZnSe	1.50	38.1	3.91	99.3	0.160	4.06
260345	ZnSe	2.00	50.8	5.21	132.3	0.200	5.08

Contact a II-VI sales representative for exact specifications.

PROTECTIVE WINDOWS

ZnSe protective window



Ge protective window

To protect scan lenses from backsplatter and other workplace hazards, II-VI offers protective windows — also known as debris windows — that are either included as part of the scan lens assembly, or sold separately. These plano-plano windows are available in both ZnSe and Ge materials and also supplied mounted or unmounted.

ZnSe protective windows feature our standard AR and DAR coating. Ge protective windows feature our standard AR coating, and also a diamond-like carbon coating (DLC) that is designed to withstand the most severe conditions encountered in industrial operations. Other increased durability coatings are also available upon request.

Below are common protective window sizes.

Part #	Material	Diameter inches	Diameter (mm)	Edge Thickness inches	Edge Thickness (mm)	Coating Type	Wavelength (μm)
110009	ZnSe	2.75	69.85	0.236	6.0	AR	10.6
616847	ZnSe	3.0	76.2	0.25	6.4	AR	10.6
402157	ZnSe	3.15	80	0.118	3.0	AR	10.6
473651	ZnSe	3.46	87.9	0.118	3.0	DAR	10.6
139647	ZnSe	4.3	109.2	0.375	9.5	AR	9.3
774352	ZnSe	5.5	139.7	0.375	9.5	AR	9.3
185594	ZnSe	5.5	139.7	0.375	9.5	AR	10.6
425225	Ge	4.25	108	0.197	5.0	DLC	9.4
221345	Ge	4.64	118	0.197	5.0	DLC	9.4
505791	Ge	4.76	121	0.197	5.0	DLC	9.4

OUTPUT COUPLERS

Partial reflectors are commonly used as laser output couplers or beam attenuators.

For your convenience, II-VI maintains commonly used coatings and substrate radii of curvature in inventory. Specifications for these products are indicated on this page. For available special substrate sizes and coatings, please contact a II-VI sales representative for a quotation.

Laser output couplers often require a slightly wedged substrate to eliminate interference from multiple reflections inside the component. If you require a specific wedge value, please specify this when ordering.

Specifications		Standards
Dimensional Tolerances	Diameter Thickness (plano) Thickness (radiused)	+0.000"/-0.005" +0.005"/-0.010" ±0.010"
Parallelism	Plano Radiused, Diameter < 1" Radiused, Diameter ≥ 1"	≤ 3 arc minutes ≤ 10 arc minutes ≤ 5 arc minutes
Clear Aperture (polished)		90% of diameter
Surface Figure (power/irregularity) at 0.63μm	Plano Radiused	1 fringe/½ fringe (varies depending upon radius)
Surface-Dig		20-10
Side 1: Reflectivity Tolerance at 10.6μm		1% to 5%: ±0.5%xR 6% to 85%: ±3% 86% to 95%: ±1.5% 96% to 98%: ±1% 99%: ±0.2% 99.5%: ±0.2%
Side 2: AR Coating Reflectivity at 10.6μm		≤ 0.20%

Part #	Description	Diameter inches	Diameter (mm)	Edge Thickness inches	Edge Thickness (mm)	Reflectivity	Radius** Side 1/Side 2
988175	ZnSe	1.0	25.4	0.236	5.99	65%	30MCC/30MCX
774314	ZnSe	1.0	25.4	0.236	5.99	50%	PO/PO
132098	ZnSe	1.1	27.94	0.220	5.59	50%	20MCC/15MCX
346822*	ZnSe	1.181	30.0	0.236	5.99	50%	30MCC/30MCX
554288	ZnSe	1.5	38.1	0.236	5.99	30%	10MCC/10MCX
187879	ZnSe	1.5	38.1	0.236	5.99	UC***	10MCC/15MCX
120765	ZnSe	1.5	38.1	0.236	5.99	30%	20MCC/PO
903007	ZnSe	2.0	50.8	0.300	7.62	48%	30MCC/20MCX

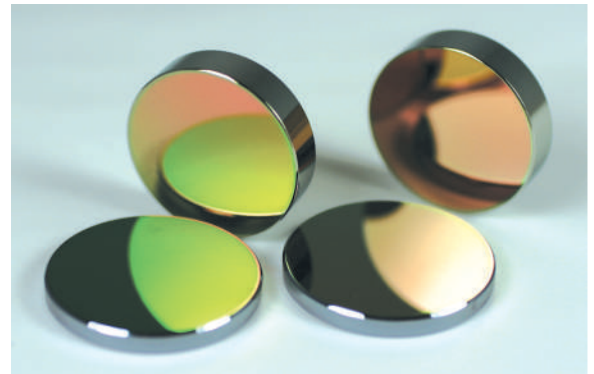
**MP-5 type coating*
***M is meter, CC is concave, CX is convex, PO is plano*
****UC is uncoated*
Contact a II-VI sales representative for exact specifications.

888.558.1504 (toll-free in USA and Canada) 724.352.1504 (phone) 724.352.4980 (fax)
www.iiviinfrared.com

REAR MIRRORS

Rear mirrors, typically GaAs, Ge, or ZnSe, are partial reflectors with a very high reflection-to-transmission ratio (99.0 to 99.7%), and are key optical components in laser resonators or laser cavities. Rear mirrors, like output couplers, are a part of the lasing process. Thus, high reflectivity is desired. The slight transmission of rear mirrors is used in conjunction with power meters to test for laser resonator output power.

When laser resonator designs require rear mirrors to be total reflectors, Si, Cu, or Mo substrates are used, the latter being typically uncoated.



Specifications		Standards
Dimensional Tolerances	Diameter Thickness (plano) Thickness (radiused)	+0.000"/-0.005" +0.005"/-0.010" ±0.010"
Parallelism	Plano Radiused, Diameter < 1" Radiused, Diameter ≥ 1"	≤ 3 arc minutes ≤ 10 arc minutes ≤ 5 arc minutes
Clear Aperture (polished)		90% of diameter
Surface Figure (power/irregularity) at 0.63μm	Plano Radiused	1 fringe/½ fringe (varies depending upon radius)
Scratch-Dig		20-10
Side 1: Reflectivity Tolerance at 10.6μm		99%: ±0.2% 99.5%: +0.2/-0% 99.7%: ±0.1%
Side 2: AR Coating Reflectivity at 10.6μm		≤ 0.20%

Part #	Description	Diameter inches	Diameter (mm)	Edge Thickness inches	Edge Thickness (mm)	Reflectivity	Radius* Side 1/Side 2
234709	Ge	1.0	25.4	0.236	5.99	99.5%	15MCC/PO
722287	Ge	1.1	27.94	0.220	5.59	99.5%	20MCC/PO
432529	Ge	1.181	29.99	0.236	5.99	99.6%	30MCC/PO
766409	Ge	2.0	50.8	0.375	9.53	99.5%	30MCC/PO
536364	GaAs	1.0	25.4	0.236	5.99	99.7%	30MCC/PO
230089	GaAs	1.1	37.94	0.120	3.05	99.7%	20MCC/PO
911209	ZnSe	1.5	38.1	0.236	5.99	99%	20MCC/PO

**M is meter, CC is concave, PO is plano*
Contact a II-VI sales representative for exact specifications.

BAND-SELECTIVE RESONATOR OPTICS

Most CO_2 lasers operate in the wavelength band at 10.6μm. This wavelength band is fine for cutting steel and certain other materials; however, other industrial laser applications — such as plastics processing — need a different, specific wavelength band for maximum production efficiency.

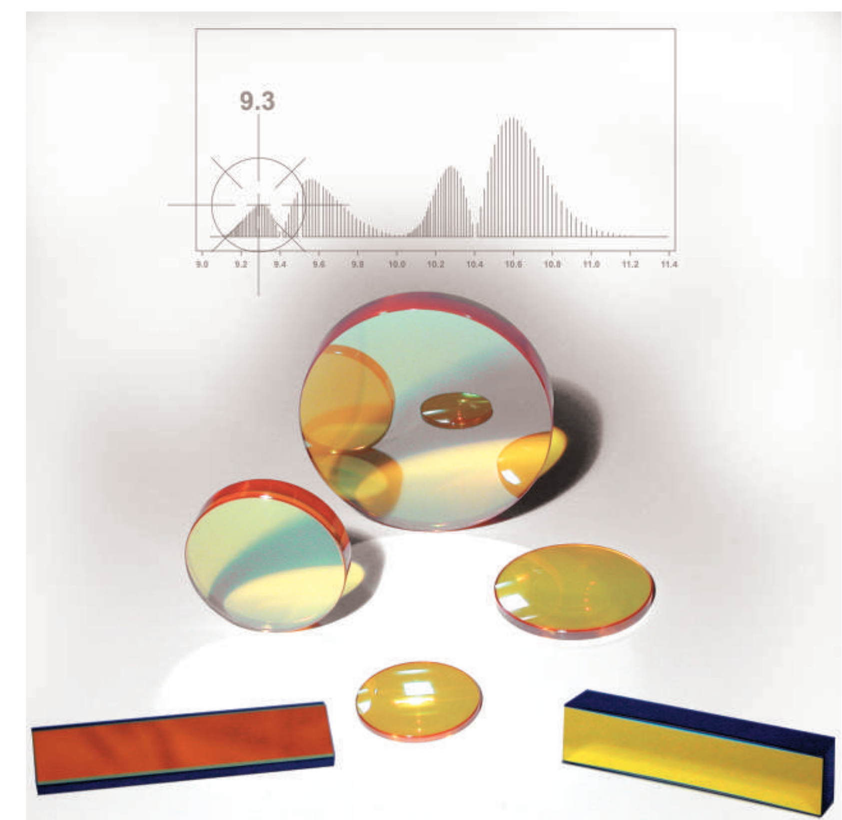
II-VI's band-selective resonator optics effectively "lock" a CO_2 laser to a specific wavelength band for specialized industrial applications, such as the 9.3μm band for circuit board drilling and plastics marking.

Our band-selective resonator optics are designed for both standard CO_2 gas mixes and isotope fills.

CO_2 laser types include:
- Traditional stable resonator (partially reflective output coupler, rear mirror, bend mirrors)
- Unstable resonator (rear mirror and output total reflector mirror)

Selectable bands (using standard gas mix) include:
- 9.3μm
- 9.6μm
- 10.2μm
- 10.6μm

By different combinations of band-selective resonator optics and gases, the user can make the laser lase at other wavelength bands depending on a particular application need.



STANDARD MIRROR COATINGS

	Uncoated Metal			Silver Based		Gold Based					Gold Based	Maximum Metal Reflector				Phase Retarding			Polarization Control		
	Al	Cu	Mo	PS	ES	BG	PG	EG	PEG		SEG	MMR	MMR-A	DEMMR	DZMMR	TRZ	λ/4 RPR*	λ/4 HRPR*	ATFR	PLM	PLM-W
%R @ 0° AOI @ 10.6µm	98.3	99.2	98.0	99.1	99.6	99.0	98.8	99.5	99.4		99.6	99.8	99.8	99.8	+	+	+	+	+	+	+
%R @ 45° AOI S-Pol @ 10.6µm	98.7	99.4	98.8	99.4	99.7	99.4	99.3	99.7	99.6		99.8	99.9	99.9	99.8	+	+	+	+	99.0	99.5	99.8
%R @ 45° AOI P-Pol @ 10.6µm	97.4	98.9	97.3	98.8	99.2	98.5	98.4	99.2	99.1		99.3	99.7	99.7	99.6	+	+	+	+	≤ 1.5	≤ 90.0	≤ 97.0
%R @ 45° AOI R-Pol @ 10.6µm	98.3	99.2	98.0	99.1	99.5	99.0	98.8	99.5	99.4		99.6	99.8	99.8	99.7	99.7	99.5	98.0	99.0	+	+	+
%R @ 45° AOI R-Pol @ 0.6328µm	~50-90	90	~40-70	95	~60-95	90	80	~50-90	80		~50-90	40	40	80	90**	80	+	+	80	+	+
Phase Retardation @ 45° AOI	~ -1°	~ -1°	~ -1°	6°-9°	+	~ -1°	+	+	+		+	0°±2°	0°±2°	+	0°±2°	0°±2°	90°±3°	90°±6°	+	+	+

Values Shown are Minimum Values Unless Otherwise Stated

*	These products are used at 45°AOI with plane polarized light at 45° to the plane of incidence.
+	These products are not intended for use at these parameters.
**	600 to 700 nanometers

PLANO AND SPHERICAL MIRRORS

Mirrors or total reflectors are used in laser cavities as rear reflectors and fold mirrors, and externally as beam benders in beam delivery systems.

Silicon is the most commonly used mirror substrate; its advantages are low cost, good durability, and thermal stability.

Copper is typically used in high-power applications for its high-thermal conductivity.

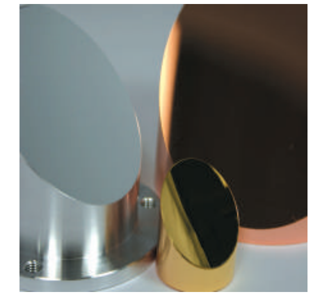
Molybdenum's extremely tough surface makes it ideal for the most demanding physical environments. Molybdenum is normally offered uncoated.

Specifications		Standards
Dimensional Tolerances	Diameter Thickness	+0.000"/-0.005" ±0.010"
Parallelism	Plano Radiused, Diameter < 1" Radiused, Diameter > 1"	≤ 3 arc minutes ≤ 10 arc minutes ≤ 5 arc minutes
Clear Aperature (polished)		90% of diameter
Surface Figure at 0.63µm	Plano and Radiused, r > 1 m	Power: 2 fringes Irregularity: 1 fringe
Scratch-Dig		10-5

Part #	Description	Diameter inches	(mm)	Edge Thickness inches	(mm)	Side 1 Coating
466761	Si	0.5	12.7	0.118	2.99	EG
850800	Si	1.0	25.4	0.120	3.05	ES
690933	Si	1.5	38.1	0.375	9.53	MMR
221987	Si	1.75	44.45	0.375	9.53	EG
408825	Si	2.0	50.8	0.200	5.08	DEMMR
341534	Si	2.0	50.8	0.200	5.08	TRZ
674480	Si	2.0	50.8	0.400	10.16	TRZ
614835	Si	3.0	76.2	0.250	6.35	TRZ
148570	Cu	1.1	37.94	0.236	5.99	EG
370229	Cu	1.969	50.01	0.200	5.08	TRZ
482518	Cu	1.969	50.01	0.354	8.99	EG
832216	Cu	1.969	50.01	0.394	10	TRZ
658306	Cu	2.362	59.99	0.236	5.99	TRZ
137530	Cu	4.0	101.6	0.75	19.05	PS
650010	Cu-WC*	4.25	107.95	1.5	38.1	ES
229095	Mo	4.0	101.6	0.350	8.89	UC

**WC is water-cooled copper*
The above parts are plano. For spherical parts, please contact a II-VI sales representative.
Contact a II-VI sales representative for exact specifications.

OFF-AXIS PARABOLIC MIRRORS



Mirrors made from copper substrates will withstand extremely high laser powers and industrial environments, providing diffraction limited focusing when properly mounted and aligned.

Copper mirrors are available with a higher reflectivity and durable molybdenum overcoating. This allows for the mirror's easy cleaning.

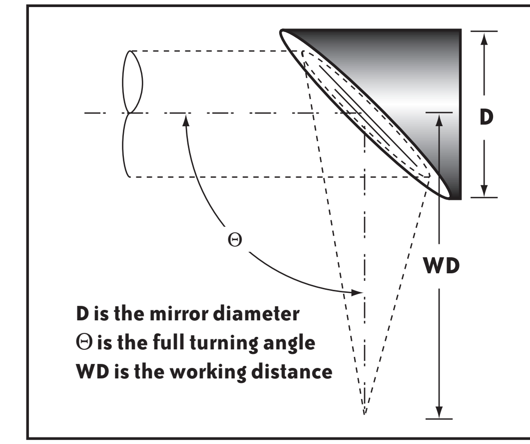
Parabolic mirrors are designed for reflecting and focusing the laser beam through 90 degrees, or any other convenient angle.

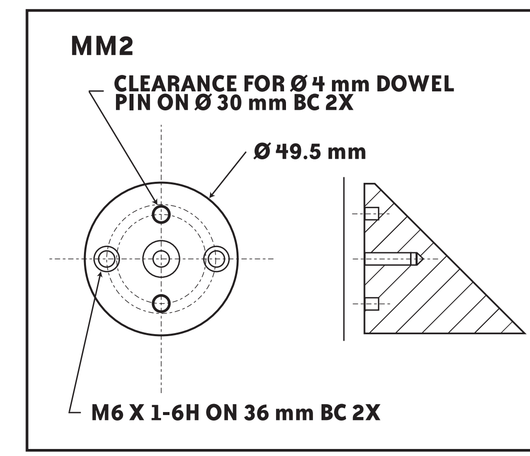
Custom design features, such as water cooling and non-standard mounting configurations, are available upon request.

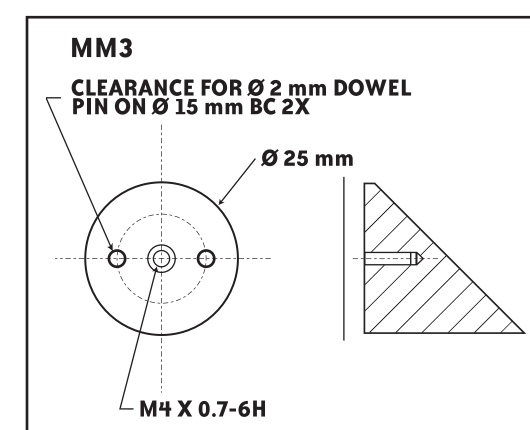
Specifications	Standards
Diameter	+0.00/-0.12 mm
Angle of Incidence	+3.5 minutes
Working Distance	±0.008"
Clear Aperature	90% of mirror surface
Surface Roughness	< 175 A RMS
Scratch-Dig	40-20
Surface Figure	2 fringes peak to valley @ 632 nm

Part #	Description	Diameter (mm)	Θ	Working Distance (mm)	Mount
PM-CU-49.5-90-200-UC*-MM2	Cu	49.5	90°	200	MM2
PM-CU-49.5-90-125-UC*-MM2	Cu	49.5	90°	125	MM2
PM-CU-49.5-90-250-UC*-MM2	Cu	49.5	90°	250	MM2
PM-CU-49.5-90-175-UC*-MM2	Cu	49.5	90°	175	MM2
PM-CU-25-90-125-UC*-MM3	Cu	25	90°	125	MM3
PM-CU-25-90-200-UC*-MM3	Cu	25	90°	200	MM3

**UC is uncoated*
Contact a II-VI sales representative for exact specifications.

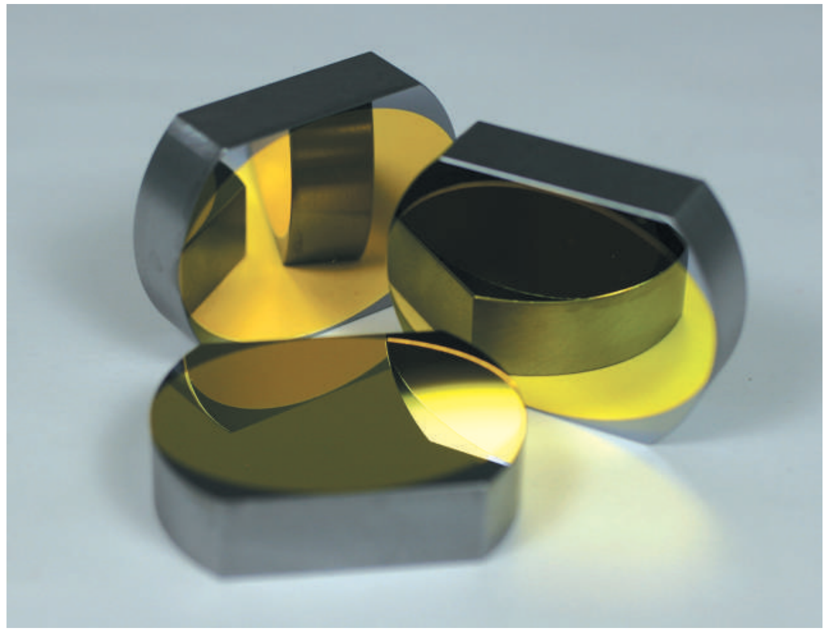






To guarantee operating specification, all mounting surfaces must be properly conditioned, screw torques cannot exceed II-VI recommendations, and the laser source must be aligned to the parabolic axis.

CYLINDER MIRRORS

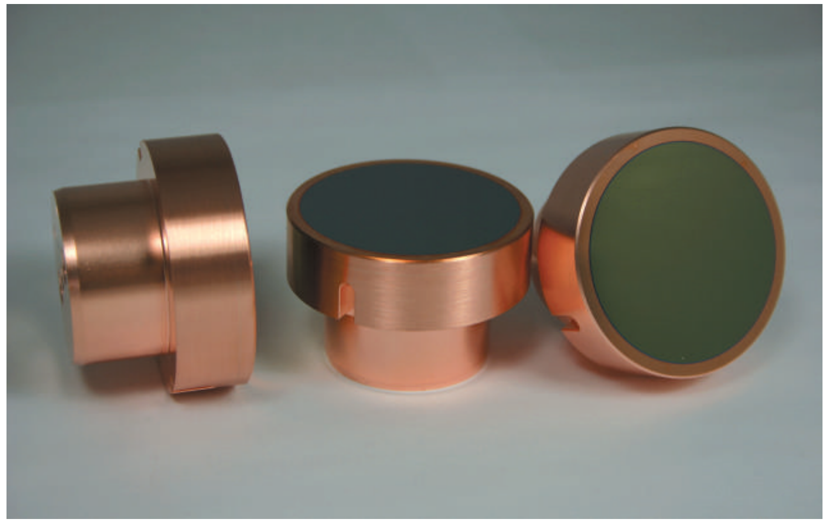


As the name suggests, cylindrical mirrors are either round or rectangular objects which have cylindrically shaped surfaces. They differ from spherical mirrors in that they focus a beam to a focal line rather than a focal point.

Reflectivity is improved by applying a highly reflective coating on the optical surface. Multilayer coatings are available for various areas of the light spectrum. Cylindrical mirrors are made from Cu, Si, Ge, Al, and other metallic materials.

Applications include laser scanners, laser diode systems, spectrophotometers, projectors, and optical data storage and retrieval systems.

TOROIDS



In many applications, spherical mirrors, cylinder mirrors, and parabolic mirrors are used to help shape the laser beam. Biconic mirrors — or the more general toroidal mirrors — can be used to combine two separate optics into one.

Biconic mirrors have two different radii on one surface. It's possible to make a biconic mirror with spherical curves or aspheric curves, depending on the application and need to eliminate aberrations. Toroids can replace common 90° bend mirrors to recollimate a laser beam.

For Reflective Phase Retarders, please go to pages 62 to 63 in the Phase Retarder section.

GALVO MIRRORS

Scanning laser systems — whether for marking, engraving, or for drilling micro via holes — all rely on galvo mirrors to precisely position the laser beam. II-VI manufactures built-to-spec galvo mirrors from mirror-grade silicon substrates. We apply our precision thin-film coatings to these substrates, producing highly efficient galvo mirrors that reflect laser light in the 1.0 to 12.0 µm range.

Ideally suited for Nd:YAG lasers (1.06µm) and CO_2 lasers (9.3 to 10.6 µm), II-VI galvo mirrors are suitable for a wide range of industrial applications. And for those applications requiring a visible helium-neon or diode laser alignment beam, our dual wavelength coatings provide maximum reflectivity for the CO_2 laser infrared beam while providing good reflectivity for the visible alignment beam. Our Dual Enhanced Maximum Metal Reflection (DEMMR) coating is the best choice for this application. Details are shown in Figures 1 and 2.

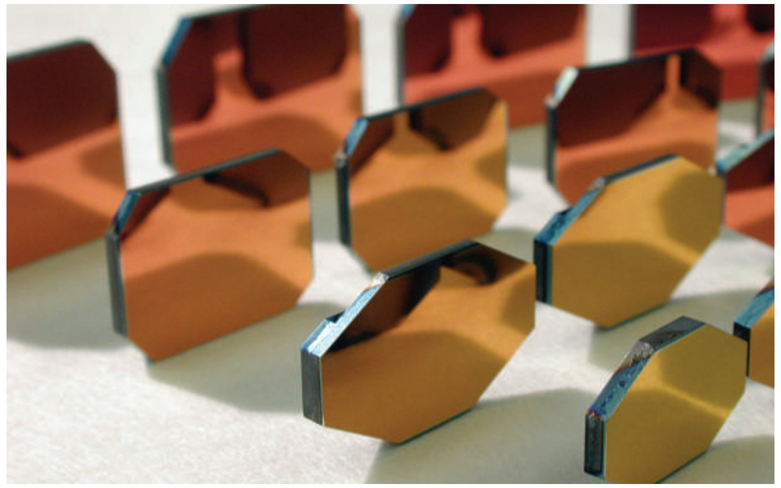
II-VI galvo mirror sizes typically range from 0.5 to 4.0 inches in diameter, based on OEM specifications.

II-VI galvo mirrors feature:

- Mirror-grade silicon substrates
- Greater thermal stability than fused silica substrates
- Geometries built to OEM specifications
- Highly reflective coatings for Nd:YAG lasers, CO_2 lasers, and CO_2 lasers with coaxial helium-neon or diode laser alignment beams

Applications include:

- Laser marking and engraving
- Laser drilling
- Laser welding
- Rapid prototyping
- Imaging and printing
- Semiconductor processing (memory repair, laser trimming)
- Remote laser welding



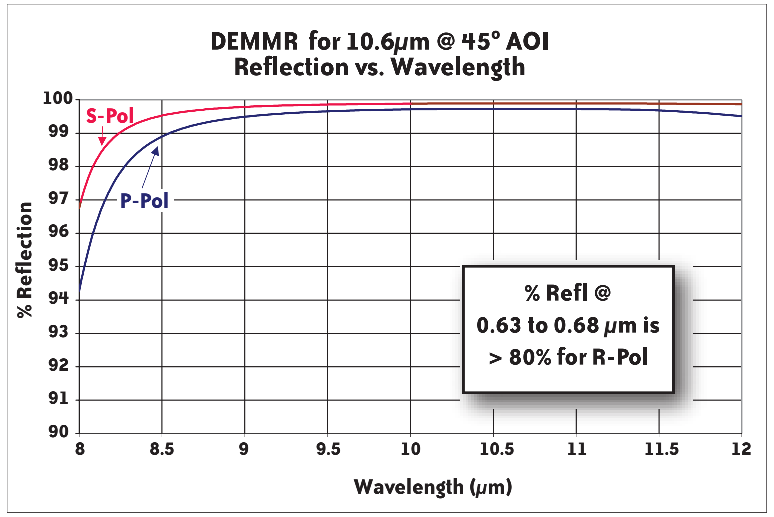


Figure 1

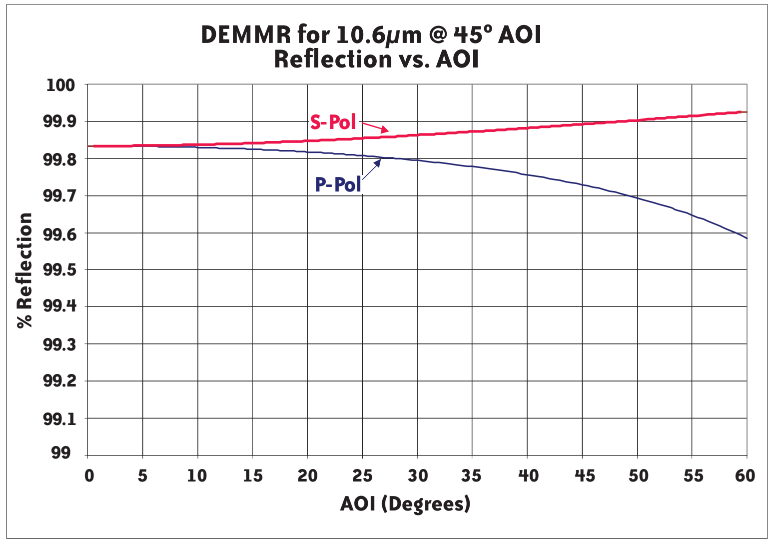


Figure 2

VARIABLE RADIUS MIRROR (VRM)

The II-VI Variable Radius Mirror (VRM) allows users to dynamically change their beam characteristics on the fly. By controlling the VRM's radius of curvature with water pressure, users can adjust the laser beam divergence.

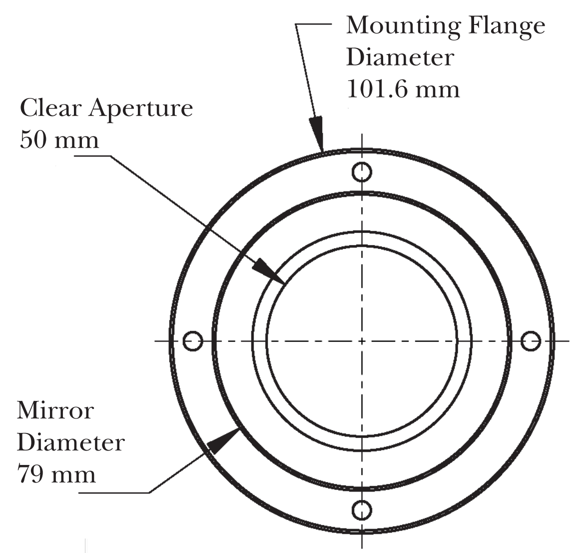
VRMs allow focus depth adjustment during material piercing; this produces optimum cutting speeds. It also allows flying optics systems manufacturers to compensate for focal length variations across the working table. This is especially important with large working tables, where laser beam divergence changes at the lens as the optical path moves across the work area.

The VRM is designed for use at near-normal angle of incidence. Many laser cutting systems use two mirrors as telescope optics. The telescope is made of one convex and one concave mirror. Replacing one of these mirrors with a VRM allows all of the benefits listed above.

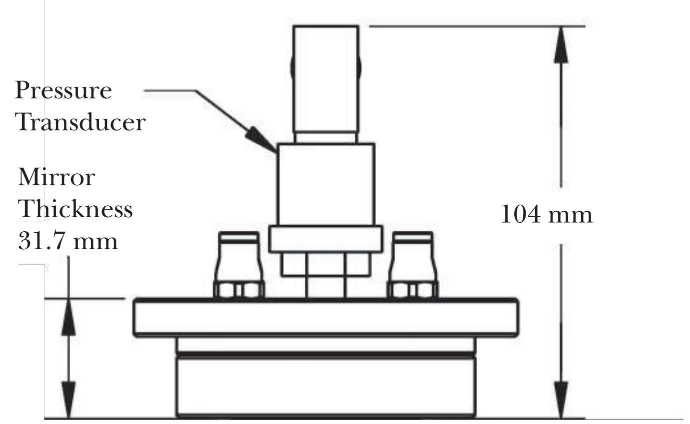
Specifications	
Substrate:	Copper
Standard Mirror Diameter:	57.1 mm, 79.0 mm
Usable Clear Aperture:	35 mm, 50 mm
Radius Range*:	6 MCC - 6 MCX 3 MCC - PO PO - 3 MCX 1.2 MCX - 1.6 MCX
Pressure Range:	3 to 11 bar
Water Flow Rate:	~1 liter/minute
Angle of Incidence:	Near normal
Reflectivity with MMR-A Type Coating:	> 99.8%
Pointing Stability:	≤ 30 arc seconds

**Customized radius range available.*
M is meter, CC is concave, CX is convex, PO is plano

Front View



Side View



Pressure Control

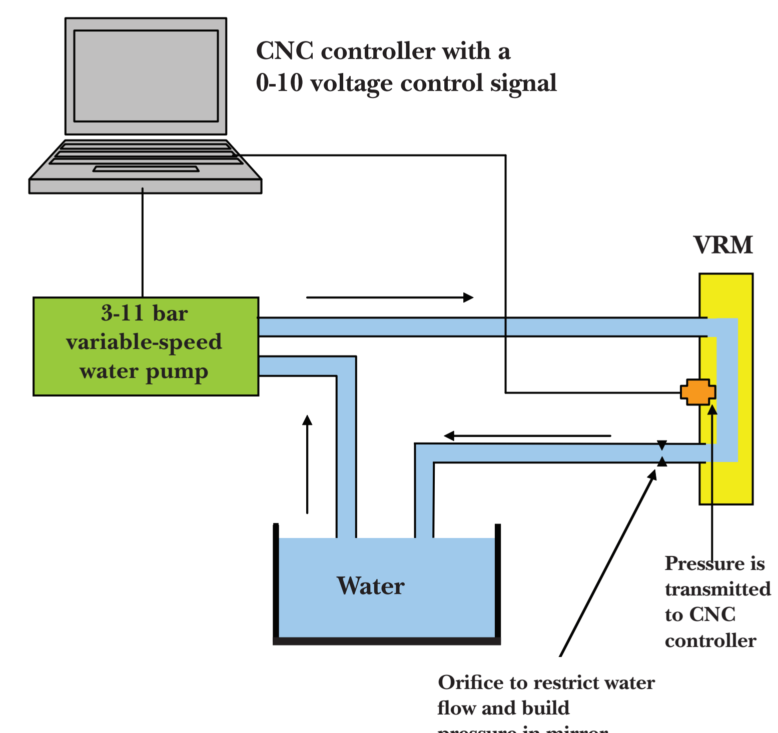
There are at least two ways to control the pressure in the VRM and, as a result, control the radius of the mirror surface. The key component is either a variable-speed pump or a proportional control valve. These items are driven by an amplifier. Input to the amplifier is typically a 0 to 10 volt signal. The amplifier is run open-ended or in a closed-loop system.

Custom Designs

II-VI can design adaptive mirrors for any beam delivery system. Using proprietary design techniques, II-VI can accurately model the VRM shape and predict how it will deform under pressure. The mirror shape is optimized to match the pressure-radius curve defined by the customer.

Water Pressure System Example

The drawing below shows the closed-loop system that uses a pressure transducer to measure the pressure in the mirror cavity. This signal is fed back to the CNC controller.



MATERIALS
LENSES
WINDOWS
RESONATOR OPTICS
MIRRORS
PHASE RETARDERS

REFLECTIVE PHASE RETARDERS

Metal cutting and other critical laser operations are sensitive to any variation in kerf width or cross-section. The kerf's quality depends on the polarization orientation relative to the cut direction. This is illustrated in Figure 1.

Current theory suggests that the assumption of a focused beam striking the work piece at normal incidence is only true at the cut's beginning. Once the kerf forms, the beam encounters metal at some large angle of incidence, Θ, as shown in Figure 2. Light which is s-polarized with reference to such a surface is reflected much more than light which is p-polarized, leading to the difference in cut quality.

Introducing a quarter-wave (90°) reflective phase retarder into the beam delivery path eliminates kerf variations by converting linear polarization to circular polarization. Circular polarization consists of equal amounts of s-polarization and p-polarization for any beam orientation, therefore all axes encounter the same composition of polarization, and material is removed uniformly regardless of cut direction. This is illustrated in Photo 1 on page 63.

A linearly polarized beam is oriented so that the plane of polarization is 45° to the plane of incidence and strikes the RPR at 45° to the normal, as shown in Figure 3. The reflected beam is circularly polarized.

The substrate choice depends upon the power level at which the laser operates. Alternate substrates, including water-cooled copper, are available. Eighth-wave and sixteenth-wave RPR designs, and designs for peak wavelengths other than 10.6µm, are also available. Please contact a II-VI sales representative to obtain a quotation.

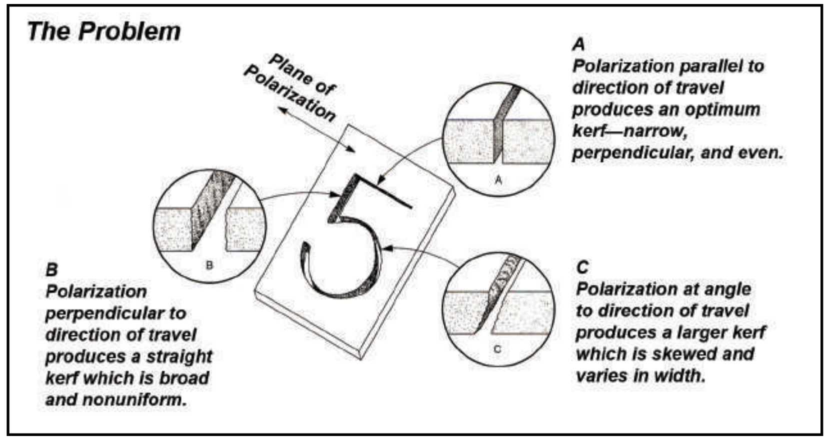


Figure 1

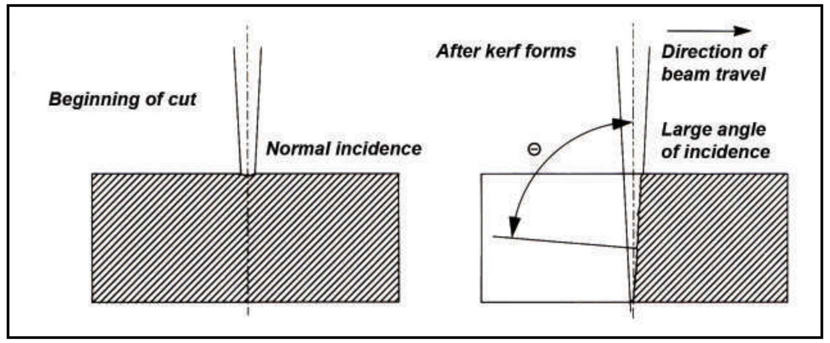


Figure 2

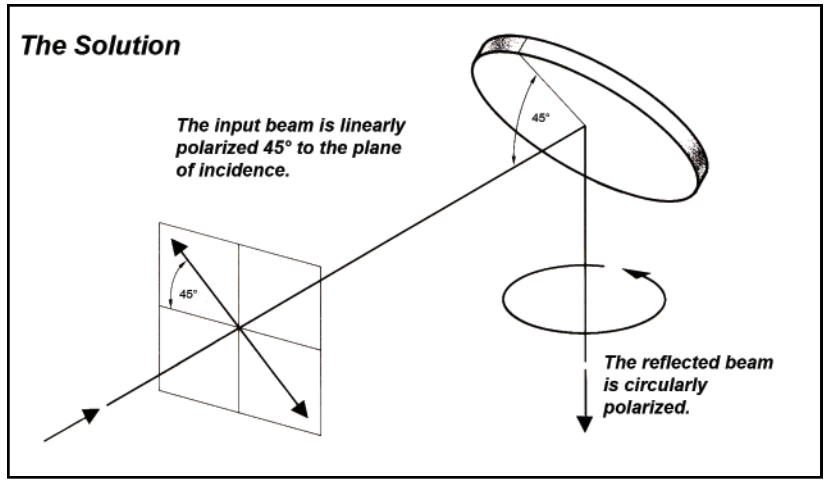


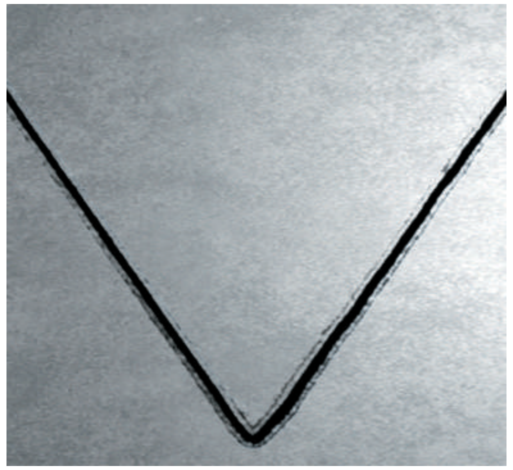
Figure 3

Specifications	Standards
Dimensional Tolerance	Diameter: +0.000"/-0.005" Thickness: ±0.010"
Parallelism	≤ 3 arc minutes
Clear Aperture (polished)	90% of diameter
Surface Figure (power/irregularity) at 0.63µm	≤ 2 fringe/½ fringe
Scratch-Dig	10-5
Reflectivity @ 10.6µm	≥ 98%
Phase Retardation for 10.6µm @ 45°	90°±3°
Ellipticity Ratio	0.90-1.11

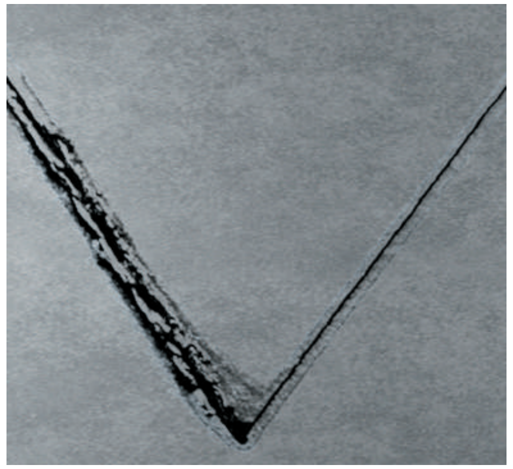
Part #	Description	Diameter inches	(mm)	Edge Thickness inches	(mm)	Phase Shift @ 10.6µm (degrees)
498237	Si	1.5	38.1	0.16	4.06	90+/-6
893833	Si	2.0	50.8	0.20	5.08	90+/-2
582132	Si	2.0	50.8	0.20	5.08	90+/-2
592353	Si	2.0	50.8	0.375	9.53	90+/-6
102719	Si	2.0	50.8	0.170	5	90+/-2
969917	Si	2.0	50.8	0.40	10.16	90+/-6
772930	Si	2.677	68	0.80	20.32	90+/-1
697768	Si	3.0	76.2	0.236	6	90+/-6
224094	Si	3.0	76.2	0.25	6.35	90+/-6
390686	Cu	1.5	38.1	0.25	6.35	90+/-6
666269	Cu	1.969	50	0.394	10	90+/-6
832944	Cu	2.25	57.15	0.394	10	90+/-2
488199	Cu-WC*	2.25	57.15	1.25	31.75	90+/-6
800102	Cu	2.362	60	0.394	10	90+/-2
634413	Cu	2.362	60	0.591	15	90+/-2
748680	Cu	3.0	76.2	0.50	12.7	90+/-6
744069	Cu	3.0	76.2	0.591	15	90+/-2

**Cu-WC: water-cooled copper*
Contact a II-VI sales representative for exact specifications.

Photo 1

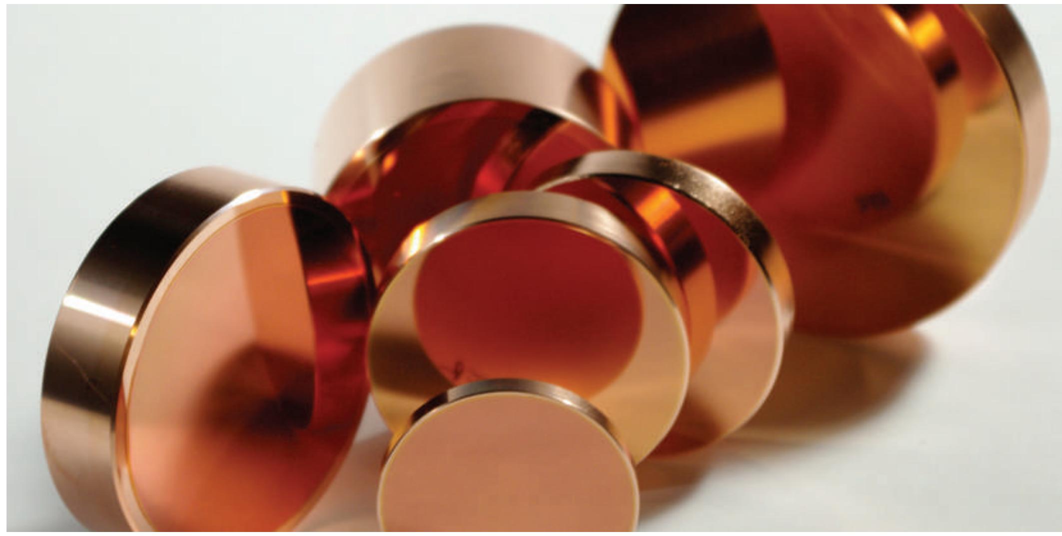


Clean cut produced by circularly polarized light.



Ragged cut produced by linearly polarized light.

ABSORBING THIN-FILM REFLECTOR (ATFR)



The Absorbing Thin-Film Reflector (ATFR) incorporates a polarization sensitive thin-film reflective coating on a Cu substrate. This coating was initially designed for use at 10.6µm and 45° angle of incidence. The coating will reflect s-polarization and absorb p-polarization; therefore, it must be placed in the beam delivery system where the incident beam is s-polarized.

In cutting applications where the workpiece is highly reflective, reflections from the workpiece can be transmitted back through the beam delivery system into the laser cavity. This is most likely to occur during the initial stages of the cut. These back reflections can cause laser cavity mode and power instabilities. It is also possible for the returned beam to be amplified in the laser cavity and then focused on one of the beam delivery optics, causing damage to that optic.

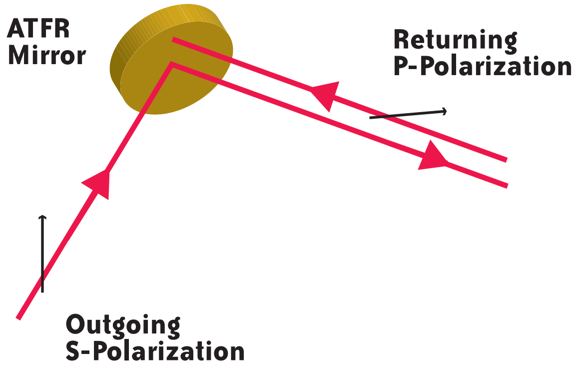
Use of the ATFR in cutting highly reflective metals, such as copper, brass, or aluminum, is especially important since these materials are highly reflective. The beam delivery systems used for cutting applications convert the linear polarization to circular polarization by means of reflective phase retarders (RPR). In this type of beam delivery system, reflected energy from the workpiece is converted back to linear polarization by the RPR. The plane of the reflected linear polarization is rotated 90° to the outgoing linear polarized laser beam. If one of the mirrors in the beam delivery system is oriented so that the outgoing laser beam is s-polarized, then the back reflected energy must be p-polarized at this mirror.

The property of the ATFR that makes it an ideal mirror for preventing unwanted reflections from reaching the laser cavity is its absorption of the reflected p-polarized laser beam.

Specifications	Standards
Reflectivity @ 10.6µm, 45° AOI	≥ 99.0% (S-pol) ≤ 1.5% (P-pol)
Reflectivity @ 0.6328µm, 45° AOI	≥ 80.0% (R-pol)
Angle of Incidence	S-pol: 45° P-pol: 45°

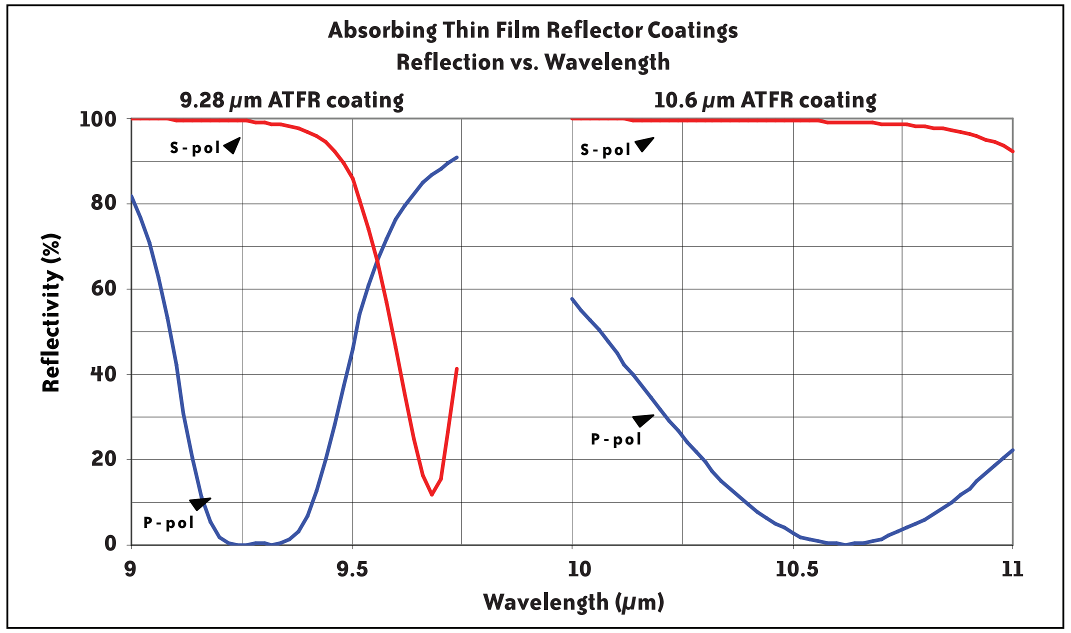
Spectral Performance for other wavelengths

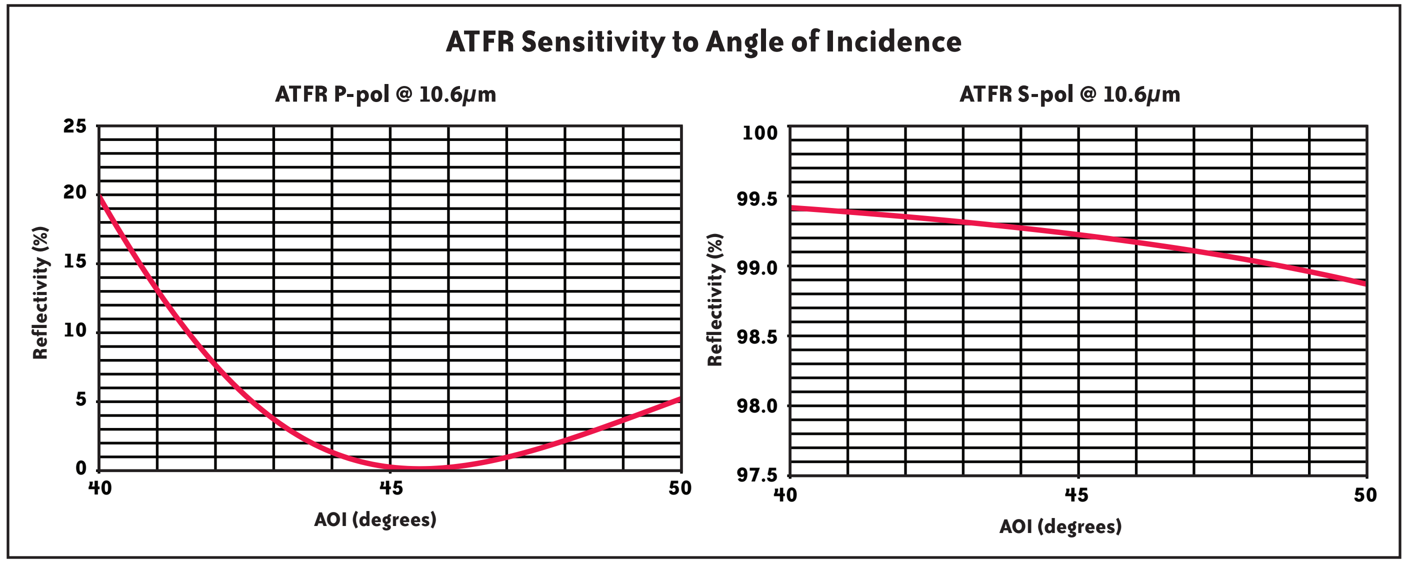
Wavelength (µm)	Reflectivity @ 45° AOI	
	S-pol	P-pol
10.24	≥ 98.5%	≤ 3.0%
9.55	≥ 98.5%	≤ 3.0%
9.38	≥ 98.5%	≤ 3.0%
9.28	≥ 98.5%	≤ 3.0%
9.15	≥ 98.5%	≤ 3.0%



Part #	Description	Diameter inches	Diameter (mm)	Thickness inches	Thickness (mm)
682239	Cu	1.5	38.1	0.16	4.06
432326	Cu	1.969	50.0	0.394	10.0
160586	Cu	2.0	50.8	0.375	9.53
504774	Cu	2.25	57.15	1.25	31.75
728695	Cu	2.362	60.0	0.591	15.0
255328	Cu	3.0	76.2	0.50	12.7

Contact a II-VI sales representative for exact specifications.





PRISMS & RHOMBS

It's often necessary to alter or manipulate the source's polarization. For example, a reflective phase retarder converts linear to circular polarization and improves the laser cutting quality. (For reflective phase retarders, please see pages 62 to 63.) However, most polarization altering devices — the reflective phase retarder and waveplates — are very wavelength sensitive and offer only narrowband, or single wavelength operation.

The Fresnel prisms and rhombs described on this page utilize the principle that when light undergoes total internal reflection, there is a relative phase change between the s- and p-polarization components. This effect is only weakly dependent on wavelength (see below Figure 1). Thus, these components are ideal for those working at either multiple distinct wavelengths or with broadband sources in the 8 to 12 µm region.

By manipulating the rhomb's geometry, devices which produce quarter-wave, half-wave, or virtually any required retardation can be constructed. Please contact a II-VI sales representative with your design requirements.

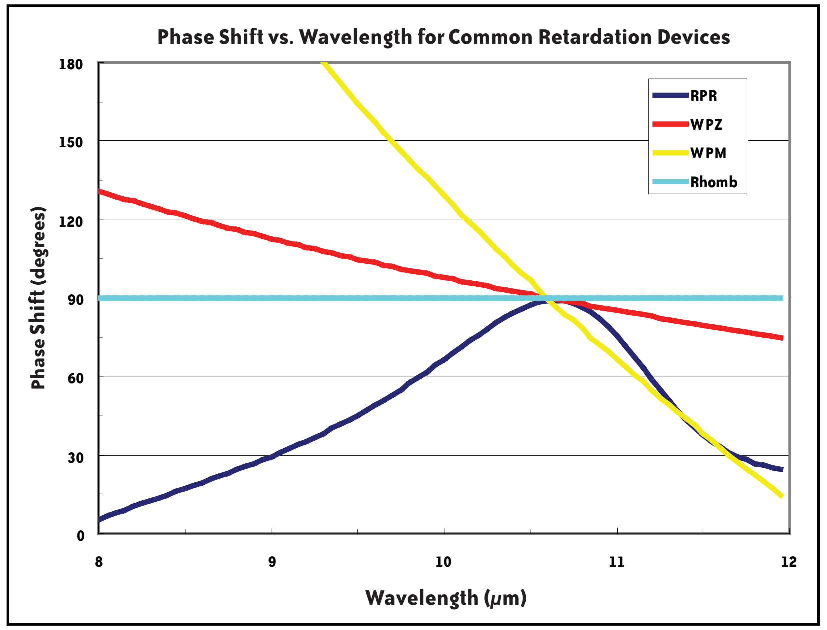
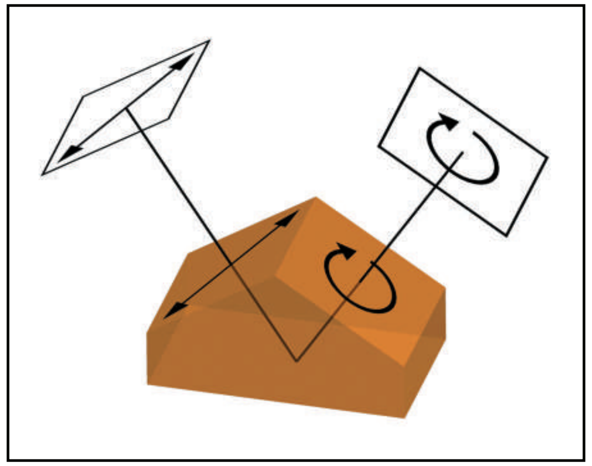
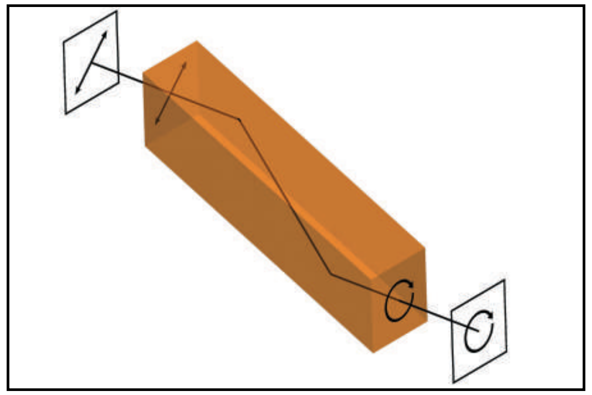


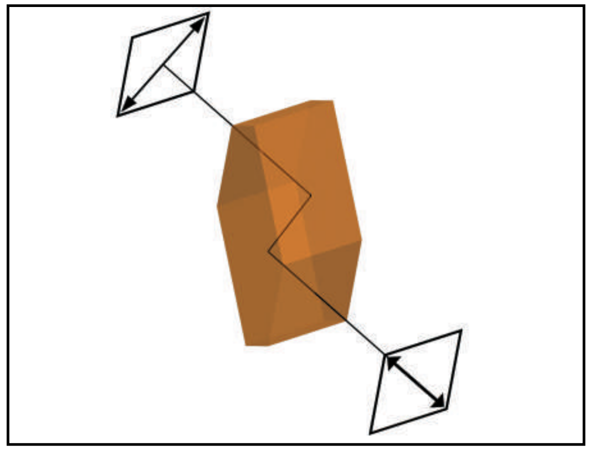
Figure 1



This quarter-wave prism converts linear into circular polarization, and turns the beam path.



This quarter-wave rhomb produces an output beam which is parallel, but displaced from, the input.



This half-wave rhomb changes the polarization's orientation for a linearly polarized input. The output polarization orientation is varied by rotating the rhomb around the optical axis. The output beam is parallel to, but displaced from, the input beam.

MODULATORS

Electro-optic modulators are used in a variety of applications to either amplitude-modulate (AM modulation) or phase-modulate (FM modulation) a laser beam. Made of CdTe, they are used with HeNe lasers operating at 3.391µm, CO lasers operating at 5 to 7 µm, and CO_2 lasers operating at 9 to 11 µm.

Modulator Applications

- Internal cavity
  - Mode locking
  - Q-switching
  - Cavity dumping
- External cavity
  - Beam intensity modulation
  - Pulse shaping
  - Ultra shot pulse generation
- Internal or external cavity
  - Frequency modulation or wavelength shifting

WAVEPLATES

Waveplates use a phenomenon known as birefringence to alter the incoming laser beam polarization state. The most common waveplate uses are for turning linearly polarized light into circularly polarized light (quarter-wave plates), and to rotate the polarization plane of a linearly polarized source (half-wave plates).

II-VI manufactures both multiple order and zero order waveplates. Zero order waveplates have the dual advantage of being less sensitive to changes in both operating temperature and input wavelength.

Applications

- Converting linear to circular polarization
- Rotating the polarization plane

Features

- High-power handling
- Low insertion loss
- Apertures up to 1.0"
- Visible transmission for easy alignment
- Rotating mounts available

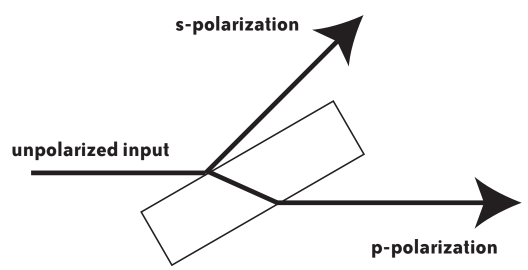
WPZ cell

WPM Model Waveplate

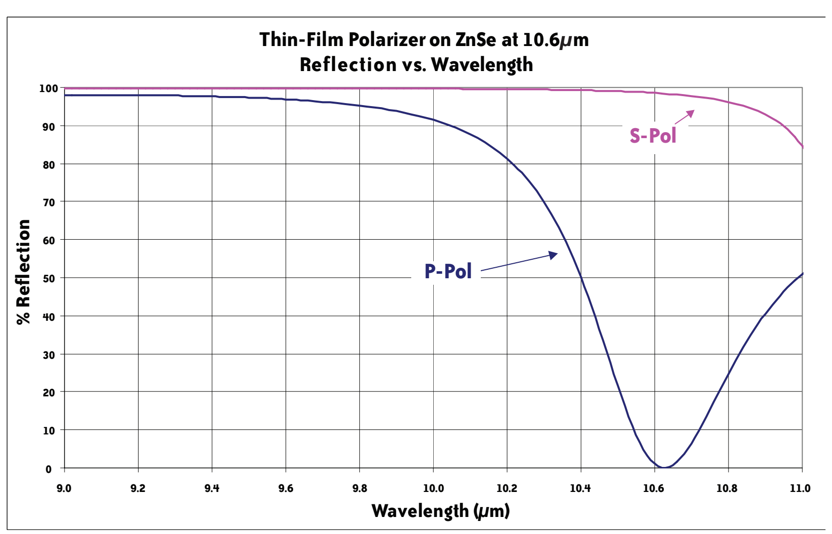
THIN-FILM POLARIZERS

Thin-Film Polarizers (TFPs) can split a laser beam into two parts with orthogonal polarizations. Conversely, TFPs can be used to combine two beams with orthogonal polarizations. TFPs consist of a coated plate which is oriented at Brewster's angle with respect to the incoming beam. The thin-film coating serves to enhance the beam's s-polarized reflectivity, while maintaining the p-polarized component's high transmission.

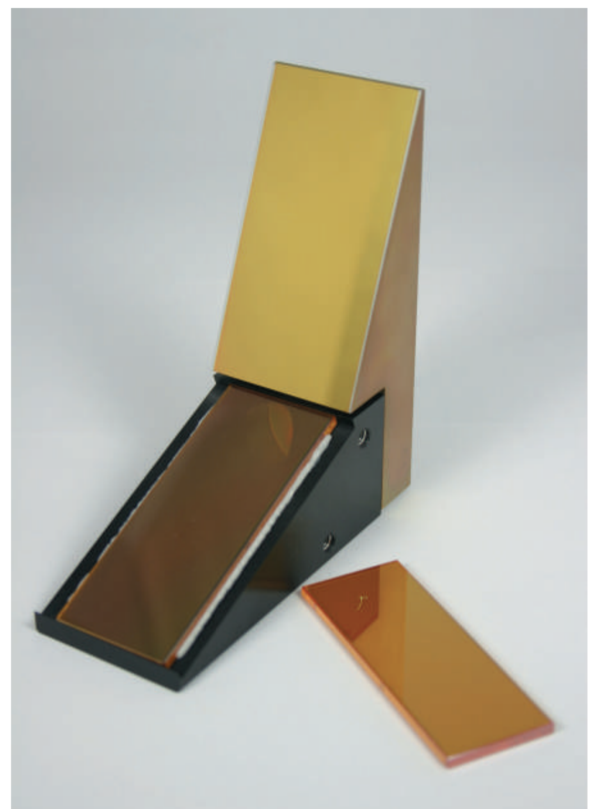
Below is a TFP schematic splitting an unpolarized input beam into s-polarized and p-polarized components:



The standard TFP reflects the s-polarized beam at Brewster's angle; for those applications which require a 90° separation between the s-polarized and p-polarized beams, our optional turning mirror can be added. II-VI offers both ZnSe and Ge TFPs.



II-VI can design TFP coatings for wavelengths other than 10.6 microns, and formulations for other materials to meet your requirements. Contact a II-VI sales representative to discuss.

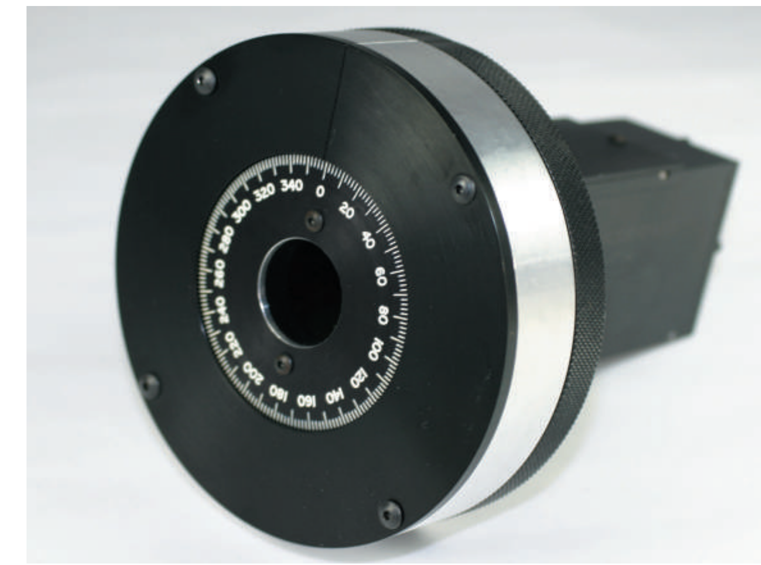


Product Type	Material Type	Clear Aperture of Window	Type of Mounting
TFP	ZnSe or Ge	0.30 0.50 0.70 0.90	U=Unmounted M=Fixed mount R=Rotating mount

Other TFP sizes are available. Please discuss rotating mounts and specialized mounting schemes for unique requirements with a II-VI sales representative.

POLARIZER-ANALYZER-ATTENUATOR

Polarizer-Analyzer-Attenuator is a stacked series of ZnSe plates placed at Brewster's angle to an incoming beam. At each plate, virtually all of the p-polarized component is transmitted, while most of the s-polarized component is reflected. The net result, after the beam has traversed several plates, is a beam which is virtually only p-polarized.



Applications

- Unpolarized beam polarization
- Laser beam polarization analysis
- Continuously variable attenuation of linearly polarized beams
- Electro-optic modulation systems

Features

- High-power handling
- Visible transmission for easy alignment
- Low-insertion loss
- High-extinction ratio (> 500:1)
- Broadband operation (2 to 14 μm)
- Optional exit port or heat sink cooling

Specifications	Model PAZ		
	Plates 6	4	2
Transmission @ 10.6μm (aligned in a collimated, polarized beam)	> 98%	> 98%	> 99%
Beam deviation	< 1 mrad	< 1 mrad	< 1 mrad
Extinction ratio	> 500:1	> 200:1	> 30:1
Standard apertures, air-cooled version	6, 10, 15, 20, 25, 30, 35 mm		
Standard apertures, H_2O-cooled version	6, 10, 15, 20, 25, 30, 35 mm		
Wavelength region	2 to 14 μm	2 to 14 μm	2 to 14 μm

Germanium units (PAG) with higher extinction ratios are also available. Contact a II-VI sales representative for details.

BEAM EXPANDERS

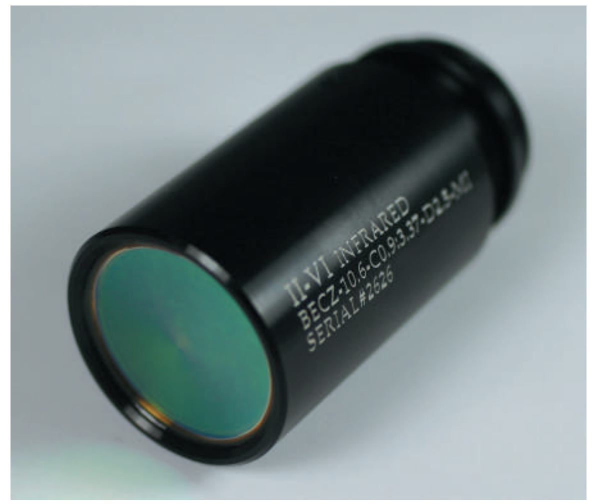
TRANSMISSIVE & REFLECTIVE

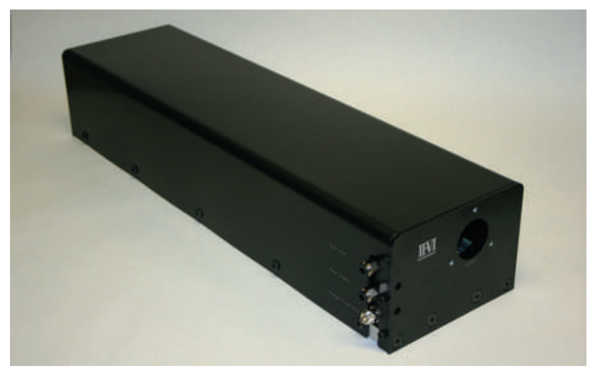
A beam expander is a two or more element optical system that changes the beam's size and divergence characteristics. Beam expanders have numerous uses. Smaller focal spot sizes can be achieved by expanding a beam prior to focusing. Beam expanders also improve a beam's collimation allowing the beam to diverge less over long distances. They can also be used to reduce the beam diameter, which may be useful when using an acousto- or electro-optic modulator. Using a spatial filter with a beam expander can "clean up" an asymmetric beam profile, making it more symmetric and providing more uniform energy distribution.

Features

- Low insertion loss
- High-power operation
- Visible transmission
- Minimum beam deviation
- Fixed or adjustable focus
- Customizing available

Pictured to the right: top, a transmissive beam expander for the marking industry, and bottom, a reflective beam expander for high-power CO_2 cutting machines.





The following is a list of transmissive ZnSe beam expanders. Contact a II-VI sales representative for more information on beam expanders.

Part #	Input CA (inches)	Input CA (mm)	Output CA (inches)	Output CA (mm)	Expansion Ratio	Housing Length (inches)	Housing Length (mm)	Housing Diameter (inches)	Housing Diameter (mm)
BECZ-10.6-C0.7:2.85-D3-MI	0.45	11.43	0.70	17.78	3.00	1.75	44.45	1.20	30.48
BECZ-10.6-C0.7:2.5-D4-MI	0.45	11.43	0.70	17.78	4.00	1.75	44.45	1.20	30.48
BECZ-10.6-C0.7:2.72-D5-MI	0.45	11.43	0.70	17.78	5.00	1.75	44.45	1.20	30.48
BECZ-10.6-C0.9:3.7-D2-MI	0.45	11.43	0.90	22.86	2.00	1.75	44.45	1.20	30.48
BECZ-10.6-C0.9:2.83-D3-MI-1B	0.45	11.43	0.90	22.86	3.00	1.97	50.01	1.34	34.01
BECZ-10.6-C0.9:2.5-D4-MI	0.45	11.43	0.90	22.86	4.00	1.75	44.45	1.20	30.48
BECZ-10.6-C0.9:2.43-D5-MI	0.45	11.43	0.90	22.86	5.00	1.75	44.45	1.20	30.48
BECZ-10.6-C0.9:2.79-D6-MI	0.45	11.43	0.90	22.86	6.00	2.13	53.98	1.20	30.48
BECZ-10.6-C0.9:2.79-D7-MI	0.45	11.43	0.90	22.86	7.00	2.13	53.98	1.20	30.48
BECZ-9.4-C1.0:4.45-D2-MI	0.68	17.15	1.00	25.40	2.00	1.97	50.04	1.50	38.10
BECZ-10.6-C1.35:3.74-D6.67-MI	0.40	10.16	1.35	34.29	6.67	2.50	63.50	2.30	58.42
BECZ-10.6-C1.4:6.4-D2-MI	0.68	17.15	1.35	34.29	2.00	2.36	59.99	2.50	63.50
BECZ-10.6-C1.4:10-D3-MI	0.68	17.15	1.40	35.56	3.00	5.00	127.00	2.00	50.80

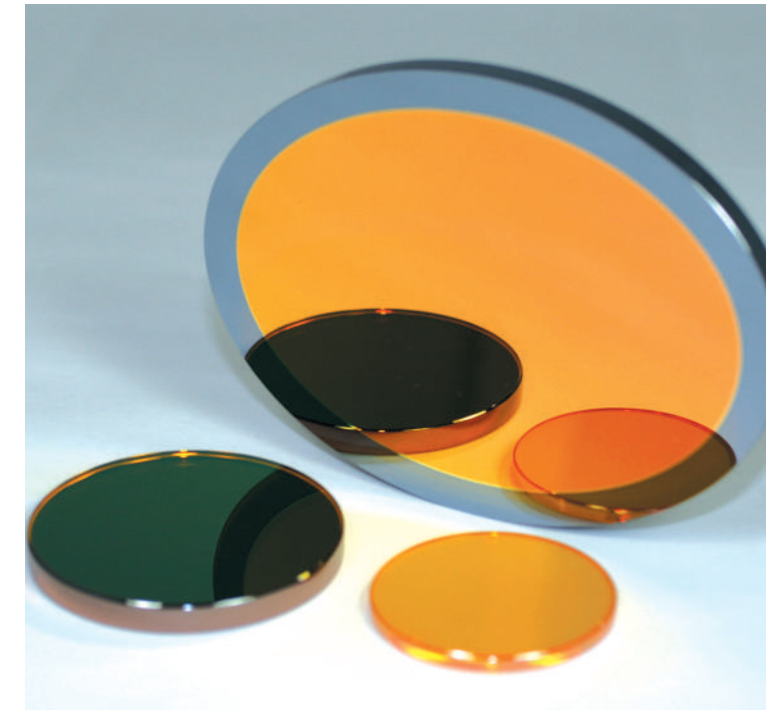
BEAMSPLITTERS

Beamsplitters are used to reflect a certain percentage of incident energy, while transmitting the remaining energy. In most cases, beamsplitters are angle, wavelength, and polarization sensitive.

Most beamsplitter coatings are highly polarization sensitive. Thus, if the source's polarization state varies with time, as in some randomly polarized lasers, the beamsplitter's transmission will also vary with time.

The beamsplitters described here are designed for use at 45° angle of incidence and 10.6µm wavelength. At this angle of incidence, there can be significant differences in the transmittance/reflectance values for s- and p-polarizations. ***It is essential that the laser's polarization state be specified when ordering these optics.*** See our polarization tutorial on pages 96 to 99 for definitions of s- and p-polarizations.

Our standard beamsplitter is supplied with a wedge of 6 to 10 arc minutes. This wedge amount significantly reduces interference caused by reflections off the second surface, which can cause an etalon effect and disturb optical performance. All II-VI beamsplitters are optimized for lowest absorption and highest damage threshold.



Custom reflectivities are available for beamsplitters. Contact a II-VI sales representative for more information.

Part #	Description	Diameter inches	Diameter (mm)	Edge Thickness inches	Edge Thickness (mm)	Reflectivity @ 10.6µm	Angle of Incidence	Polarization
813441	ZnSe	0.75	19.05	0.080	2.03	50%	45°	R-Pol
604488	ZnSe	1.00	25.4	0.120	3.05	50%	45°	R-Pol
256816	ZnSe	1.00	25.4	0.120	3.05	50%	45°	P-Pol
921686	ZnSe	1.00	25.4	0.120	3.05	50%	45°	S-Pol
947711	ZnSe	1.00	25.4	0.120	3.05	50%	45°	I-Pol*
381053	ZnSe	1.50	38.1	0.120	3.05	50%	45°	P-Pol
617751	ZnSe	1.50	38.1	0.120	3.05	50%	45°	S-Pol
931727	ZnSe	1.50	38.1	0.120	3.05	50%	45°	I-Pol*
839010	ZnSe	2.00	50.8	0.200	5.08	50%	45°	R-Pol
965624	ZnSe	2.00	50.8	0.200	5.08	50%	45°	P-Pol
622394	ZnSe	2.00	50.8	0.200	5.08	50%	45°	S-Pol
461951	ZnSe	2.00	50.8	0.200	5.08	50%	45°	I-Pol*

**Note: I-Pol is polarization insensitive, meaning it's used for all polarizations (S, P, R). I-Pol beamsplitters are opaque to visible wavelengths. Please refer to our polarization tutorial on pages 96 to 99 to determine how to specify the polarization of the beamsplitter.*

BEAMSPLITTER

ALTERNATIVES

Because of the virtually limitless number of nominal reflectivity and polarization states for beamsplitters, II-VI does not maintain a standard beamsplitter stock. Thus, when manufacturing a beamsplitter, a special coating run will be performed to meet the precise specifications you require. A coating lot charge is incurred to provide this service.

However, under some circumstances, it's possible to use our standard partial reflector coatings designed for 0° incidence as a 45° angle of incidence beamsplitter. When this is done, remember that neither the beamsplitter nor the second surface anti-reflection coating is designed for use at 45°.

For this reason, it's not possible to put a standard tolerance on these parts. Fortunately, because these are standard coatings, they cost significantly less than having a special beamsplitter fabricated, so that their price advantage may outweigh their performance disadvantage.

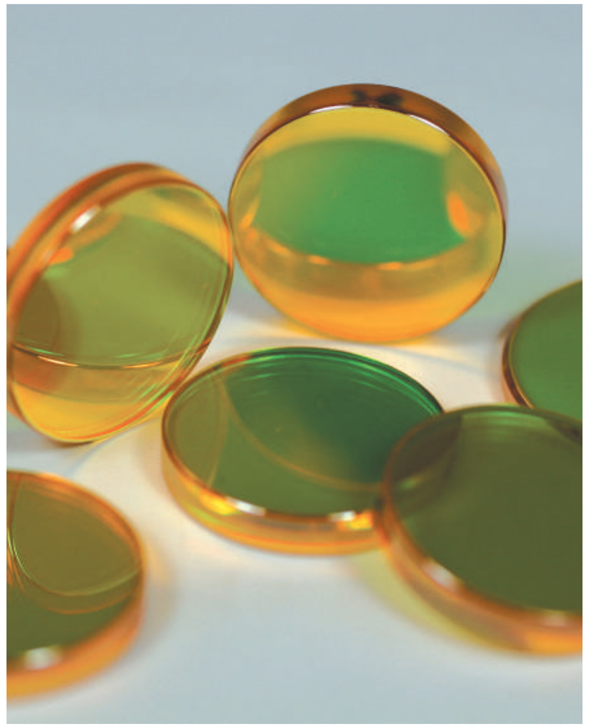
With beamsplitters operated at 45°, it's necessary for the substrate to have a slight wedge amount in order to eliminate interference effects. When purchasing a standard 0° angle of incidence partial reflector for use at 45°, it is essential that a substrate wedge angle of 6 to 10 arc minutes be specified at the time for ordering. Furthermore, we will laser test your part for reflectivity at s- and p-polarization free of charge if you request it at the time of order.

Beamsplitter Alternatives

Substrate	(%) Reflectivity @ Normal Incidence	(%) Reflectivity @ 45° AOI S-Pol	(%) Reflectivity @ 45° AOI P-Pol	(%) Reflectivity @ 45° AOI R-Pol
ZnSe	0.2	≤2.0	≤0.5	≤1.5
ZnSe	40	52.6	21.3	37.0
ZnSe	50	62.7	29.3	46.0
ZnSe	55	66.1	30.7	48.2
ZnSe	60	72.0	38.6	55.3
ZnSe	65	74.9	40.4	57.6
ZnSe	70	79.0	45.2	62.1
ZnSe	75	83.2	50.8	67.0
ZnSe	80	87.1	57.5	72.3
ZnSe	85	91.1	65.8	78.5
ZnSe	90	92.7	67.0	79.8
ZnSe	95	97.3	82.1	89.7
ZnSe	99	99.1	91.5	95.1
ZnSe	99.5	99.8	93.8	96.5
Ge	99	99.6	96.5	98.0
Ge	99.5	99.8	98.6	99.2
GaAs	99.5	99.8	98.3	99.2
GaAs	99.7	99.6	96.5	98.0

NOTE: It is recommended that a 6-10 minute wedge be specified for beamsplitter and beamsplitter alternative coatings to reduce the possibility of etaloning.

BEAM COMBINERS



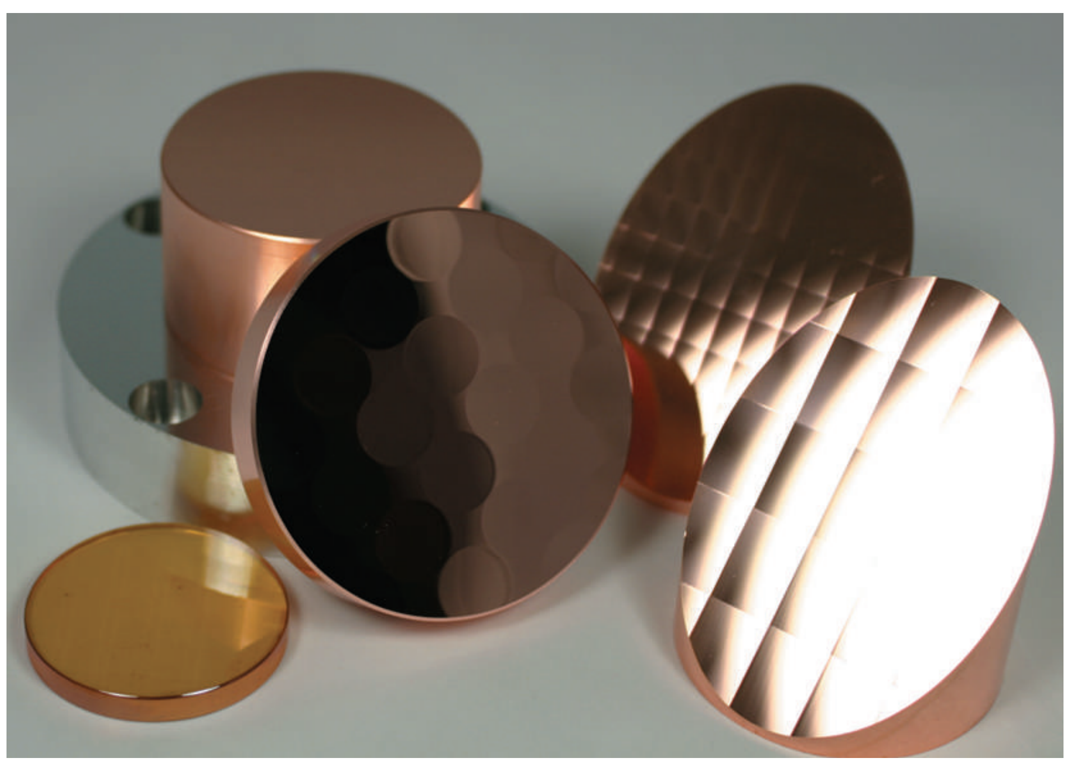
Beam combiners are partial reflectors that combine two or more wavelengths of light — one in transmission and one in reflection — onto a single beam path. ZnSe, ZnS, or Ge beam combiners are optimally coated to transmit infrared light and reflect visible light. Typically, they are used to combine infrared CO_2 high-power laser beams and HeNe visible laser alignment beams.

Part #	Description	Diameter inches	Diameter (mm)	Edge Thickness inches	Edge Thickness (mm)	Transmission @ 10.6μm	Reflectivity	Angle of Incidence	Polarization
250771	ZnSe	0.5	12.7	0.080	2.03	98%	90% @ 0.633μm	45°	R-Pol
864220	ZnSe	0.75	19.05	0.080	2.03	98%	90% @ 0.633μm	45°	R-Pol
404518	ZnSe	0.75	19.05	0.080	2.03	98%	90% @ 0.670μm	45°	R-Pol
394265	ZnSe	1.0	25.4	0.120	3.05	98%	90% @ 0.633μm	45°	R-Pol
170306	ZnSe	1.0	25.4	0.120	3.05	98%	90% @ 0.670μm	45°	R-Pol
285378	ZnSe	1.5	38.1	0.120	3.05	98%	90% @ 0.633μm	45°	R-Pol
625266	ZnSe	2.0	50.8	0.200	5.08	98%	90% @ 0.633μm	45°	R-Pol

DIAMOND-TURNED CUSTOM OPTICS

Most optics exhibit rotational symmetry. They are used in the vast majority of existing applications. Yet optics exhibiting non-rotational symmetries often possess numerous advantages over their more traditional, rotationally symmetric counterparts.

Examples include biconic lenses and mirrors, which combine two surface radii on a single substrate; faceted lenses and mirrors, which combine multiple plano surfaces onto a single substrate; and optical arrays — both reflective and transmissive — which combine multiple curved surfaces onto a single substrate. Additional non-rotationally symmetric optics include long-working-distance off-axis parabolas, ring-focus parabolas, and rooftop beamsplitters.



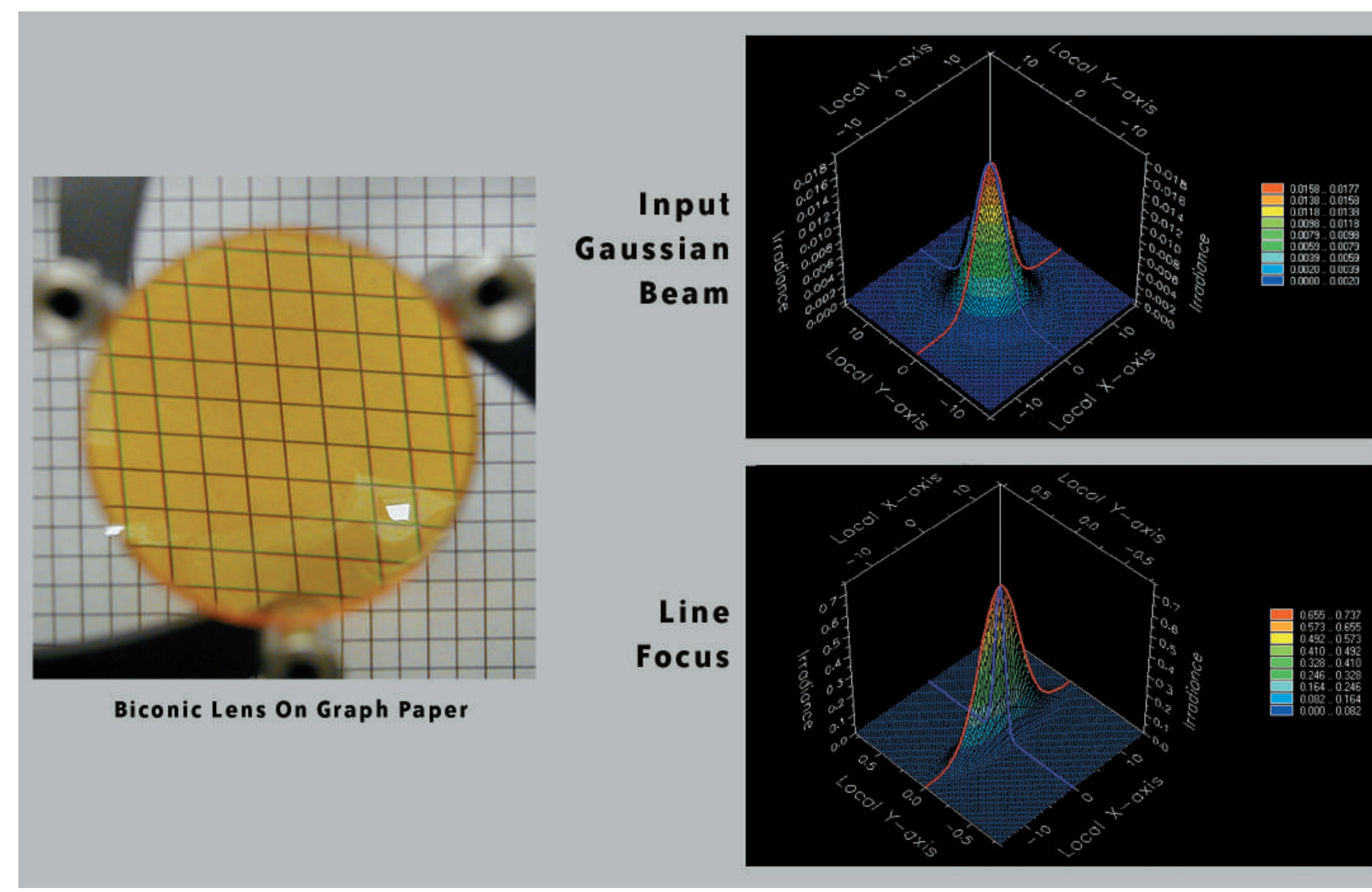
BICONIC LENSES

Biconic lenses have two different radii on one surface. It is possible to make a biconic lens with spherical curves or aspheric curves, depending on the application and need to eliminate aberrations. Biconic lenses are used to produce an elliptically shaped focus or line focus. These lenses are also used in anamorphic beam expanders to reduce astigmatism in the laser beam. Many waveguide-type lasers produce astigmatic beams. Since most laser applications require symmetric Gaussian beams, astigmatic beams must be corrected.

The usual type of optic used in anamorphic beam expanders and elliptical focus lenses is the cylinder lens. For the beam expander application and some focusing applications, it is necessary to use two cylinders, resulting in difficult alignment procedures. The biconic lens can reduce the number of elements used in this application and, more importantly, reduce alignment headaches.

- *Biconic optical power can be placed on one surface.*
- *Easy to align. Perpendicularity of the curves is ensured by machining.*
- *Useful in anamorphic beam expanders.*
- *As a focusing lens, it will produce elliptically shaped spots.*
- *Curvatures can be spherical or aspherical.*

BICONIC LENSES



Biconic Lens On Graph Paper

888.558.1504 (toll-free in USA and Canada) 724.352.1504 (phone) 724.352.4980 (fax)

www.iiviinfrared.com

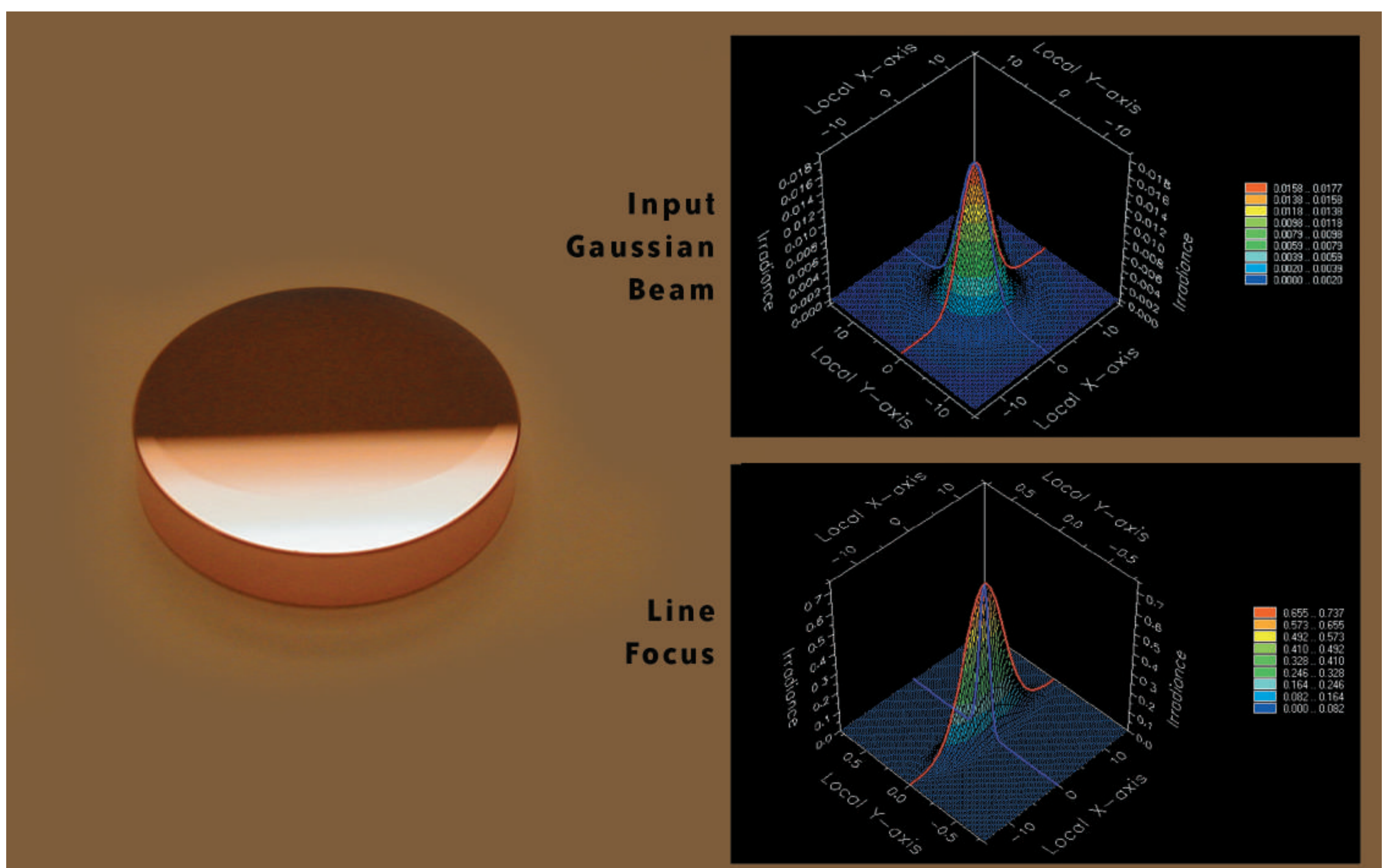
BICONIC MIRRORS

In many applications, spherical mirrors, cylindrical mirrors, and parabolic mirrors help shape the laser beam. Biconic mirrors — or the more general toroidal mirrors — can combine two separate optics into one.

Biconic mirrors have two different radii on one surface. It is possible to make a biconic mirror with spherical curves or aspheric curves, depending on the application and need to eliminate aberrations. When appropriately designed, they can replace common 90° bending mirrors to recollimate a laser beam in a long delivery path.

BICONIC MIRRORS

- *Biconic optical power can be placed on one surface.*
- *Curves can be designed to produce diffraction-limited focus at 45° AOI.*
- *As a focusing mirror at 0° AOI, it will produce elliptically shaped spots.*
- *Useful in anamorphic beam expanders.*
- *Curvatures can be spherical or aspherical.*



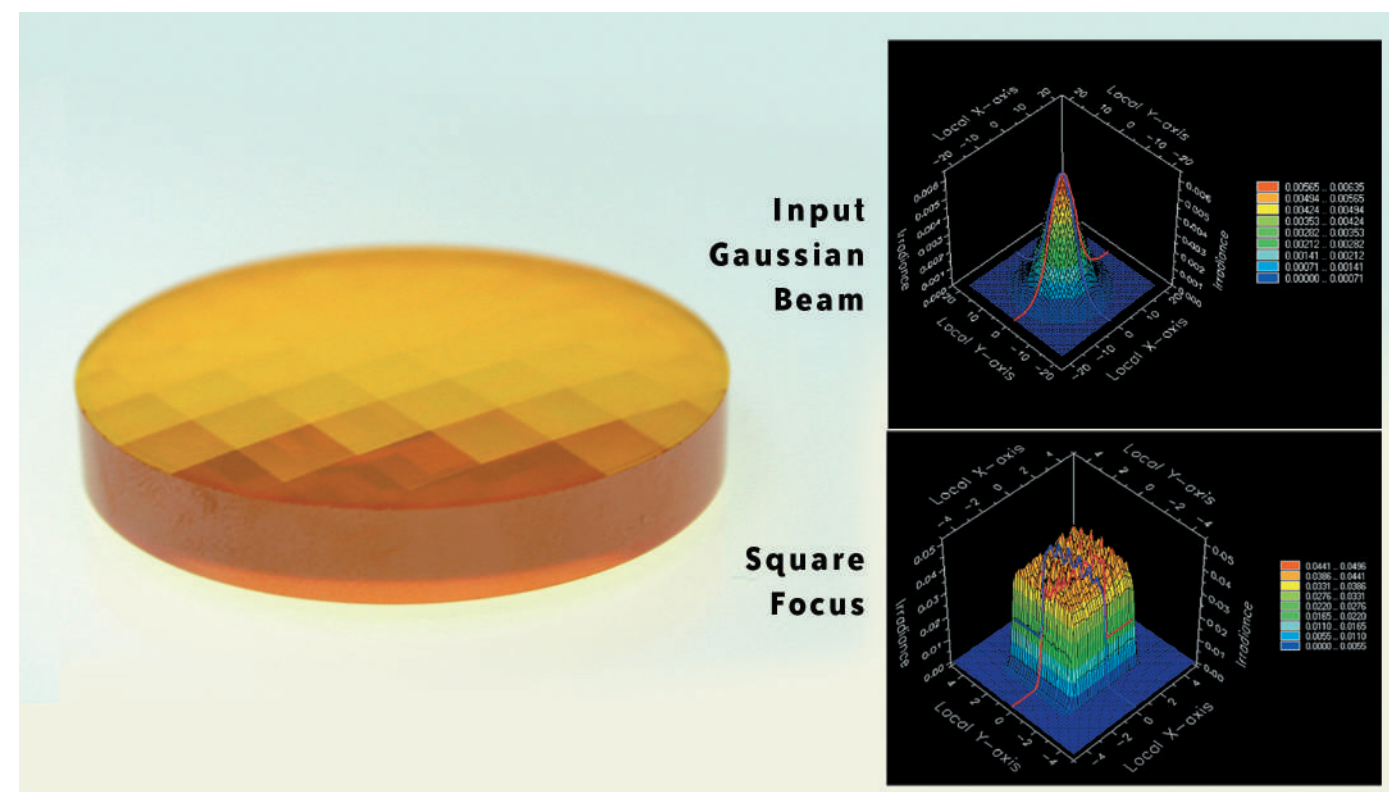
TRANSMISSIVE BEAM INTEGRATORS

Transmissive beam integrators are used with laser applications requiring a relatively large, focused flat-top intensity. Faceted integrators focus a high-power beam to a relatively flat-top beam with a size and shape that is equivalent to the individual facet size and shape. Traditionally, it has been extremely difficult to produce transmissive faceted integrators. Today, however, these faceted integrator lenses are made using advanced diamond turning techniques. Although the primary substrate material for faceted integrator lenses is ZnSe, it is possible to produce this surface on Ge or any other diamond-turnable material.

Faceted lenses are a good alternative to the faceted mirror. Facets are arranged on the lens surface in almost any shape or form. There are some practical limits to the size of the facets that are machined, but typical facet sizes of 2 to 8 mm are possible on mirror blanks up to 100 mm in diameter.

TRANSMISSIVE BEAM INTEGRATORS

- *Transmissive beam integrators produce relatively flat intensity profiles.*
- *Integrated beams can be square or rectangular.*
- *Focused beam sizes are relatively large (2 mm and above) and are ideal for welding and heat treating.*
- *Degree of integration will depend on noncoherence of the laser beam.*
- *Work best with laser beams having poor coherence.*



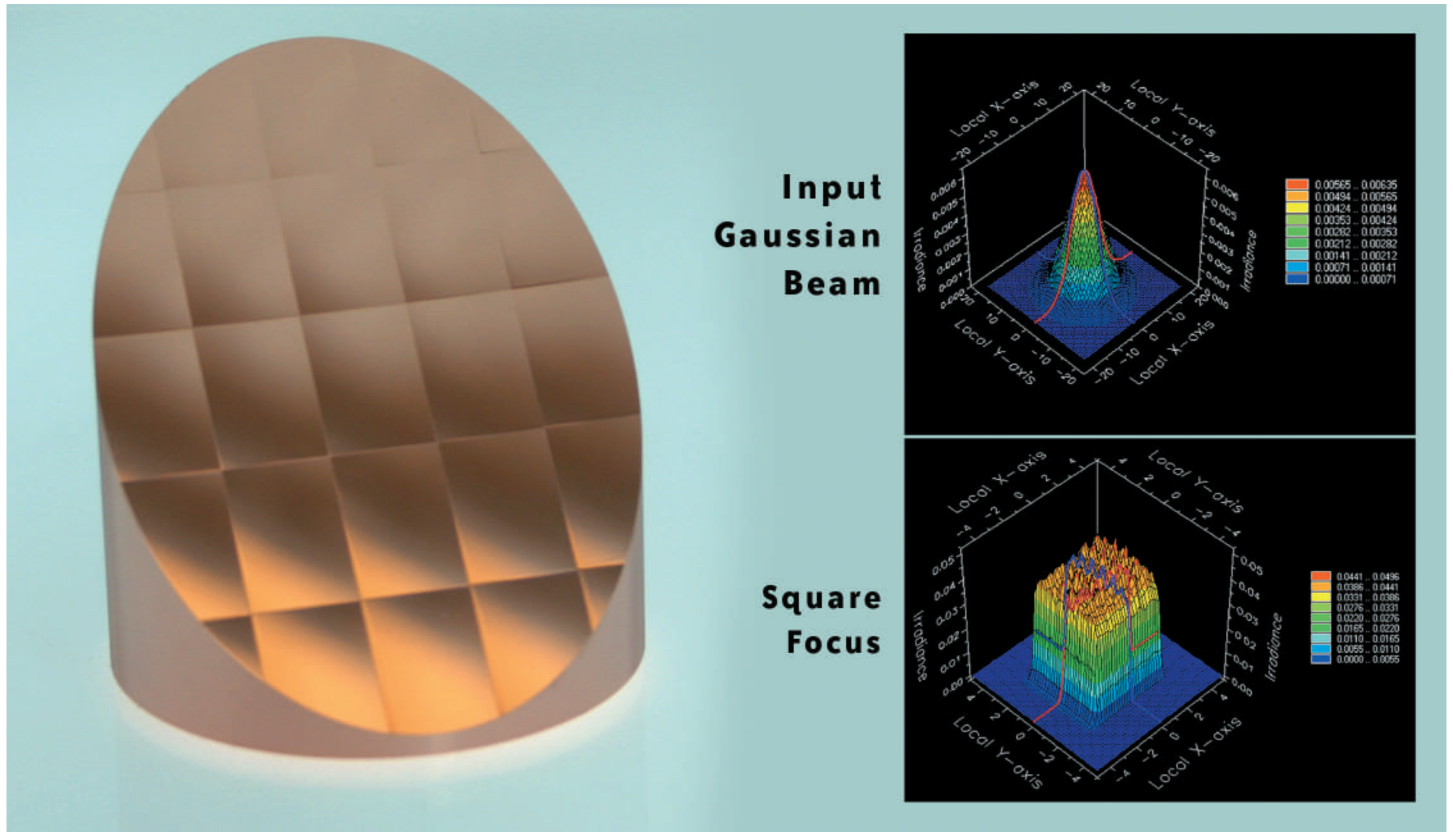
REFLECTIVE BEAM INTEGRATORS

Reflective beam integrators are widely used in high-power lasers for welding, cladding, and heat treating applications. Faceted integrators focus a high-power beam to a relatively flat-top beam with a size and shape that is equivalent to the individual facet size and shape. Traditionally, reflective integrator optics are produced by making individual faceted mirrors and then arranging them on a curved substrate. Today, however, these faceted integrator mirrors are made using advanced diamond-turning techniques. The tedious and time-consuming job of arranging individual facets on a substrate is no longer required, allowing the additional advantage of the mirror being directly water cooled.

Facets are arranged on the mirror in almost any shape or form. There are some practical limits to the size of the facets that are machined, but typical facet sizes of 2 to 8 mm are easily possible on mirror blanks up to 75 mm in diameter.

REFLECTIVE BEAM INTEGRATORS

- *Reflective beam integrators produce relatively flat intensity profiles.*
- *Integrated beams can be square, rectangular, or circular.*
- *Mirrors are made of copper and are ideal for high-power lasers.*
- *Focused beam sizes are relatively large (2 mm and above) and ideal for welding and heat treating.*
- *Degree of integration depends on noncoherence of laser beam.*
- *Works best with laser beams having poor coherence.*



FOCUSED FLAT-TOP DOUBLETS

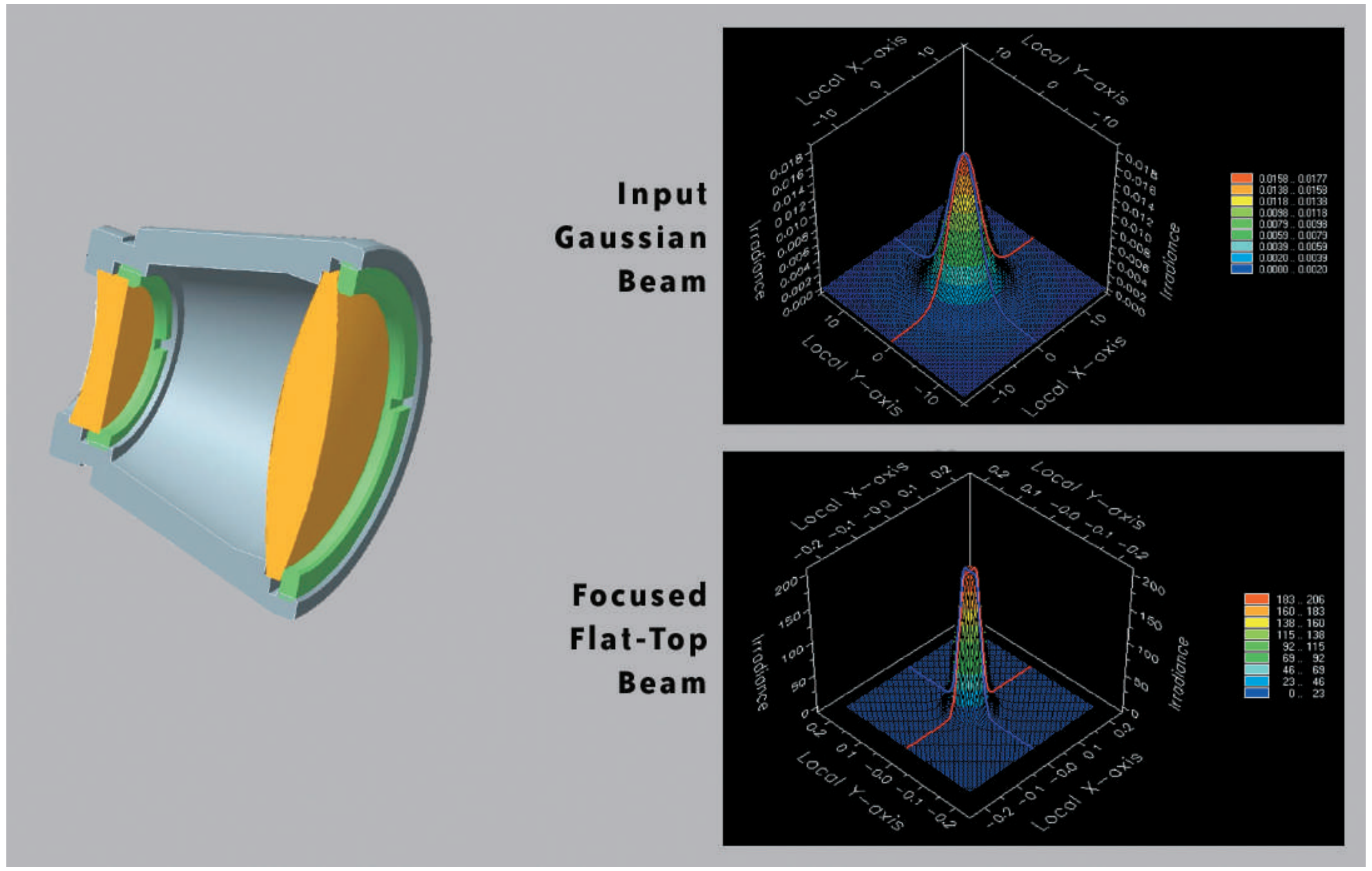
II-VI designs a simple form lens to convert a Gaussian mode to a flat-top intensity profile.

Converting one beam mode to another type is always a difficult process. There are different products to address this problem, including diffractive lenses, special beam integrators, combinations of aspheric lenses, and phase plates. As with many design types, it's desirable to use the simplest form. The II-VI aspheric form is one of the simplest types.

The method used to convert a Gaussian beam to a flat-top at focus is determined somewhat by the required focused beam size. A faceted beam integrator is necessary for large spot sizes (see pages 75 and 76). However, when it's necessary to focus a laser beam to a flat-top intensity with a spot size of 100µm, it's also necessary to go to more sophisticated aspherics or diffractives. II-VI accomplishes this with a simple aspheric form. Depending on focal length, this lens is produced as a singlet or doublet.

FOCUSED FLAT-TOP DOUBLETS

- *Focal lengths from 25 mm and up.*
- *Unit may consist of one or two lenses, depending on desired spot size.*
- *Requires Gaussian input beams with M^2 values < 1.1 for best results.*
- *Lenses are custom designed for each application.*
- *Applications for drilling and material processing.*



LONG-WORKING-DISTANCE OFF-AXIS PARABOLAS

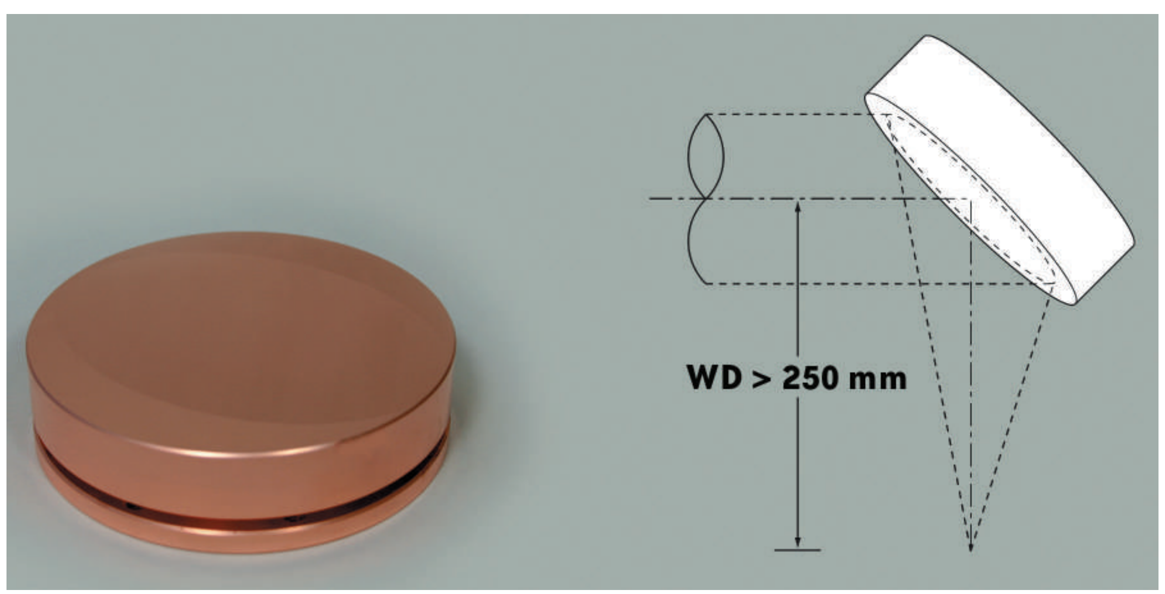
In the past, the working distance (WD) of off-axis parabolic mirrors was limited to the two-axis diamond turning lathe's swing diameter. Today, II-VI routinely produces long-working-distance parabolas with any turning angle using slow tool servo technology.

Like standard-working-distance off-axis parabolic mirrors, long-working-distance mirrors are made from copper substrates (either tilted or flat) which withstand extremely high laser powers and industrial environments. These mirrors provide diffraction-limited focusing when properly mounted and aligned. Also, copper mirrors are coated to provide greater reflectivity.

II-VI designs parabolic mirrors to reflect and focus the laser beam through 90° (standard) or any other convenient angle. Custom-designed features, such as water cooling and nonstandard mounting configurations, are available upon request.

LONG WORKING DISTANCE OFF-AXIS PARABOLAS

- *Working distances that exceed standard capabilities of two-axis machines.*
- *Excellent figure accuracy < 0.5μm.*
- *Excellent RMS surface roughness < 6 nm.*
- *Large-diameter optics up to 250 mm.*



ROOFTOP BEAMSPLITTERS

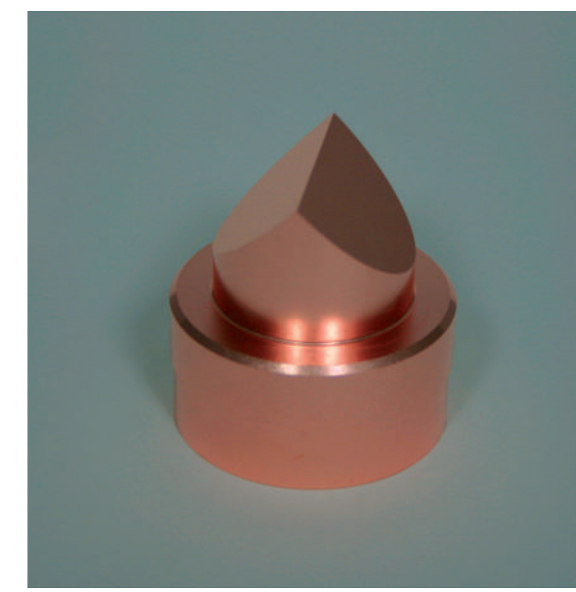
Prisms and transmissive beamsplitters are common optical elements used to split laser beams into two separate beams. These devices are common at visible and the IR wavelengths. For very high laser powers in the IR (1 to 10.6 μm), most prisms and beamsplitters are not useful because they suffer from thermal lensing. This occurs especially in CO_2 lasers at CW power levels > 500 W. For these high powers, it is possible to split the beam using a metal rooftop prism.

Rooftop beamsplitters, made from copper, are direct water cooled. This allows use at laser powers in excess of 6 kW. A 90° rooftop mirror is used to physically split the beam into two working beams. These two beams will travel 180° from each other. With some simple mirrors, the beams are used in welding and heat-treating applications.

The rooftop mirror is made from a single substrate with two precision-aligned mirrors. Each mirror surface is flycut to achieve figure and finish. The angle between each mirror's face is controlled to within 10 arc seconds (if required).

ROOFTOP BEAMSPLITTERS

- *Prism beamsplitter is used to split very high-power IR laser beams into two working beams.*
- *Mirrors are made of copper or aluminum.*
- *Copper mirrors can be direct water cooled for use at very high laser powers of > 5 kW.*



VORTEX LENSES

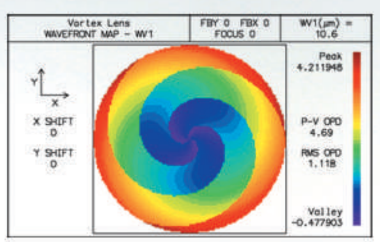
The vortex lens is unique because it has spiral-phase steps machined into the curved surface. This spiral pattern controls the phase of the transmitted beam. When the spiral steps are machined into a curved lens surface, they produce a focused beam with zero energy or power in the middle. In other words, the vortex lens produces a ring focus. One other focused beam feature is that the phase is spiraling as the beam propagates; therefore, it's sometimes called a spiral lens.

Traditionally, these lens types were produced using diffractive elements. Now they are machined directly with diamond turning techniques. The result is a precision spiral step or vortex lens that can produce a ring focus.

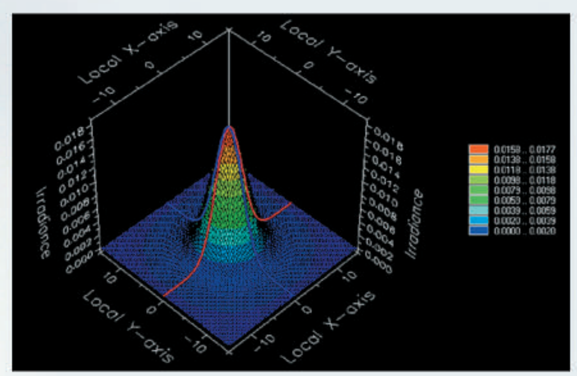
Vortex lenses are made from any type of diamond-turnable material. For use at 10.6μm, this includes materials such as ZnSe and Ge. It is also possible to put this surface on a reflective mirror such as Cu or Al.

VORTEX LENSE

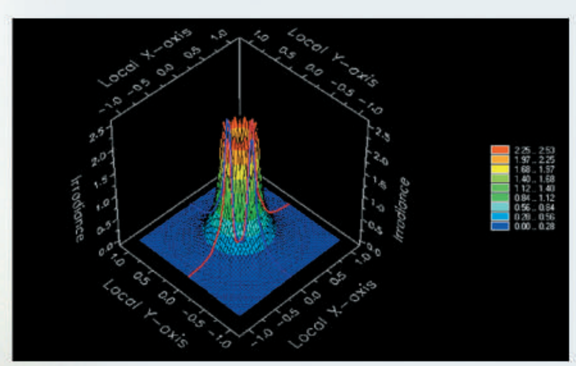
- *Provides a unique optical surface for producing a spiral-phased focused beam.*
- *Spiral phase at focus produces a ring mode.*
- *Can be used in ring-focus applications.*



Input Gaussian Beam



Ring-Focused Beam



OPTICAL ARRAYS

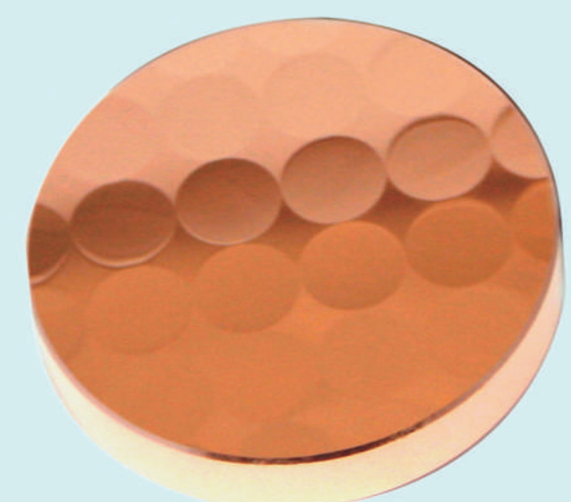
Certain optical system designs require multiple optical elements to be positioned accurately as an array. In the past, individual optics were produced and connected to a common substrate, which posed significant position and alignment challenges. Now, with II-VI's advanced diamond-turning techniques, it is possible to machine monolithic optical arrays directly on a substrate, with II-VI's fast tool servo technology. Typical substrate materials include ZnSe and Ge, and metals including Cu and Al.

A common application for this optical design is a focusing lens array with lenslets having identical focal lengths. However, it is not necessary to produce only lenslets with equal focal lengths on one substrate. Individual elements may have different focal lengths, including a mixture of positive and negative elements. It is also possible to combine lenses and mirrors.

Monolithic optical arrays provide the designer with one more tool in the design bag for producing small, complex, optical elements for advanced applications.

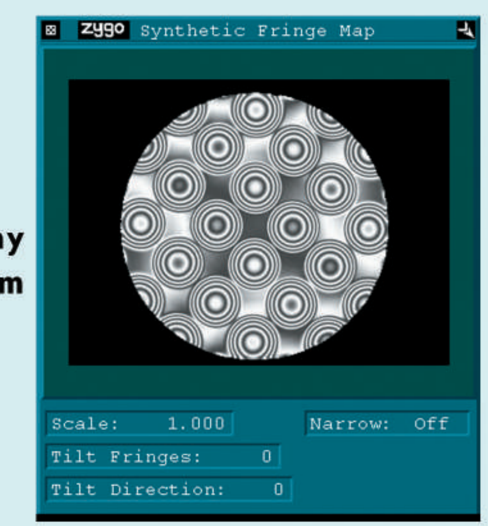
OPTICAL ARRAY

- *Monolithic optical arrays provide unique, compact optical solutions.*
- *Lenslet arrays are easily machined and provide multifocus arrays.*
- *Combinations of lenses, mirrors, or other optical elements are possible on one substrate.*

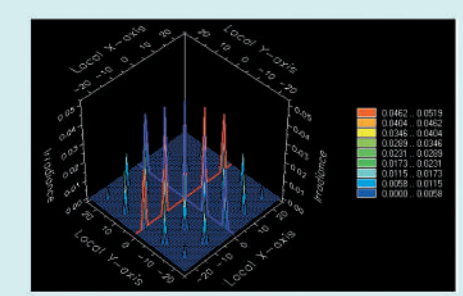


Reflective Optical Array

Optical Array Interferogram



Infrared Camera Image Of Focused Beam



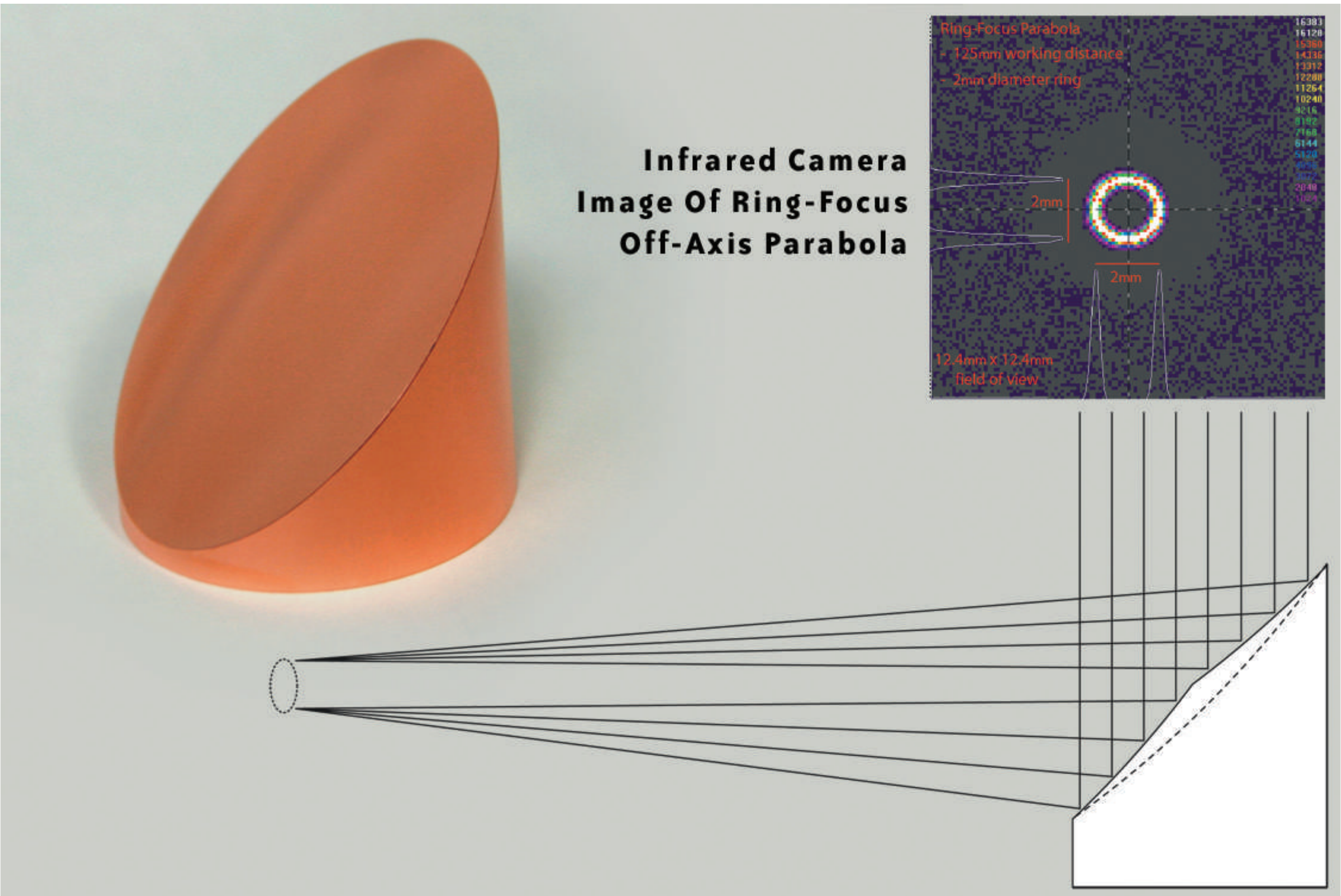
RING-FOCUS OFF-AXIS PARABOLAS

The ring-focus off-axis parabola is an optic that combines the properties of a 90° parabolic focusing mirror with an axicon focusing optic. Typically, ZnSe lenses with a conical term are used to create a ring focus. The ring-focus off-axis parabola eliminates the transmissive optic by combining the axicon with an off-axis parabolic mirror. The resulting geometry is a free-form surface which II-VI generates using slow tool servo technology.

This approach offers versatile design specifications for working distance, ring diameter, and turning angle. For high-power applications, a direct-cooled copper substrate design can be employed.

- *One optic performs the work of two.*
- *Usable in higher power laser systems.*
- *Produced from standard off-axis parabolic substrate.*
- *Excellent RMS roughness < 6nm.*
- *Easily designed to produce any desired ring diameter at focus.*

RING FOCUS OFF-AXIS PARABOLAS



CO_2 LASER CONSUMABLES

From rear mirrors to focusing lenses, and every optic in between, II-VI Infrared offers replacement laser optics and components, including focusing lenses and focusing (parabolic) mirrors, bend mirrors, collimators, reflective phase retarders, rear mirrors, output couplers, and output windows.

Our replacement laser optics are made from II-VI's own zinc selenide (ZnSe), as well as copper (Cu), gallium arsenide (GaAs), germanium (Ge), molybdenum (Mo), and silicon (Si). II-VI Infrared's world-class thin-film coatings are applied to enhance optical properties, while our quality assurance program includes comprehensive testing, documentation, and statistical analysis to ensure that each optic and component performs to customer requirements.

For additional information, contact a II-VI Infrared sales and support representative.

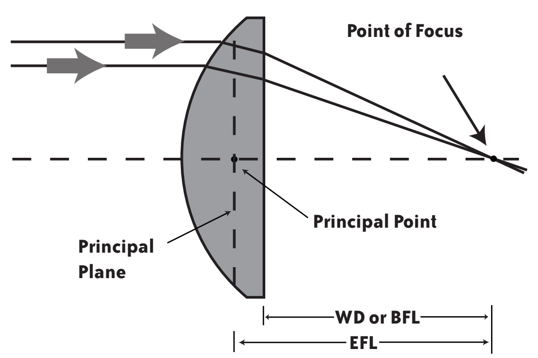
In addition to optics and optical components, we also offer a comprehensive line of over 750 replacement laser nozzles and accessories, all in stock and built to major OEM specifications.

For more information on our replacement nozzles and accessories, including downloadable product catalogs, log onto http://www.iiviinfrared.com/nozzles.

TUTORIALS

LENSES

All lenses, regardless of their shape, share certain common characteristics. The most important is focal length. It is critical to understand just how focal length is measured and how the lens focus point is affected through various factors.



Principal plane is the imaginary surface formed at the intersection of incoming parallel rays and outgoing focused rays.

Principal point is the intersection of the principal surface with the optical axis.

Point of Focus is where incoming rays parallel to the optical axis are focused and cross the optical axis.

Effective Focal Length (EFL) is the distance, along the optical axis, from the principal point to the point of focus.

Working Distance (WD) or **Back Focal Length (BFL)** is the distance from the last lens surface to the image plane.

Figure 1 Focal length definition

Focal Length

As illustrated in Figure 1, three different values describe lens focal length. The most common is the effective focal length (EFL), which determines the lens magnification power and is the measure most commonly used describing a lens focal length in specification tables.

The EFL is calculated by formulae and relates to a non-physical "principal plane" in or near the lens. The non-physical plane position varies with the lens design and cannot be located from visual inspection. The back focal length (BFL) and working distance (WD) relate the focal point to physical points on the lens surface which are easily observed.

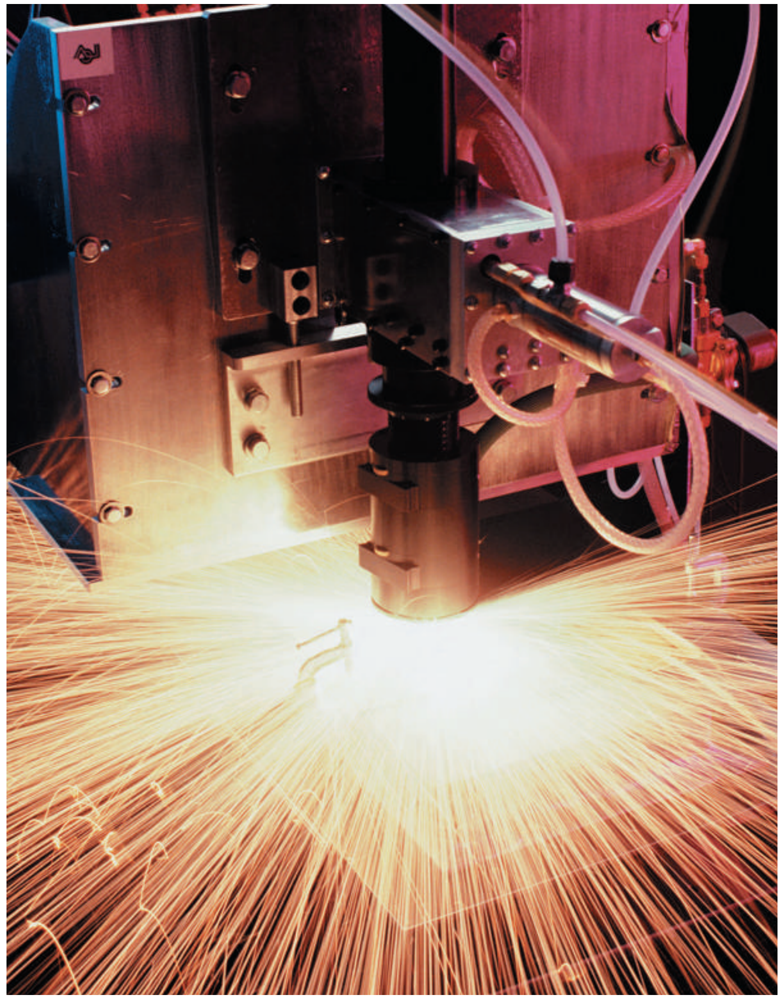
Only when presented with an object at infinity — which corresponds to a perfectly collimated input — will a lens form a spot at an image distance corresponding to its EFL. For any other object distance, the image forms further from the lens than the focal length. Ideally, image distance is related to object distance by the formula:

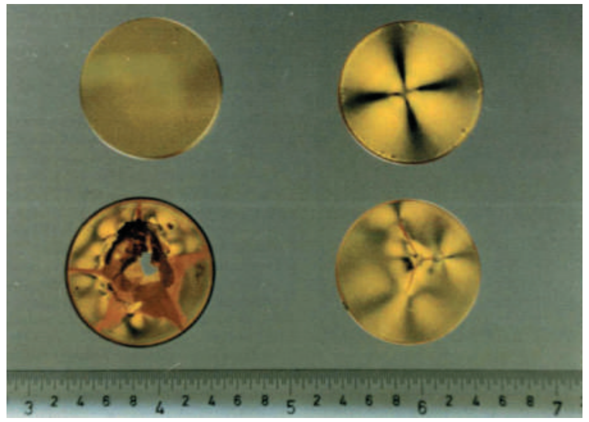
$$\frac{1}{f} = \frac{1}{o} + \frac{1}{i}$$

where o is the distance from the object to the first principal point of the lens, i is the distance from the second principal point to the image, and f is the lens focal length. The geometry of this situation is shown on Figure 2, on the opposite page. When dealing with lasers, the object is generally considered to be the beam waist. Laser manufacturers provide data on the beam waist location relative to the laser so the image distance can be readily calculated.

This relationship is important because in many laser beam delivery systems — "flying optics" systems — the lens system moves relative to the laser's beam waist during operation. As a result, the focal spot position will also shift.

There are several real-world effects which influence focal position for a lens, especially in high-power laser systems. Laser power absorption during operation causes the lens to heat up. The temperature change leads to a change in index of refraction, the optic's thermal expansion, and stress induced changes in index of refraction (photoelastic effects). The result is thermal lensing, which causes an operational change in focal length.





Starting clockwise at the top left: The progression of a thermally stressed lens.

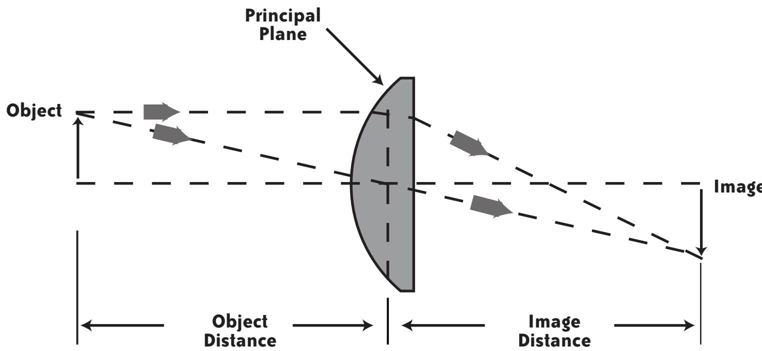


Figure 2 Relationship of object and image distance

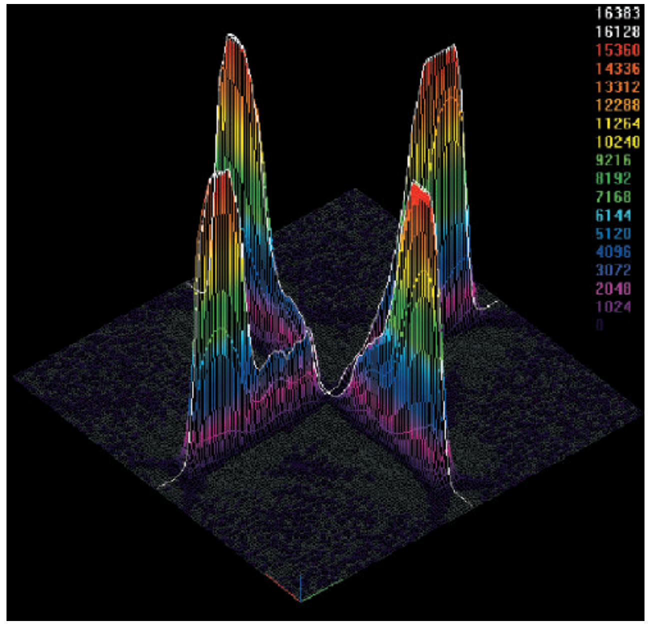
SPOT SIZE

Cutting applications require focusing a laser beam to a minimum spot size. This is necessary to maximize the energy density and produce precision cuts. Many factors affect spot size. The most important are:

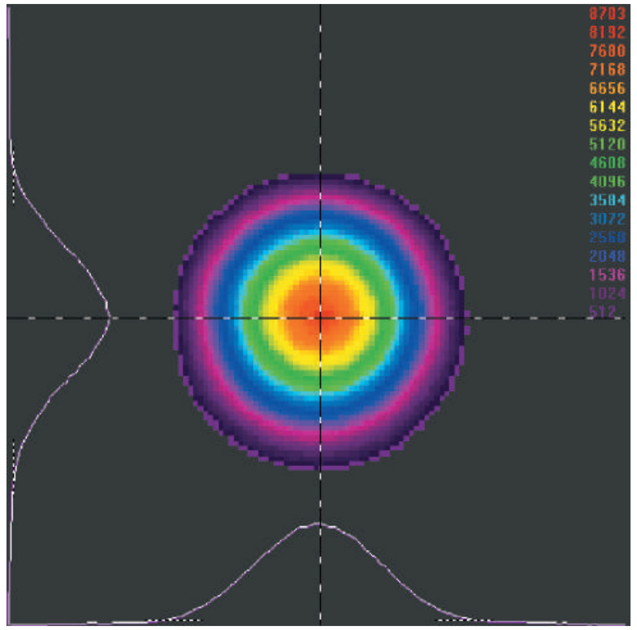
- Laser mode (M^2)
- Diffraction
- Spherical aberration

Lens shape and focal length determine the latter two factors. Of course, laser mode is determined by the laser and beam delivery system.

II-VI offers plano-convex, meniscus, and aspheric lenses in a wide variety of standard focal lengths and diameters. The following images show how these three factors affect spot size, and how to calculate spot size for plano-convex, meniscus, and aspheric lenses. The notes outline a simple procedure for picking the right lens for a given application.



The image above, captured using a Spiricon® Pyrocam™ III camera, is a CO_2 laser beam focused with a "Cross Hair" lens. The lens surface is divided into four quadrants. Each quadrant has a slightly tilted cylindrical parabolic shape. This surface shape results in each quadrant focusing that portion of the laser beam to a line segment.



The image above, captured using a Spiricon® Pyrocam™ III camera, is a CO_2 grating tuned laser beam near the laser output. The beam intensity is approximately Gaussian in distribution.

Diffraction

Diffraction, a natural and inescapable result of the wave nature of light, is present in all optical systems and determines the ultimate theoretical limit on their performance. Diffraction causes light beams to spread transversely as they propagate. If a "perfect" lens is used to focus a collimated laser beam, the spot size is limited only by diffraction.

Spot size formula:

$$\text{spot size due to diffraction} = \frac{4M^2\lambda f}{\pi D}$$

where,

- M^2 is the beam mode parameter
- λ is wavelength
- f is lens focal length
- D is input beam diameter at the lens (at the $1/e^2$ point)

This equation is used to determine the spot size produced by an aspheric lens.

Diffraction's most important factor is that the spot size increases linearly with focal length but is inversely proportional to beam diameter. **Thus, as the input laser beam diameter increases for a given lens, spot size decreases due to lower diffraction.** Also, as focal length decreases for a given laser beam diameter, spot size again decreases.

M^2 - Laser Mode Parameter

As seen in the previous formula for diffraction, focal spot size is directly proportional to the laser mode parameter, M^2. M^2 expresses how quickly a given beam diverges while propagating; a perfect TEM_{00} laser beam has M^2=1. This parameter is measured by advanced instruments, or is obtained from laser manufacturers' specifications.

SPHERICAL ABERRATION

When collimated, on-axis light is focused by an ideal lens. All light rays cross the optical axis at a single point, forming a spot with a diameter determined by the diffraction formula on page 91. However, many lenses exhibit a phenomenon termed spherical aberration. This causes light rays impinging near the lens edge to cross the optical axis closer to the lens than those going through the lens center, as shown in Figure 3. Spherical aberration increases spot size and causes best focus to occur at a different location than the calculated effective focal length.

Spherical aberration, a function of several factors, includes lens shape, orientation, and index of refraction. For example, the best shape for a crown glass lens used to focus visible light to a minimum spot size is a biconvex lens. Conversely, for a ZnSe lens used at 10.6µm, the best design for a minimum spot size is a meniscus lens.

The exact spot size for a given lens under specific circumstances is determined by ray tracing; however, a useful formula for estimating the spot size due to spherical aberration in a best form lens is:

$$\text{spot size due to spherical aberration} = \frac{kD^3}{f^2}$$

where,

- k is an index of refraction function
- D is input beam diameter at the lens (at the $1/e^2$ point)
- f is lens focal length

The most important point to note from the preceding formula is that the spot size due to spherical aberration is proportional to the cube of the beam diameter and inversely proportional to the square of the focal length. Thus, as the laser beam diameter decreases for a given lens, spot size rapidly decreases due to spherical aberration. Similarly, as focal length increases for a given laser beam diameter, the spherical aberration spot size is again reduced. For all the materials listed, the k value is significantly smaller for meniscus lenses than for plano-convex lenses. Thus, when spherical aberration is significant, the meniscus lens will perform better than the plano-convex lens.

The value of k is given for several materials at 10.6µm in the following table.

k @ 10.6µm		
Material	Meniscus	Plano-convex
ZnSe	0.0187	0.0286
GaAs	0.0114	0.0289
Ge	0.0087	0.0295
CdTe	0.0155	0.0284

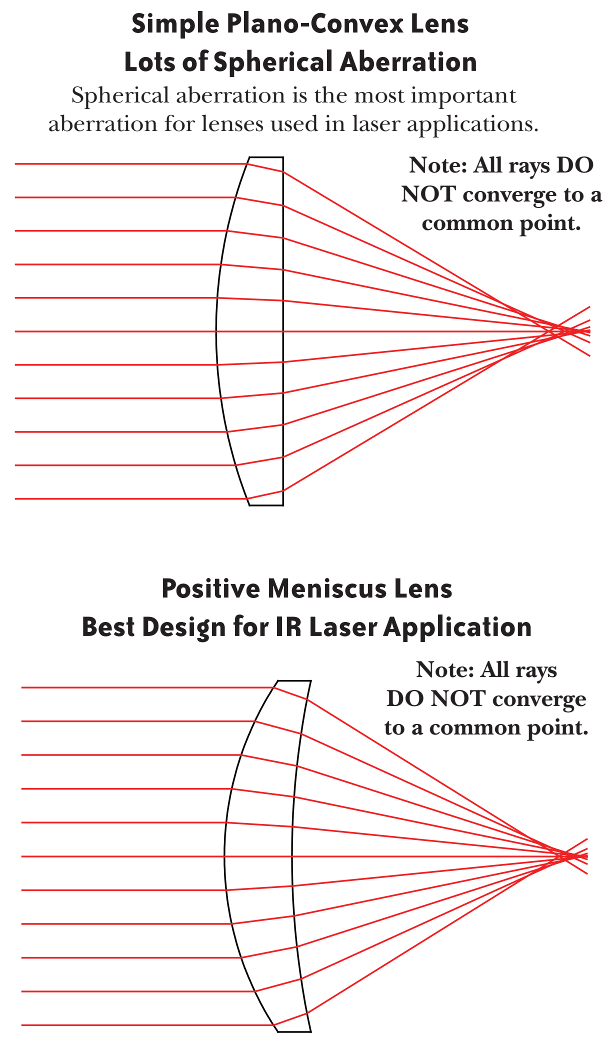


Figure 3 Spherical aberration

DETERMINING SPOT SIZE

Minimum spot size for a given lens is obtained by balancing the effects of diffraction and spherical aberration. As an example, the spot size due to diffraction and spherical aberration for a 5.00" focal length meniscus ZnSe lens is plotted as a input beam diameter function in Figure 4. A perfectly diffraction limited input beam (M^2=1) is assumed. Also plotted is the sum of the aberration and diffraction spot sizes.

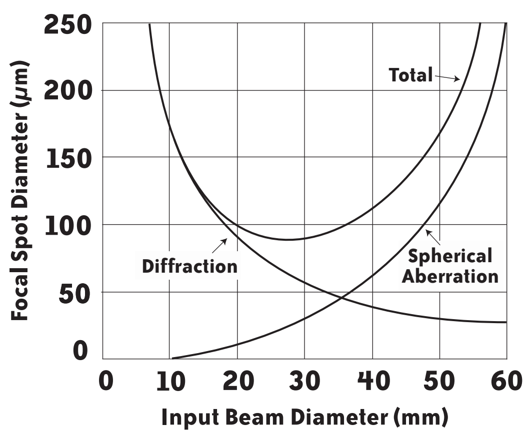


Figure 4 Spot size due to aberration and diffraction

The graph shows that spot size obtained by summing the aberration and diffraction contributions reaches a minimum value about 85µm at an input beam diameter approximately 25 mm. While simply summing the aberration and diffraction contributions may not be rigorously correct, it does provide what is probably a worst case estimate for actual spot size, and is generally an adequate criteria for choosing a lens. To summarize:

$$\text{spot size}_{\text{total}} = \text{spot size}_{\text{diffraction}} + \text{spot size}_{\text{aberration}}$$
$$= \frac{4\lambda M^2 f}{\pi D} + \frac{kD^3}{f^2}$$

where,

- λ is wavelength
- M^2 is the beam mode parameter
- f is lens focal length
- k is an index of refraction function
- D is input beam diameter at the lens (at the $1/e^2$ point)

LENSES
SPOT SIZE
SPHERICAL ABERRATION
DETERMINING SPOT SIZE
CHOOSING THE RIGHT FOCUSING LENS

CHOOSING THE RIGHT FOCUSING LENS

Using the formula shown in our "Determining Spot Size" section on page 93, we can derive the minimum spot size for two common cases:

CASE 1:

Determining the optimum input beam diameter when lens focal length is fixed.

Often, there are constraints on lens focal length due to system mechanical considerations. For instance, there may be a lower limit on the distance from the focusing lens to the workpiece. In this situation, it's most practical to pick a lens with a focal length that meets the system's mechanical constraints, and then alter the input beam diameter to the lens to achieve a minimum focal spot size.

For determining the input beam diameter, which will provide minimum spot size, we take the equation for spot size, differentiate it with respect to beam diameter, and then set it equal to zero to find the minimum value. This yields the following equation:

Optimum beam diameter for a fixed EFL:

$$D = \left(\frac{4\lambda M^2 f^3}{3\pi k}\right)^{1/4}$$

where,

- D is input beam diameter at the lens (at the $1/e^2$ point)
- λ is wavelength
- M^2 is the beam mode parameter
- f is lens focal length
- k is an index of refraction function

Referring back to our previous example, using a ZnSe best form meniscus lens with focal length constrained to be 5.00" or 127 mm, we get an optimum input beam diameter of 26 mm. Inserting this value into the spot size equation yields a spot size of 86µm, as we obtained by reading the graph in the "Determining Spot Size" section. If we perform the calculation for a 5.00" focal length plano-convex ZnSe lens, we get an optimum input beam diameter of 24 mm, which provides a 96µm focus spot diameter.

If the input beam diameter obtained from this calculation does not closely match the existing beam diameter in the system, then expand or contract the laser beam to this size. The beam can be expanded or contracted using a beam expander/condenser, or by constructing a beam expander/condenser using individual lenses.

CASE 2:

Determining the optimum focal length when lens input beam diameter is fixed.

If it's impossible or undesirable to alter the system's beam diameter, then knowing what focal length to use to produce a minimum spot size is beneficial.

To determine the focal length which will provide minimum spot size, we again take the equation for spot size, this time differentiating it with respect to focal length, and then setting it equal to zero to find the minimum value. This yields the following equation:

Optimum EFL for a fixed beam diameter:

$$f = \left(\frac{\pi k D^4}{2\lambda M^2}\right)^{1/3}$$

where,

- f is lens focal length
- k is an index of refraction function
- D is input beam diameter at the lens (at the $1/e^2$ point)
- λ is wavelength
- M^2 is the beam mode parameter

Once the optimum focal length is chosen, choose the stock lens with the focal length closest to the optimum value. For more critical applications, II-VI can readily fabricate an optic to the exact focal length and tolerances required.

As seen from the preceding discussion, there is a limit on the focus spot size which can be achieved when either focal length or input beam diameter is constrained. If the minimum spot size from the calculation is larger than required for the application at hand, then there is no choice but to change some optical system parameters.

NOTE

With higher-power CO_2 lasers, it is not generally advisable to use a lens with a diameter greater than 1.5 times the beam diameter ($1/e^2$). Ratios greater than this increase the chance of inducing thermal distortions in the lens. This is caused by too great a thermal gradient across the optic as a result of the greater distance between the heated central beam region and the cooler edge of the lens.

LENS SHAPE

As seen from the formula for spot size on page 91, the diffraction contribution to spot size is independent of lens shape, while the aberration contribution is dependent on lens shape through the parameter k. Thus, it is mainly when the aberration contribution becomes significant, which occurs at low f-numbers, that lens shape becomes important.

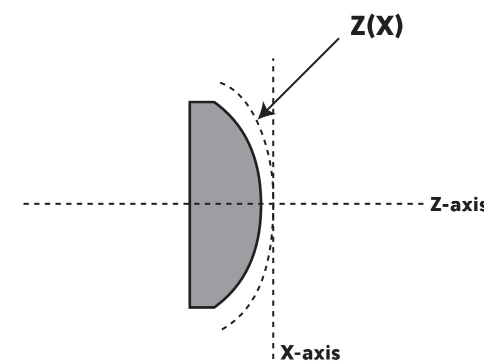
II-VI offers best form meniscus, plano-convex, and aspheric lenses. The prime advantage of plano-convex lenses is lower cost, whereas meniscus lenses can provide better performance. Thus, determining which lens shape is appropriate for a specific application is a tradeoff between the cost and performance factors. To make this evaluation, formulas are used to calculate the spot size for the two different lens shapes, shown in the example of the 5.00" focal length lens on pages 94 to 95.

In some cases, calculating exact spot size is not possible. This is true when the laser contains higher order modes, which can be difficult to accurately detect and analyze as to their effect on lens performance. Under these circumstances, use the general rule that when operating below f/5, the meniscus lens will yield demonstrably better performance. Above f/5, it is unlikely there is any significant difference in lens performance.

ASPHERIC LENSES

The use of aspheric surfaces in the optical systems design allows the designer to achieve better spot size performance, or alternatively achieve similar performance while using fewer elements in the system. These aspheric surfaces are extremely difficult to fabricate using conventional polishing processes. Our diamond turning facility at II-VI includes two-axis machines which can produce precision optical finishes with aspheric geometry. Infrared materials suitable for this machining process are germanium, zinc selenide, zinc sulfide, and silicon.

The sketch below shows a plano-convex aspheric lens element with the aspheric curve parameters definition.



$$Z(X) = \frac{(1/R)x^2}{1 + \sqrt{1 - (K+1)(1/R)^2 x^2}} + A_4x^4 + A_6x^6 + A_8x^8 \ldots A_{20}x^{20}$$

where,

- R is radius of curvature at vertex (base radius)
- K is conic constant
- A4...A20 is aspheric coefficient

For single element lens designs, the designer may use an aspheric surface to correct for spherical aberration, thus the theoretical spot size is limited only by diffraction. The table below shows the theoretical spot size for 2.50" focal length lenses and a 21 mm diameter Gaussian beam at $1/e^2$ points and an M^2 value of 1.

Lens Type	Theoretical Spot Size
Plano-convex	106μm
Meniscus	84μm
Aspheric	41μm

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POLARIZATION

Polarization is an important optical property inherent in all laser beams. Brewster windows, reflective phase retarders, and absorbing thin-film reflectors use the advantage of polarization. On the other hand, it can cause troublesome and sometimes unpredictable results when ignored. Since virtually all laser sources exhibit some degree of polarization, understanding this effect is necessary in order to specify components properly. The following text gives a basic polarization definition and presents the polarization types most commonly encountered.

Light is a transverse electromagnetic wave; this means that the electric and magnetic field vectors point perpendicular to the direction of wave travel (Figure 1). When all the electric field vectors for a given wavetrain lie in a plane, the wave is said to be plane or linearly polarized. The orientation of this plane is the direction of polarization.

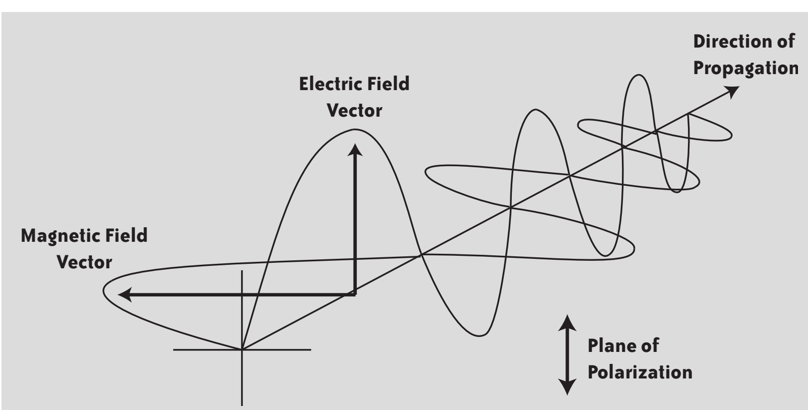


Figure 1 Definition of a polarization vector

Unpolarized light refers to a wave collection which has an equal distribution of electric field orientations for all directions (Figure 2). While each individual wavetrain may be linearly polarized, there's no preferred direction of polarization when all the waves are averaged together.

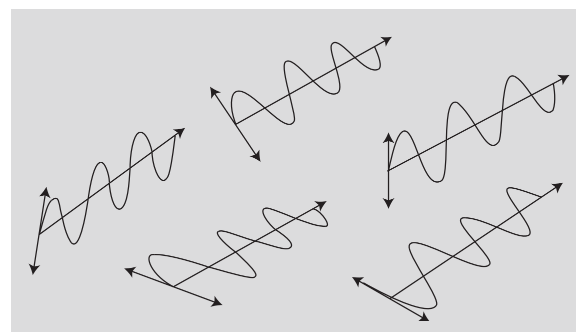


Figure 2 Unpolarized light

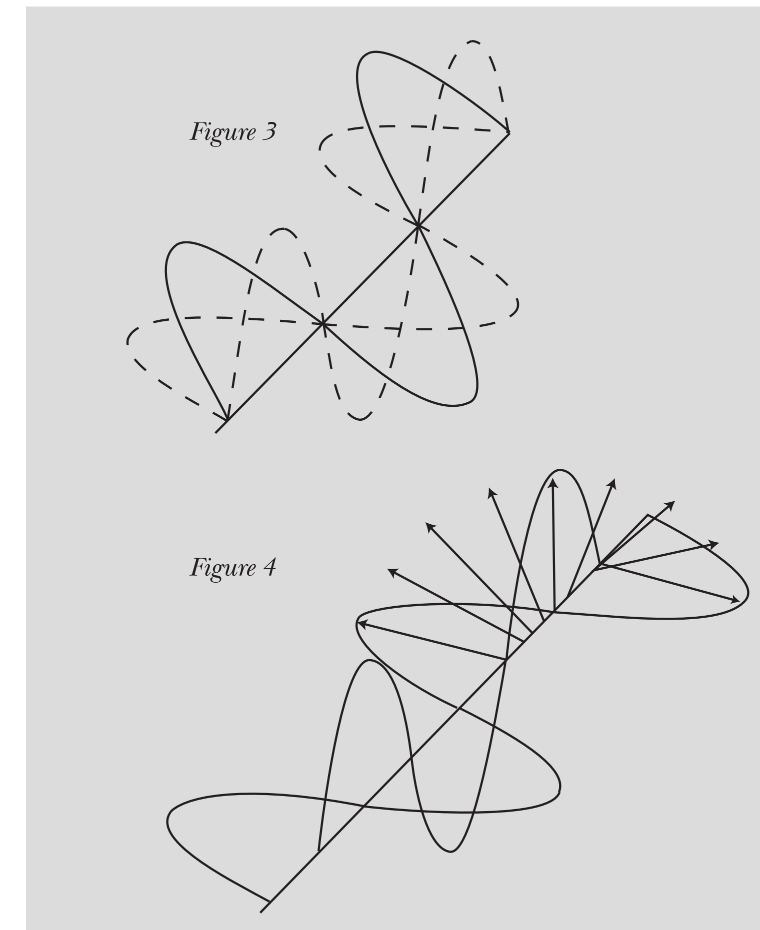
Randomly polarized light is exactly what it says; the light is plane polarized, but the direction is unknown, and may vary with time. Random polarization causes problems in optical systems since some components are polarization sensitive. If the polarization state changes with time, then the components' transmission, reflection, and/or absorption characteristics will also vary with time.

Polarization is a vector that has both direction and amplitude. Like any vector, it's defined in an arbitrary coordinate system as the sum of orthogonal components. In Figure 3, we see a plane polarized wave which points at 45° to the axes of our coordinate system. Thus, when described in this coordinate system, it has equal x- and y-components. If we then introduce a phase difference of 90° (or one-quarter wavelength) between these components, the result is a wave in which the electric field vector has a fixed amplitude but whose direction varies as we move down the wave train (Figure 4). Such a wave is said to be circularly polarized since the tip of the polarization vector traces out a circle as it passes a fixed point.

If we have two wave trains with unequal amplitude and with a quarter-wave phase difference, then the result is elliptical polarization. The tip of the polarization vector will trace out an ellipse as the wave passes a fixed point. The ratio of the major to the minor axis is called the ellipticity ratio of the polarization.

Always state the polarization orientation when ordering optical coatings for use at non-normal incidence. If you are unsure about how to determine the polarization state of your source, please contact our applications engineers for assistance.

(Continued onto page 100.)

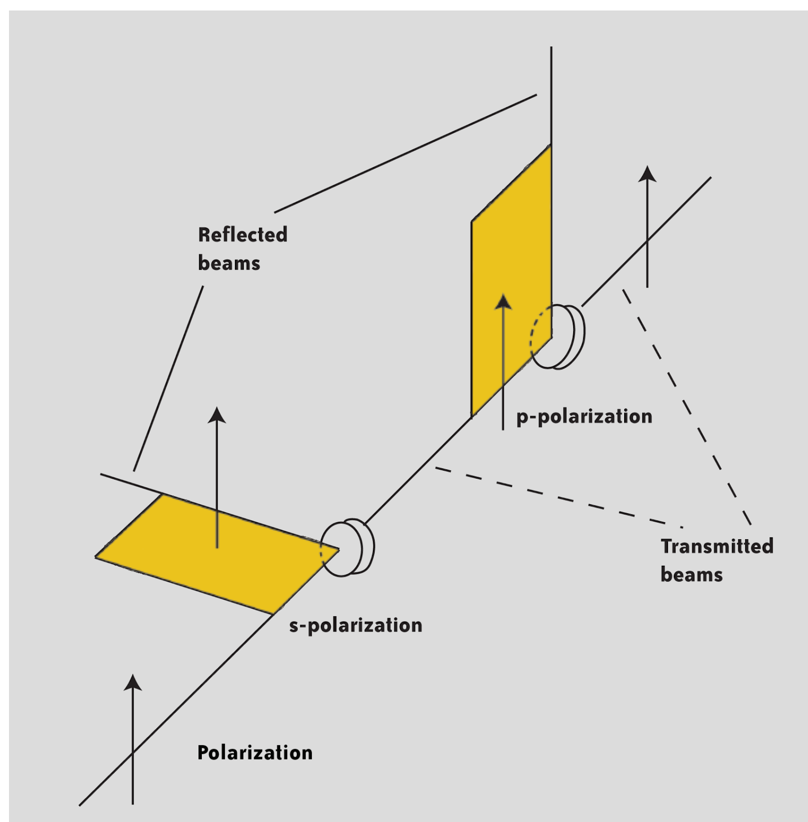


A wave is resolved into two equal components, each at 45° to the orginal (Figure 3). Introducing a quarter-wave phase difference between these components produces a result in a wave whose amplitude is constant (Figure 4), but whose polarization vector rotates.

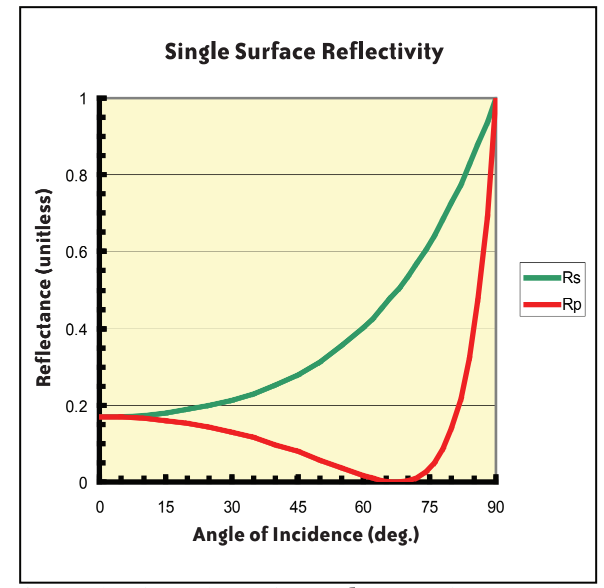
POLARIZATION

(Continued from page 99.)

When light strikes an optical surface, such as a beamsplitter, at a non-perpendicular angle, the reflection and transmission characteristics depend upon polarization. In this case, the coordinate system we use is defined by the plane containing the input and reflected beams. Light with a polarization vector lying in this plane is called p-polarized, and light which is polarized perpendicular to this plane is called s-polarized. Any arbitrary state of input polarization can be expressed as a vector sum of these s- and p-components.



For s-polarization, the input polarization is perpendicular to the plane (shown in color) containing the input and output beams. For p-polarization, the input polarization is parallel to the plane (shown in color) containing the input and output beams.



A graph of single surface reflectance for s- and p-polarization as a function of angle of incidence for ZnSe at 10.6µm.

To understand the significance of s- and p-polarizations, examine the graph which shows the single surface reflectance as a function of angle of incidence for the s- and p-components of light at a wavelength of 10.6µm striking a ZnSe surface. Note that while the reflectance of the s-component steadily increases with angle, the p-component at first decreases to zero at 67° and then increases after that. The angle at which the p-reflectance drops to zero is called Brewster's Angle. This effect is exploited in several ways to produce polarizing components or uncoated windows which have no transmission loss such as the Brewster windows.

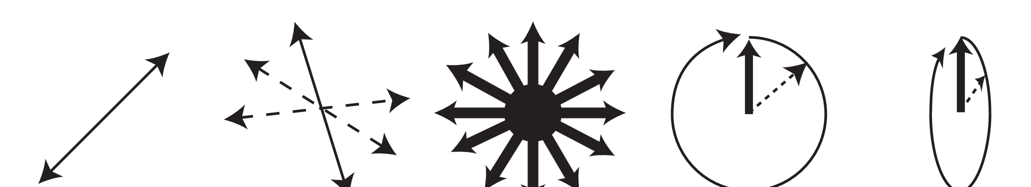
The angle at which p reflectance drops to zero, termed Brewster's Angle, can be calculated from:

$$\Theta_B = \tan^{-1}(n)$$

where Θ_B is Brewster's Angle and n is the material's index of refraction.

Polarization state is particularly important in laser cutting applications. See pages 62 to 63 for our reflective phase retarders, which provide the optimum polarization for laser cutting.

Polarization Summary



Linear polarization has constant amplitude and orientation.	*Random polarization has an orientation which varies with time.*	*Radially polarized light contains polarization vectors oriented radially to the beam.*	*Circular polarization has constant amplitude, but orientation vector describes a circle.*	*Elliptical polarization vector traces out an ellipse over time.*

PRESSURE LOADING

It's not unusual to use a lens or window as the port between a vacuum chamber and the outside, or to encounter a situation where an optic must withstand pressure loading. Given the cost of most infrared optics, as well as the potential safety issues, it's important that the optic under pressure be sufficiently thick to withstand the loading without breaking. On the other hand, since increasing thickness reduces optical transmission, it's desirable to minimize thickness for optical considerations.

The formulae given in the following text show how to calculate the necessary thickness for an optic under pressure. It is assumed that the window is unclamped and supported by a flat flange around its edge. Other important factors which may affect the required thickness for a given application, but which are not included in this treatment, include:

- Mounting flange size
- Stress resulting from mounting or sealing
- Flange clamping stresses
- Mounting flange flatness
- Stress due to thermal expansion
- Vibration effects
- Pressure cycling or surges
- Thermal shock/cycling
- Mounting surface rigidity
- Mounting surface roughness
- Optic edge roughness
- Desired optical specifications

Since it's not possible to include all these factors in our analysis, it's common practice to include a "safety factor" in the equation which increases the predicted thickness to an amount which should be adequate for most applications. Doing this yields the following equations.

For a circular window the minimum thickness is:

$$T_{min} = \sqrt{\frac{1.1Pr^2S}{M}}$$

where,

- T is the thickness in inches
- r is the radius of the unsupported circular area in inches
- P is the pressure in psi
- S is the safety factor (A safety factor of 4 is typical for most applications.)
- M is the rupture modulus of the material being used in psi

The value for rupture modulus is given for each material used by II-VI in the materials section.

M Values for Common II-VI Materials	
ZnSe	8,000 psi
ZnS MS	10,000 psi
ZnS	15,000 psi
Ge	13,500 psi
GaAs	20,000 psi

For a rectangular window, the minimum thickness is given by:

$$T_{min} = \sqrt{\frac{SPX^2Y^2}{M\ (X^2 + Y^2)}}$$

where,

- T is the thickness in inches
- S is the safety factor (A safety factor of 4 is typical for most applications.)
- P is the pressure in psi
- X is the unsupported length of the longer side of the part in inches
- Y is the unsupported length of the shorter side of the part in inches
- M is the rupture modulus in psi

IR OPTICS HANDLING & CLEANING

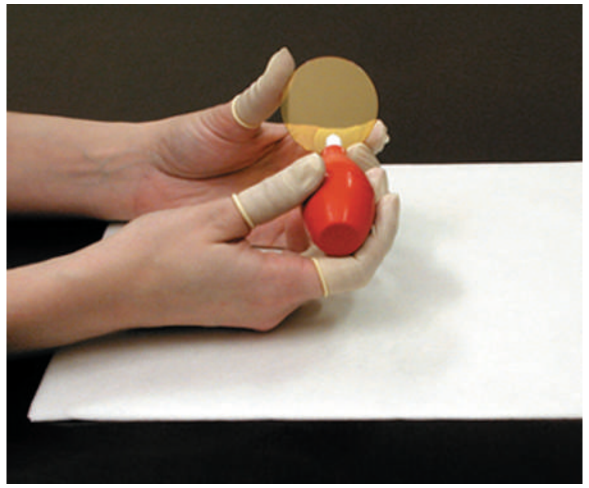
Great care should be taken when handling infrared optics. Please note the following precautions:

1. Always wear powder-free finger cots or rubber/latex gloves when handling optics. Dirt and oil from the skin can severely contaminate optics, causing a major degradation in performance.
2. Do not use any tools to manipulate optics — this includes tweezers or picks.
3. Always place optics on supplied lens tissue for protection.
4. Never place optics on a hard or rough surface. Infrared optics can be easily scratched.
5. Bare gold or bare copper should never be cleaned or touched.
6. All materials used for infrared optics are fragile, whether single crystal or polycrystalline, large or fine grained. They are not as strong as glass and will not withstand procedures normally used on glass optics.

Due to the problems encountered when cleaning mounted optics, it is recommended that the cleaning procedures described here be performed only on unmounted optics. If cleaning must be performed on a mounted optic, refer to the instructions printed in italics and in brackets [ ]. These are additional steps that must be performed when cleaning mounted optics.

Note
Except for Step 1 and Step 2, the cleaning procedures described here should not be used for new optics. New optics are cleaned and packaged prior to leaving II-VI to ensure their high quality condition upon receipt. If you suspect a problem with contamination, or other cosmetic defects with a new optic, please contact II-VI Infrared immediately.

Step 1 - Mild Cleaning for Light Contamination (dust, lint particles)



Use an air bulb to blow off any loose contaminants from the optic surface before proceeding to the cleaning steps. If this step does not remove the contamination, continue to Step 2.

Note:
Avoid using shop air lines because they usually contain significant amounts of oil and water. These contaminants can form detrimental absorbing films on optical surfaces.

[*No additional steps necessary for mounted optics.*]

Step 2 - Mild Cleaning for Light Contamination (smudges, fingerprints)

Dampen an unused cotton swab or a cotton ball with acetone or isopropyl alcohol. Gently wipe the surface with the damp cotton. Do not rub hard. Drag the cotton across the surface just fast enough so that the liquid evaporates right behind the cotton. This should leave no streaks. If this step does not remove the contamination, continue to Step 3.

Note:
Use only paper-bodied 100% cotton swabs and high-quality surgical cotton balls.

HPLC (low water content) or reagent grade acetone and isopropyl alcohol are recommended.

[*No additional steps necessary for mounted optics.*]

(Step 2 continued onto page 106.)

IR OPTICS HANDLING & CLEANING

(Step 2 continued from page 105.)

Step 2 (continued) - (alternative method) "Drop and Drag" - Mild Cleaning for Light Contamination

(Note: The "Drop and Drag" method is not a preferred cleaning method of II-VI Infrared.)

Lay the lens tissue on the optic's surface. Using an eyedropper, squeeze a few drops of acetone onto the lens tissue, wetting the complete optic's diameter.

Without lifting the lens tissue, drag the lens tissue across the optic just fast enough so that the liquid evaporates behind the tissue. This should leave no streaks. If this step does not remove the contamination, continue to Step 3.

Note:
Use only the lens tissue supplied in the optics cleaning kit or another high-quality lens tissue.

HPLC (low water content) or reagent grade acetone is recommended.

[*This method cannot be used for mounted optics.*]

Step 3 - Moderate Cleaning for Moderate Contamination (spittle, oils)

Dampen an unused cotton swab or cotton ball with white distilled vinegar. Using light pressure, wipe the optic's surface with the damp cotton. Wipe excess distilled vinegar with a clean dry cotton swab. Immediately dampen a cotton swab or cotton ball with acetone. Gently wipe the optic's surface to remove any acetic acid. If this step does not remove the contamination, continue to Step 4.

Note:
Use only paper-bodied 100% cotton swabs.

Use only high-quality surgical cotton balls that have been sorted to remove any with embedded abrasives.

White distilled vinegar with a 6% acetic acid content should be used.

[*No additional steps necessary for mounted optics.*]

Step 4 - Aggressive Cleaning for Severely Contaminated Optics (splatter)

Caution: Step 4 should NEVER be performed on new or unused laser optics. These steps are to be done only on optics that have become severely contaminated from use and have no acceptable results yielded from Steps 2 or 3 as previously noted.

If the thin-film coating is removed, the optic's performance will be destroyed. A change in apparent color indicates the removal of the thin-film coating.

For severely contaminated and dirty optics, an optical polishing compound may need to be used to remove the absorbing contamination film from the optic.

A.
Shake the container of polish thoroughly before opening. Pour four or five drops of polish onto a cotton ball. Gently move the cotton ball in circular patterns across the surface to be cleaned. **Do not press down on the cotton ball!** Let the cotton ball drag lightly across the surface under its own weight. If too much pressure is applied, the polish will quickly scratch the optic's surface. Rotate the optic frequently to avoid excessive polishing in any one direction. Clean the optic in this manner for no more than 30 seconds. If, at any time during this step, you notice the optic's surface change color, stop polishing immediately. This color change indicates that the outer portion of the thin-film coating is being eroded.

[*For a mounted optic, a fluffed cotton swab may have to be substituted for the cotton ball if the entire optic's surface is to be uniformly cleaned. This is especially true with small diameter optics. Be careful not to apply pressure when using a cotton swab!*

For a fluffed cotton swab, take the unused cotton swab and rub it back and forth on a soft piece of foam that is free of foreign particles.]

B.
After using the polish, wet an unused cotton ball with distilled water and gently swab the optic's surface. Thoroughly wet the surface to remove as much of the polish residue as possible. **Do not let the optic's surface dry!** This will make the remaining polish removal much more difficult.

[*For a mounted optic, a fluffed cotton swab may be substituted. Try to remove as much polish residue as possible, especially near the mount's edges.*]

(Step 4 continued onto page 108.)

IR OPTICS HANDLING & CLEANING

(Step 4 continued from page 107.)

Step 4 (continued) - Aggressive Cleaning for Severely Contaminated Optics (splatter)

C.
Quickly wet a fluffed cotton swab with isopropyl alcohol and gently clean the optic surface thoroughly. Cover the entire surface with the swab to dislodge as much polish residue as possible.

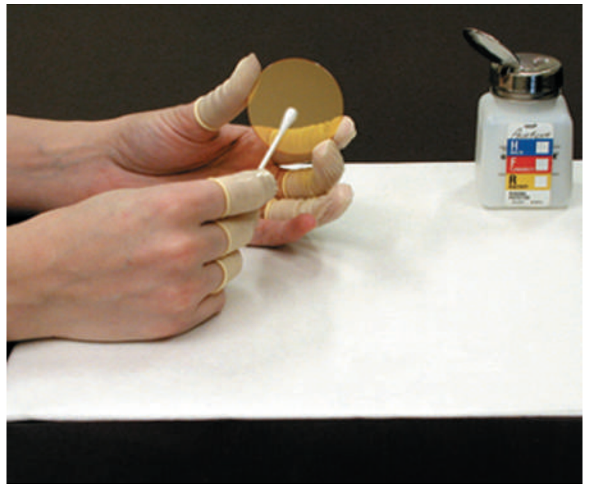
NOTE:
If the optic is 2.00" or larger, a cotton ball may be substituted for the cotton swab in this step.

[*For a mounted optic, place the cotton swab in the optic's center and clean outwards in a spiral motion toward the optic's edges.*]

D.
Wet a fluffed cotton swab with acetone and clean the optic's surface, removing any remaining isopropyl alcohol and polish residue in the process. When performing the final cleaning with acetone, lightly drag the cotton swab across the optic, overlapping strokes until the entire surface has been wiped. Move the swab very slowly for the final strokes to assure that the acetone on the optic's surface dries immediately behind the swab. This will eliminate streaks on the surface.

[*For a mounted optic, start in the optic's center and work outward in a spiral pattern toward the edge with a fluffed swab dampened with acetone. Use a new cotton swab dampened with acetone and run it around the outside of the optic against the mount to remove the polish residue. Repeat this step several times if necessary to assure that no polish residue is left on the optic's edges when the cotton swab is lifted from the surface.*]

[*For a mounted optic, it may be impossible to remove every trace of residue from the surface, especially near the outer edge. Try to be certain any remaining residue is along the optic's outermost edge only, and not in the center.*]



The final step is to carefully examine the optic's surface under good light in front of a black background. Any visible polish residue should be removed by repeating steps 4B-4D as many times as required.

NOTE:
Contamination and damage types, such as metal splatter, pits, etc., cannot be removed. If the optic shows the contamination or damage mentioned, it will probably need to be replaced.

ABSORPTION

Laser Optics and Absorption's Dominant Role

Since its beginning in 1971, II-VI has played a key role in developing optical materials and coatings that enabled the CO_2 laser to emerge into a leading technology for materials processing, and for applications in fields as diverse as laser surgery, laser imaging, target acquisition, and surveillance.

CO_2 laser technology advancements allowed lasers — with power levels exceeding 1 kW — to develop in the early 1970s. The corresponding need in understanding optical materials and optical coatings was evident.

High-power infrared lasers performance, including high-energy density waveguide lasers, depends heavily upon the absorption control levels in optical substrates, their thin-film coatings, and interfaces. II-VI is the leader in infrared laser optics technology.

II-VI Infrared's MP-5® ultra-low absorption lens

Absorption in Laser Optics

Contamination due to foreign materials on the optic's surface includes dust, oil, grease, fingerprints, and hydrocarbons. These contaminants, if deposited on the optic's surface, may lead to absorption and shorten optic lifespans and efficiency.

Localized heating, caused by contamination, can lead to "thermal runaway" in high-power laser optics. High temperatures create an increase in free carriers within the bulk material which increases absorption. This process reaches an avalanche state, and thermal runaway commences at > 50° C for Ge, and > 200° C for ZnSe and GaAs.

Surface imperfections also cause absorption and can include:

- Scratches
- Pits or digs
- Imbedded polishing abrasives
- Pinholes in coatings
- Inclusions in coatings

These surface defects act as damage sites which suffer degradation due to intense perturbations in the electric field surrounding the sites.

Factors Affecting Absorption

- **Substrate bulk absorption**
- **Coating absorption**
- **Surface contamination**
- **Surface deterioration**

Absorption Effects in CO_2 Lasers

The CO_2 wavelength absorption level coupled with the optic thermal conduction characteristics and its mount are important in determining the laser system's performance and optic's lifespan.

While the source and control of factors contributing to absorption are complex, the results are clear and include:

- Decreased output power
- Fluctuations in output power
- Mode instability
- Focal point drifting
- Coating failures
- External cavity optics failures
  (due to output coupler thermal lensing or
  beam delivery system contamination)

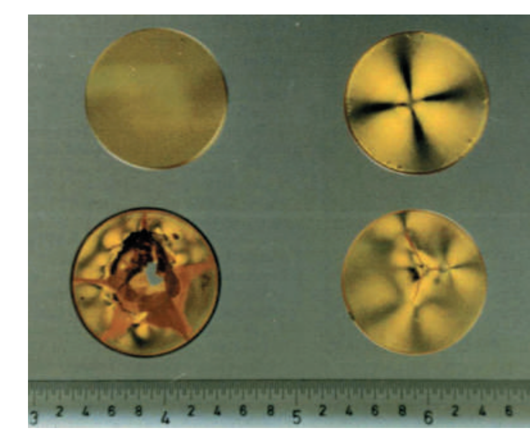
All these failure mechanisms are the result of thermal lensing (the actual change of an optic's physical characteristics due to absorption). The thermal lensing effect on the beam mode is increased further by a change in the material's refractive index due to temperature. This latter and more significant effect induces additional optical distortion in the transmitted beam.

Testing to Ensure Low Absorptivity

II-VI was the first IR optics manufacturer to establish a laser vacuum calorimetry test facility for measuring absorption in commercial CO_2 laser optics.

In laser calorimetry, optic samples are mounted in a vacuum for thermal isolation. The sample is then irradiated with a CO_2 laser beam, while thermocouples monitor the sample temperature rise. The laser beam is then turned off and the sample is cooled. By precisely measuring the sample mass, the laser beam incident power, and the heating and cooling slopes generated during the test, the total sample absorption (as a percentage of incident laser power) is determined.

To maintain the leadership in quality and low-absorption coatings, the laser calorimetry system regularly undergoes calibration testing and refinement by II-VI's technical staff.



Starting clockwise at the top left: The progression of a thermally stressed lens.

USEFUL FORMULAS & ABBREVIATIONS

Spot Size

$$\text{spot size}_{total} = \text{spot size}_{diffraction} + \text{spot size}_{aberration}$$

$$= \frac{4\lambda M^2 f}{\pi D} + \frac{k D^3}{f^2}$$

Optimum beam diameter for a fixed EFL:

$$D = \left(\frac{4\lambda M^2 f^3}{3\pi k}\right)^{1/4}$$

Optimum EFL for a fixed beam diameter:

$$f = \left(\frac{\pi k D^4}{2\lambda M^2}\right)^{1/3}$$

where,

- f is lens focal length
- D is input beam diameter at the lens (at the $1/e^2$ point)
- k is an index of refraction function
- M^2 is the beam mode parameter
- λ is wavelength

k @ 10.6μm		
Material	**Meniscus**	**Plano-convex**
ZnSe	0.0187	0.0286
GaAs	0.0114	0.0289
Ge	0.0087	0.0295
CdTe	0.0155	0.0284

Please see pages 91 to 93 for more detail.

SAG (Sagitta) of a Spherical Surface

$$SAG = R - \sqrt{R^2 - \left(\frac{d}{2}\right)^2}$$

where,

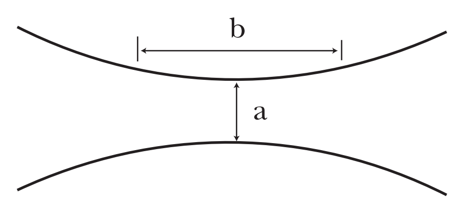
- R is radius of curvature
- d is diameter

Depth of Focus (DOF)

$$DOF = b = \frac{8\lambda M^2}{\pi}\sqrt{\rho^2 - 1}\left(\frac{f}{D}\right)^2$$

where,

- f is lens focal length
- D is input beam diameter at the lens (at the $1/e^2$ point)
- M^2 is the beam mode parameter
- λ is wavelength
- ρ is the tolerance factor



Example: If within the distance b, the spot size is to increase by no more than 5 percent (.05) from its minimum value at the waist (a), then ρ=1.05.

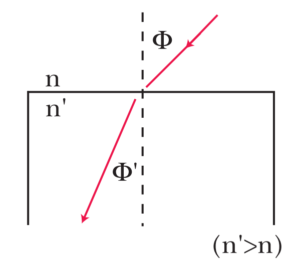
Thick Lens Equation

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2} + \frac{t(n-1)}{nR_1R_2}\right)$$

where,

- f is lens focal length
- n is material's index of refraction
- t is center thickness
- R is radius of curvature (R_1: convex is positive, concave is negative R_2: concave is positive, convex is negative)

Snell's Law

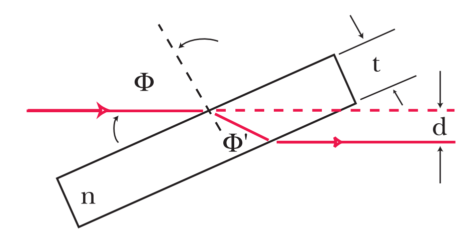


$$n \sin \Phi = n' \sin \Phi'$$

where,

- Φ is angle of incidence
- n is index of refraction of the material

Displacement Through Parallel Plate

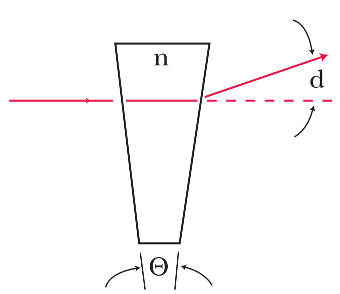


$$d = t \sin \Phi \left(1 - \frac{\cos \Phi}{n \cos \Phi'}\right)$$

where,

- Φ is angle of incidence
- n is index of refraction of the material
- t is thickness
- d is displacement

Deviation Through Small Wedge



$$d \sim (n-1)\,\Theta$$

where,

- Θ is the part's wedge angle
- n is the material's index of refraction
- d is angular beam deviation

ETV (Edge Thickness Variation) and Wedge

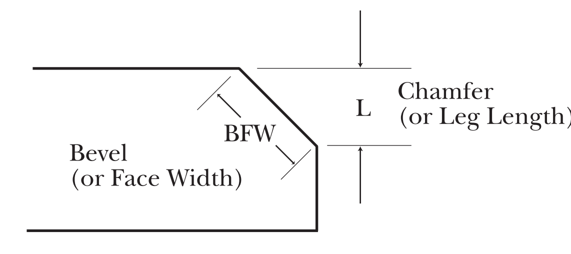
$$ETV = d \tan \Theta$$

$$Wedge = \Theta = \tan^{-1}\left(\frac{ETV}{d}\right)$$

where,

- d is diameter of part
- Θ is wedge angle of part in degrees

Bevel Face Width (BFW)



Given the chamfer (or leg length) and angle of 45°:

$$BFW = L \times 1.414$$

Converting Between Waves and Fringes (2 Different Wavelengths)

CO_2 Laser 10.6μm Surface Figure	HeNe 0.6328μm Fringes
λ/2	16.74
λ/4	8.37
λ/8	4.18
λ/10	3.35
λ/20	1.67
λ/40	0.84
λ/80	0.42
λ/100	0.33

Converting Between Waves and Fringes (Single Wavelength)

Wave	Fringes
λ/1	2.0
λ/2	1.0
λ/4	0.5
λ/8	0.25
λ/10	0.20
λ/20	0.10
λ/30	0.07
λ/40	0.05

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www.iiviinfrared.com

USEFUL FORMULAS & ABBREVIATIONS

The following abbreviations are commonly used on II-VI Infrared's product labeling.

ABS	Absorption
AG	As Generated
Al	Aluminum
AOI	Angle of Incidence
AR	Anti-Reflection Coating
ASPH	Asphere
ATFR	Absorbing Thin-Film Reflector
BBAR	Broadband Anti-Reflection Coating
BC	Beam Combiner
BS	Beamsplitter
CA	Clear Aperture (coated)
CC	Concave
CdTe	Cadmium Telluride
CSM	Customer Supplied Mount
Cu	Copper
CT	Center Thickness
CTG	Coating
CX	Convex
CYL	Cylinder
DAR	Dual Wavelength Anti-Reflection Coating
DEG	Degree
DIA	Diameter
DLC	Diamond-Like Coating
DT	Diamond-Turned
EFL	Effective Focal Length
ET	Edge Thickness
ETV	Edge Thickness Variation
FG	Fine Grind
F	Fittings
FL	Focal Length
FS	Fine Shine
GaAs	Gallium Arsenide
Ge	Germanium
ID	Inside Diameter
In	Indium
IRR	Irregularity
LM	Laser Marked
M	Meter
MEN	Meniscus
MM	Millimeter
Mo	Molybdenum
NEG	Negative
OD	Outside Diameter
OFHC	Oxygen Free High Conductivity
OG	Optical Grade
PR	Partial Reflector
PO	Plano
POL	Polarization
POS	Positive
PWR	Power
R	Reflectivity
REFL	Reflector
RWK	Rework
SC	Single Crystal
SD	Scratch-Dig
Si	Silicon
SMTY	Sufficient Material to Yield
SPT	Single Point Turned
T	Transmission
THK	Thickness
UC	Uncoated
VP	View Polished
W	Wedge
WC	Water-Cooled
WD	Working Distance
WL	Wavelength
WDW	Window
WS	Witness Sample
W&L	Width and/or Length
ZnSe	Zinc Selenide
ZnS	Zinc Sulfide
ZnS MS	Zinc Sulfide MultiSpectral

TERMS & CONDITIONS OF SALE

All orders received by II-VI Incorporated ("II-VI") are expressly conditioned upon the following conditions of sale:

1) Acceptance

Any additional or different terms set forth in any purchase order or other communication from Buyer are objected to and not binding upon II-VI unless and until accepted in writing by an authorized representative of II-VI.

2) Standard Warranty

II-VI warrants to the Buyer of each product of II-VI's own manufacture ("Product") that each Product will be free from defects in materials and workmanship subject to the following conditions:

The obligations of II-VI under this Standard Warranty shall be limited to either, at the option of II-VI: (1) the replacement or repair of any Product upon the shipment of such Product, freight prepaid by Buyer to the II-VI factory; or (2) the provision to Buyer of a credit against future purchases in an amount equal to the purchase price of the defective Product.

IN NO EVENT WILL II-VI BE LIABLE FOR ANY INCIDENTAL OR CONSEQUENTIAL DAMAGES OF BUYER. THE FOREGOING REMEDIES ARE THE SOLE AND EXCLUSIVE REMEDY OF BUYER FOR ANY BREACH OF WARRANTY UNDER THIS CONTRACT.

All claims under this Standard Warranty must be made within ONE (1) YEAR after the date on which the Product was delivered to Buyer. In the case of a replacement or repair of a Product, Buyer shall only ship a defective Product to II-VI after an authorized representative of II-VI has provided a Return Authorization (RA) number for such warranty claim. Returns will be subject to a restocking fee.

With respect to such returns, Buyer is solely responsible for properly packaging any Product to be returned to II-VI under this Standard Warranty. Products must be packaged in their original manufacturer's packaging or equivalent. Products must be packaged in separate shipping containers with Return Authorization (RA) numbers clearly marked on the outside of the shipping containers. If there are questions regarding proper packaging and shipping, contact II-VI for guidelines. II-VI will not be responsible for replacing or repairing any Product damaged while in transit to II-VI due to faulty or deficient packaging.

This Standard Warranty shall be void and shall not apply with respect to any Product which, upon inspection by II-VI, shows evidence of damage as a result of abuse, misuse, mishandling, accidental damage, alteration, negligent handling, or improper installation or application, or as a result of alteration or other causes beyond the control of II-VI.

This Standard Warranty shall not apply to goods or parts included in or supplied with Products; such goods or parts carry only such warranties, if any, as are provided by the manufacturers of such goods or parts, which warranties may be more restrictive than the Standard Warranty provided by II-VI.

With respect to any previously-purchased Product, II-VI shall have no obligation to install updates or upgrades to any components in such Product, even if the exclusion of such updates or upgrades of such components renders such Product obsolete when compared to a new Product of a substantially similar type.

THERE ARE NO WARRANTIES THAT EXTEND BEYOND THE DESCRIPTION CONTAINED HEREIN. THIS WARRANTY VOIDS AND EXCLUDES ANY AND ALL OTHER WARRANTIES OR REPRESENTATIONS, WHETHER EXPRESS OR IMPLIED OR ARISING UNDER ANY LAW, RELATING TO THE GOODS, INCLUDING BUT NOT LIMITED TO WARRANTIES OF MERCHANTABILITY AND/OR FITNESS FOR ANY PARTICULAR PURPOSES.

NO PERSON, FIRM, OR CORPORATION IS AUTHORIZED TO ASSUME ON BEHALF OF II-VI ANY ADDITIONAL OBLIGATION OR LIABILITY NOT EXPRESSLY PROVIDED HEREIN, EXCEPT IN A WRITING DULY EXECUTED BY AN OFFICER OF II-VI.

3) Limitation of Liability

In no event shall II-VI be liable for any incidental or consequential damages. The liability of II-VI on any claim of any kind shall in no event exceed the price of the Product which gives rise to the claim. Except as to title, all such liability shall terminate upon expiration of the warranty period of the Product.

The invalidity of any of the previous paragraphs shall not affect the remainder of this paragraph or any other paragraph in this section.

4) Patent Infringement

Buyer shall hold II-VI harmless against any expense or loss resulting from infringement of patents or trademarks arising from compliance with Buyer's designs or specifications.

5) Delivery and Title

Delivery dates are approximate and are based upon prompt receipt of all necessary information from Buyer. Under no circumstances does II-VI guarantee date of shipment.

Unless otherwise specified by II-VI, shipment will be made and title will pass F.O.B. point of shipment. II-VI shall ship Products as it deems appropriate unless instructed otherwise in writing by Buyer.

6) Risk of Loss

Risk of loss or damage shall pass to Buyer upon shipment. Loss or damage that occurs during shipping by a carrier selected by Buyer is Buyer's responsibility.

7) Uncontrollable Delays

II-VI shall not be liable for delivery delays due to causes beyond its reasonable control including, but not limited to, acts of God, acts of Buyer, acts of military authority, governmental priorities, labor strikes, and transportation delays.

8) Financial Conditions

If II-VI determines in good faith that the financial condition of Buyer at any time does not justify the continuation of production or shipment on the terms of payment originally specified, II-VI may require full or partial payment in advance. In the event of Buyer bankruptcy or insolvency, II-VI shall be entitled to cancel any outstanding order and shall receive reimbursement for its cancellation charges.

9) Payment Terms

Unless terms are specifically set forth on the Order Acknowledgement, Buyer shall pay at such time and such terms as specified in II-VI's original invoice. Any quotations shall be valid for the period stated on the quotation.

10) Cancellation

Buyer may not cancel its order after shipment has been made. Buyer may cancel its order prior to shipment only upon written notice and consent of II-VI. If II-VI consents to any such cancellation, Buyer may be required to pay cancellation charges which include lost profits and all expenses incurred in connection with the cancelled order.

11) Jurisdiction

The validity, performance, and all matters relating to the interpretation and effect of this agreement shall be governed by the laws of the Commonwealth of Pennsylvania.