# SPECIAL OPTICS®

## A NAVITAR COMPANY

Custom Optical Solutions

# ABOUT US

## Custom Lens Design and Precision Lens Manufacturing

Special Optics is dedicated to rapidly designing, prototyping, and manufacturing innovative and high performance optical systems. **Our expertise spans applications from Defense & Security, Semiconductor, Medical, Hyperspectral Imaging, Laser Micromachining, Long Range Surveillance, Machine Vision, custom microscopy and UV.** We routinely look at the toughest optical problems and deliver breakthrough solutions through world-class optical design. If you need an innovative partner to help turn your ideas into reality, we invite you to contact us about your application. **Setting new standards for performance and beating the competition** doesn't happen by accident.

## From Concept to Design to Volume Production

Special Optics excels at the optical design and rapid prototyping of complete electro-optical systems while our parent company, Navitar excels at high volume precision lens production. So when your optical design project advances past the prototype stages, you can count on Navitar's world leading manufacturing capabilities and customer service to deliver the consistent quality that you need. Navitar is standing by ready to deliver repeatable performance of every unit that comes off the production line.

# CONTENTS

# OUR PRODUCTS

## Our Products

- UV Objective Lenses
- Laser Scanning Lenses
- Digital Radiology Lenses
- Fisheye Lenses
- SWIR Lenses
- Long Range Surveillance Lenses
- Hyperspectral Lenses
- High Resolution Imaging Lenses
- Telecentric Inspection Lenses
- Fluorescence Imaging Lenses
- Missile Tracking Lenses
- Laser Beam Expanders
- Custom Lenses

## Typical Applications

- Long Range Surveillance
- Laser Eye Surgery
- Unmanned Aerial Vehicles
- Laser Micromachining
- Two-Photon Microscopy
- Physical Science Research
- Lithography

## Markets We Serve

- Semiconductor
- Biotech/Life Sciences
- Defense/Security
- Laser Machining
- Research Institutes
- OEM Optics

### Manufacturing Tolerances

| Attribute | Commercial Quality | Precision Quality | Ultra Precision Quality |
|---|---|---|---|
| Diameter (mm) | +0.00/-0.10 | +0.000/-0.05 | +0.000/-0.025 |
| Center Thickness (mm) | 0.150 | 0.050 | 0.005 |
| Radius (power) | 8 rings | 4 rings | 1 ring |
| Irregularity (waves @ 633nm) | 1 | 0.25 | 0.1 |
| Wedge (mm) | 0.05 | 0.005 | .0025 |
| Decenter (arc min) | 0.05 | 0.01 | 0.005 |
| Scratch - Dig | 80 - 50 | 60 - 40 | 10 - 5 |
| AR Coating (r avg) | < 1.5% | < 0.5% | < 0.25% |

# OPTICAL AND MECHANICAL DESIGN

Since 1965 Special Optics has designed and manufactured thousands of unique lens systems. Our optical design team has cataloged base designs ranging from laser beam expanders, telecentric scanning lenses, laser projection optics and UV objective lenses to long range surveillance lenses and Hyperspectral SWIR lenses. Having a large library of lens designs allows us to meet your design needs without disproportionate design costs. This means we rarely have to design a system from “scratch”. We simply choose a base design, and modify and re-optimize to meet the necessary requirements. In this way the customer need not compromise performance by being forced to choose a standard off-the-shelf lens, but instead, can obtain an exact design without incurring extreme design charges.

## Areas of Specialization

Achromatic Beam Expanders

Apochromatic Scan Lenses

Variable Zoom Beam Expanders

IR Variable Zoom Beam Expanders

Long Working Distance High NA

Apochromatic Lenses

Biomedical Optics

High Resolution Projection Lenses

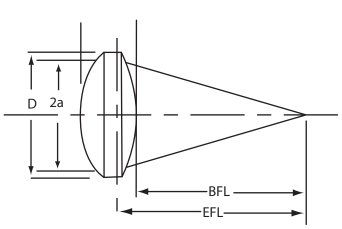
Two-Photon Microscopy Lenses

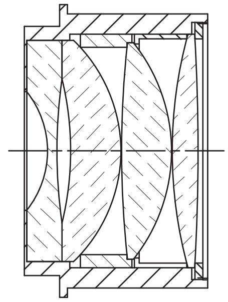
Custom Microscope Objectives

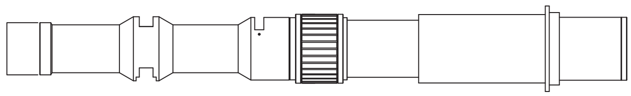
Physical Science Research Optics

View a complete list of **available test plates** at www.specialoptics.com.

We recognize that producing high resolution, diffraction-limited lens systems is often dependent, not only on the optics themselves, but on the quality of the mechanical parts used for assembly. Our mechanical design team works closely with our optical and electronic designers to produce fully integrated opto-mechanical systems and sub-systems. Using state-of-the-art mechanical design software, we insure your lens systems are both technically feasible and mechanically manufacturable. By successfully integrating both optical and mechanical designs ensures the solution we have designed for you meets all your mechanical and performance specifications.







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Special Optics supports the complete production and assembly of prototypes and OEM systems. The entire process of lens manufacture, from rough grinding through polishing, edging and coating, is completed in-house. During the process, we closely monitor all phases of production allowing us to maintain precision tolerances in wavefront, thickness and surface quality. Our experienced team of fabricators and polishers work with a great majority of glass and crystal materials used in the optics industry.

## The Process

We start with raw bulk glass which is cut and coredrilled to the appropriate diameter. Next the lens radius is cut into the surface using standard industry generators. Two grinding steps follow, first a rough 20 micron grit followed by a 9 micron grit fine grind. The lenses are now ready for polishing. Once blocking and polishing is accomplished, a final edging step is applied to bring the lens into final diameter and then correct any decentration or wedge between the lens surfaces.

## Fabrication and Polishing Capabilities

Glass and Crystal Polishing

Precision Grinding and Polishing of Optics from 4 to 280 mm in Diameter

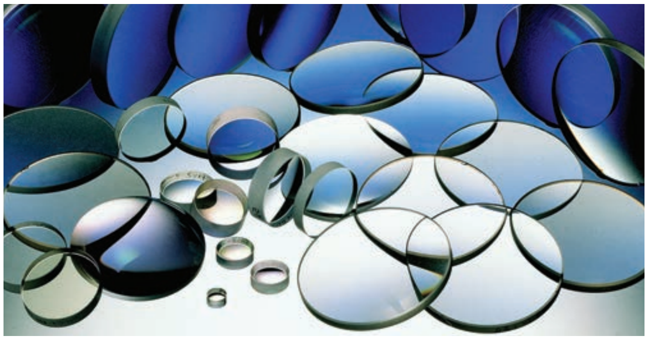
Over 1000 Test Plates on Hand

Surface Regularity Better than 1/20 Wave

10-5 Surface Quality

Interferometric Testing

Standard Radii from 2 to 13,931 mm



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Air-spaces, centration, wedge and tilt are the key determinants of a quality lens system.

## Air-Spaces

Through the use of micron indicators coupled with proprietary assembly equipment we can hold lens spacing tolerances to the order of 1 micron. This is only possible through constant reoptimization of the lens design during the assembly process.

## Centration, Wedge and Tilt

A major challenge during assembly of diffraction limited optics is to maintain the centration, wedge and tilt specifications for the system of lenses as a whole. Simply inserting lenses and spacers into lens tubes is not sufficient or even possible in many cases. Over the years, we have developed both standard and proprietary techniques for insuring that all tolerances are met.

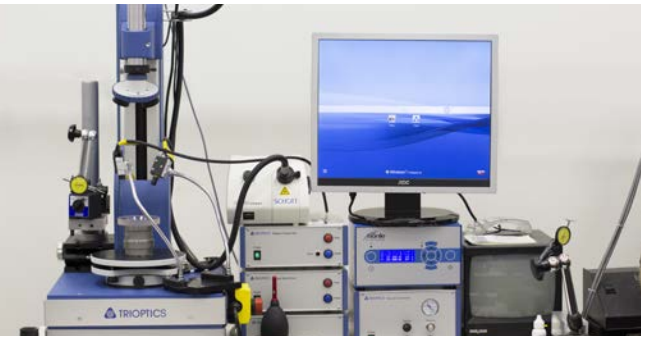
## Assembly Capabilities

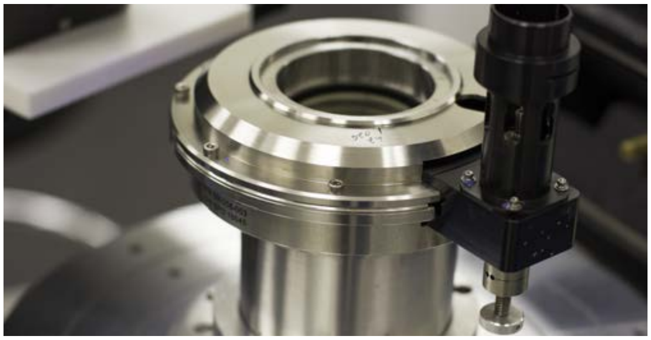
Air-Space Tolerances Held to 1 Micron

Continuous Lens Design Reoptimization During Assembly

Centration, Wedge and Tilt Tolerances Held to Better than 1 Micron

Air-Bearing Assembly and Alignment





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Testing both during manufacture and after assembly is crucial to a successful lens system. In particular, surface regularity and power of individual lenses must be continuously monitored in production.

We go the extra step to first validate our designs through interferometric and MTF testing to ensure your optical solution is going to meet your specifications.

## Interferometry

Evaluation of lens surfaces for spherical regularity is accomplished using Phase Shift Interferometry. With this equipment, we can quantitatively verify surface regularity to within 1/20 of a wave. In addition to surface evaluation, we also employ an interferometer to analyze complete lens systems. Through the use of reflection and transmission spheres, we can usually evaluate multi-element lens systems for coma, astigmatism and spherical aberration, and in some cases the resolution of the system can also be analyzed.

## Radius Testing

During the design of any lens system, an attempt is always made to relax the manufacturing tolerances as much as possible. One method we have developed is to make very accurate lens radii measurements or finished elements and test plates, thereby eliminating the radius tolerance from the design equation. We accomplish this through the use of a precision spherometer which is capable of measuring lens sagittal heights to within 1 micron.

## Lens Testing Capabilities

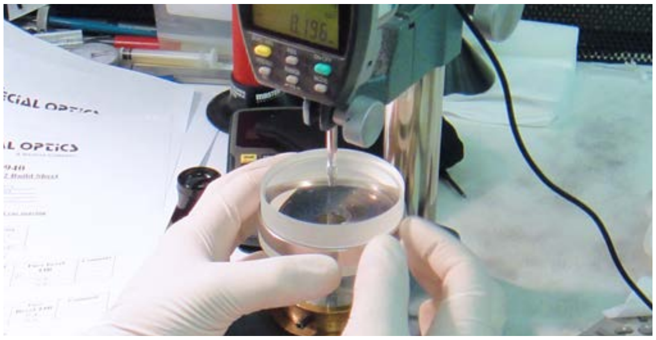
Interferometers @ 405, 532, 632 and 1064 nm

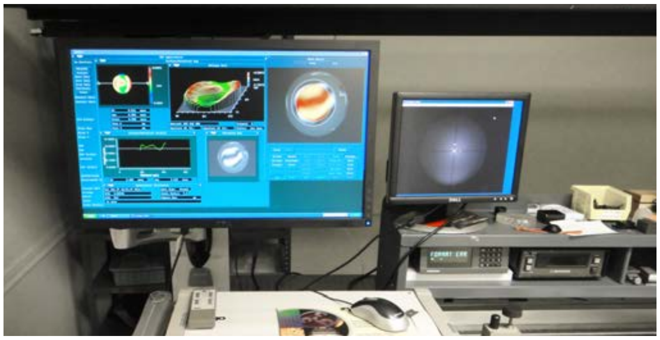
Radius Measurement to Within 1 Micron Sagittal Height

Centration to Within 1 Arc second

Flatness and Regularity to Within 1/20 Wave

Transmission and Reflection Wavefront Error







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An essential part of any multi-element lens system is the anti-reflection coatings. They have the dual effect of maximizing transmission and minimizing ghost images. Unwanted reflections can cause laser damage, false signals, laser instability and image degradation. Our coating department is capable of depositing broadband anti-reflection coatings, as well as single, double- and triple-"V" coatings on all glasses. Capabilities extend from the 248-2200 nm range.

## Broadband Coatings

Our standard broadband anti-reflecion (BBAR) coatings are multi-layer designs capable of providing less than 0.5% reflectivity throughout the specified range. In addition to the standard wavelength ranges, we can also offer shifted ranges to accommodate special requirements. For example, a 425-675 nm coating can be shifted to 500-750 nm for a minimal additional charge.

## "V" Coatings

In applications where 0.5% reflectivity is higher than the system can tolerate, a narrowband "V" coating should be used. Standard "V" coatings which offer reflectances of less than 0.25%, can be single layer MgF2 or multi-layer designs depending on the index of refraction of the substrate. In general, glasses with an index of greater than 1.7 can be coated with a single layer of MgF2 to supply less than 0.25% reflectivity. The disadvantage of the "V" coating is the narrow wavelength range, which should be balanced against the fact that, in general "V" coatings have a higher damage threshold than broadband coatings.

## Coating Capabilities

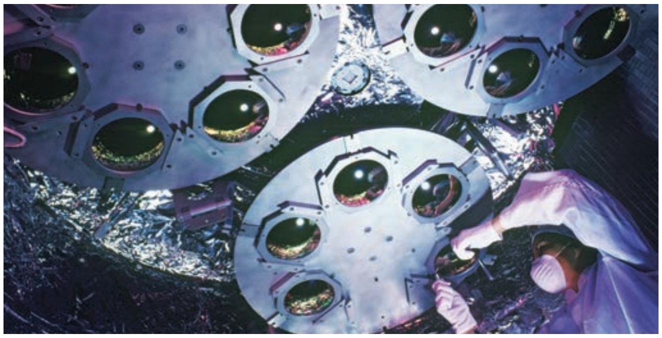
Broadband and "V" Anti-reflection Coatings

Double- and Triple-"V" Designs

> 500 MW/cm2 Damage Threshold

248-2200 nm Range Capability

In-house Thin Film Design





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# Products

- Custom Objectives
- Laser Beam Expanders
- Laser Focusing Objectives
- Laser Scanning Lenses
- Polarization Optics
- Mechanicals & Misc.
- Beam Steering Devices

# CUSTOM & STANDARD PRODUCTS

Special Optics offers an extensive line of high precision optics available in both standard models for quick delivery or custom designed for your unique requirements.

All of our optics are available for wavelengths throughout the UV and IR ranges. This includes beam expanders, focusing objectives, scanning lenses and collimators for excimer, dye, solid-state and CO2 lasers.

### Custom Objectives

Pre-Engineered High NA Objectives

### Laser Beam Expanders

Low Power
High Power
UV
Variable Zoom
Large Output

### Laser Focusing Objectives

Single Line
Achromatic/Apochromatic
Laser Diode Collimators
UV
High N.A. UV Micro Objectives

### Laser Scanning Lenses

VIS-NIR Scanning Lenses
Confocal Microscopy Lenses
Telecentric UV Lenses

### Polarization Optics

Retardation Plates
Waveplates

### Mechanicals & Misc.

Vee Block
Threaded Adapters
Alignment Apertures

### Beam Steering Devices

In-Line Beam Steerer

### Metric Zoom

Long Range Surveillance Lens



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## Pre-Engineered High NA Objective Lenses

In addition to our pre-engineered lenses, custom designed lens orders are welcomed.

### Quantum Physics / Ultra Cold Atom Research / Physics Research / Industrial

| Customer | Lens Type | Part Number | NA | F# | Aperture | EFL | Working Distance | FOV | Housing |
|---|---|---|---|---|---|---|---|---|---|
| BSCI | Dry | 54-20-60@633&1550nm | 0.17 | 3.00 | 20 | 60 | 55mm Air + 3mm Bk7 | 1.5 | Stainless |
| U of Stuttgart | Dry | 54-17-25@532&421.3nm | 0.34 | 1.47 | 17 | 25 | 19mm Air + 6.35.. Silica | 0.06 | Ultem |
| Uni-kl.de | Dry | 54-22-30@767-852nm | 0.37 | 1.36 | 22 | 30 | 21mm Air + 5mm Silica | 0.1 | Stainless |
| GWDG.DE | Water | 54-20-25@532nm | 0.40 | 1.25 | 20 | 25 | 13mm water | 0.18 | Stainless |
| U of Arizona | Dry | 54-18-21@633nm | 0.43 | 1.17 | 18 | 21 | 34.5mm Air | 0.15 | Stainless |
| Uni-frankfurt | Dry | 54-3.5-4@325nm | 0.44 | 1.14 | 3.5 | 4 | 8.5mm Air | 0.25 | Stainless |
| MIT Physics | Dry | 54-36-41@671nm | 0.44 | 1.14 | 36 | 41 | 25.83mm Air + 6.1mm Silica | 0.4 | Stainless |
| MAX Planck | Dry | 54-28-28@671&1064nm | 0.50 | 1.00 | 28 | 28 | 16mm Air + 4mm Silica | 0.15 | Ultem |
| MAX Planck | Dry | 54-25-25@532&767&780&1064nm | 0.50 | 1.00 | 25 | 25 | 12mm Air + 5mm Silica | 0.15 | Ultem |
| U of Chicago | Dry | 54-26-26@852nm | 0.50 | 1.00 | 26 | 26 | 19mm Air + 6.336 Silica | 0.15 | Ultem |
| Microcosm | Dry | 54-10-10@266nm | 0.50 | 1.00 | 10 | 10 | 1mm Air | 0.7 | Stainless |
| Controlled Semi | Dry | 54-5-5@266&488nm | 0.50 | 1.00 | 5 | 5 | 4.5mm Air + 0.17mm Silica | 0.09 | Stainless |
| USTC | Dry | 54-26-25@780nm | 0.52 | 0.96 | 26 | 25 | 19mm Air + 7.1mm Silica+1.9mm H-K9L | 0.35 | Ultem |
| Monash.edu | Dry | 54-33-31@767&780nm | 0.53 | 0.94 | 33 | 31 | 15.5mm Air + 4mm Borofloat | 0.1 | Ultem |
| Microcosm | Dry | 54-6-5@266nm | 0.60 | 0.83 | 6 | 5 | 0.6mm Air | 0.4 | Stainless |
| MAX Planck | Dry | 54-36-30@767&589nm | 0.60 | 0.83 | 36 | 30 | 18mm Air + 4mm Silica | 0.15 | Ultem |
| U of Toronto | Dry | 54-4-3.3 @ 405 nm | 0.61 | 0.83 | 4 | 3.3 | 3.5mm Air + 0.2mm Sapphire | 0.2 | Stainless |
| U of Hamberg | Dry | 54-33-26@532-770nm | 0.63 | 0.79 | 33 | 26 | 6.5mm Air + 4mm Silica | 0.15 | Ultem |
| U of Bonn | Dry | 54-25-17@589&670&760nm | 0.74 | 0.68 | 25 | 17 | 3mm Air + 3.5mm Silica | 0.25 | Ultem |
| Ultra Point | Dry | 54-3.1-1.62@244nm | 0.96 | 0.52 | 3.1 | 1.62 | 0.3mm Air | 0.13 | Stainless |

### Life Science

| Customer | Lens Type | Part Number | NA | F# | Aperture | EFL | Working Distance | FOV | Housing |
|---|---|---|---|---|---|---|---|---|---|
| Excelsius | Dry | 55-S10-3@1030nm | 0.44 | 1.14 | 8.75 | 10 | 5mm Air | 2.8 | Stainless |
| HHMI | Water | 54-19-19@800-1200nm | 0.50 | 1.00 | 19 | 19 | 5.8mm water | 1.4 | Stainless |
| Excelsius | Dry | 55-S5-0.4@1064nm | 0.65 | 0.77 | 6.5 | 5 | 4.5mm Air | 0.4 | Stainless |
| Allen Institute | Water | 54-68-50@900nm | 0.68 | 0.74 | 68 | 50 | 11.35mm water | 5 | Stainless |
| HHMI | Water | 54-10-7 @ 488-910 nm | 0.71 | 0.70 | 10 | 7 | 3.6mm water | 0.1 | Stainless |
| NDA | Water | 54-3.3-1.8@VIS | 0.92 | 0.55 | 3.3 | 1.8 | 0.486 typeA+0.6mm Sapphire+0.25mm seawater | 0.15 | Stainless |
| Stanford U | Water | 54-23-12@1-1.07nm | 0.96 | 0.52 | 23 | 12 | 1.5mm water | 0.4 | Stainless |
| HHMI | Oil | 54-10.6-5.3@480-700nm | 1.00 | 0.50 | 10.6 | 5.3 | 3mm Oil | 0.1 | Stainless |



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## Low Power Beam Expanders

**Features:**

Adjustable Focus for Collimation at Various Wavelengths

Diffraction limited design

Large input apertures

High Transmission

AR Coated

**Specifications:**

Wavefront Distortion................ < 1/4 Wave

Transmission................................ > 97%

Coating Damage Threshold... 500 MW/cm2

Useable Spectral Range.......... 248 - 1550 nm

| Model | Expansion Ratio | Input Aperture (mm) | Output Aperture (mm) | Length @ 1064 nm(mm) |
|---|---|---|---|---|
| 50-25-2X- λ | 2 X | 11.0 | 22 | 89 |
| 50-25-3X- λ | 3 X | 7.3 | 22 | 108 |
| 50-25-4X- λ | 4 X | 5.5 | 22 | 118 |
| 50-25-4.5X- λ | 4.5 X | 4.8 | 22 | 126 |
| 50-25-5X- λ | 5 X | 4.4 | 22 | 122 |
| 50-25-6X- λ | 6 X | 3.6 | 22 | 128 |
| 50-25-7X- λ | 7 X | 3.1 | 22 | 131 |
| 50-25-8X- λ | 8 X | 2.7 | 22 | 138 |
| 50-25-10X- λ | 10 X | 2.2 | 22 | 140 |
| 50-25-12X- λ | 12 X | 1.8 | 22 | 141 |
| 50-25-18X- λ | 18 X | 1.3 | 22 | 145 |
| 50-51-4X- λ | 3.9 X | 11.7 | 47 | 203 |
| 50-51-7X- λ | 6.8 X | 6.7 | 47 | 239 |
| 50-51-10X- λ | 10.2 X | 4.7 | 47 | 253 |
| 50-51-20X- λ | 20.6 X | 2.3 | 47 | 267 |
| Please replace λ in model number with working wavelength when ordering. | | | | |

## High Power Beam Expander

**Features:**

Adjustable Focus for Collimation at Various Wavelengths

Diffraction limited design

Large input apertures

High Transmission

No Focused Retro-reflections

**Specifications:**

Wavefront Distortion................ < 1/4 Wave

Transmission................................ > 97%

Coating Damage Threshold... 500 MW/cm2

Useable Spectral Range.......... 248 - 1550 nm

| Model | Expansion Ratio | Input Aperture (mm) | Output Aperture (mm) | O.D. x Length @1064 nm (mm) |
|---|---|---|---|---|
| 52-25-2X- λ | 2 X | 7.0 | 15.0 | 34.9 x 72 |
| 52-25-4X- λ | 4 X | 7.0 | 30.0 | 44.5 x 127 |
| 52-51-7X- λ | 7 X | 7.0 | 51.6 | 66.7 x 172 |
| 52-71-5X- λ | 5 X | 14 | 71.6 | 85.7 x 248 |
| 52-71-10X- λ | 10 X | 7.0 | 71.6 | 85.7 x 248 |
| 52-71-20X- λ | 20 X | 3.5 | 71.6 | 85.7 x 248 |
| Please replace λ in model number with working wavelength when ordering | | | | |

## UV Beam Expanders

**Features:**

No Focused Retro-reflections

Adjustable Lens Spacing

Low Insertion Loss

**Specifications:**

Wavefront Distortion............... < 1/4 Wave

Transmission............................... > 97%

Coating Damage Threshold... 500 MW/cm2

Useable Spectral Range.......... 0.248 - 0.355 nm

| Model | Expansion Ratio | Input Aperture (mm) | Output Aperture (mm) | Dimensions O.D. x Length (mm) | Wavelength Range (microns) |
|---|---|---|---|---|---|
| 61-25-4X- λ | 4X | 6.25 | 25 | 31.75 x 120 | 0.248 - 0.355 |
| 61-25-7X- λ | 7X | 3.5 | 25 | 31.75 x 134 | 0.248 - 0.355 |
| 61-25-10X- λ | 10X | 2.5 | 25 | 31.75 x 141 | 0.248 - 0.355 |
| Please replace λ in model number with working wavelength when ordering. | | | | | |

## Variable Zoom Beam Expanders

**Features:**

Diffraction-limited design

5 element design reduces internal focus

Continuous zoom and focus adjustments

Mechanicals designed to minimize beam wander

Reduce machine setup times

**Specifications:**

Wavefront Distortion............... < 1/4 Wave

Transmission............................... > 97%

Coating Damage Threshold... 100 MW/cm2

Useable Spectral Range.......... 450 - 1100 nm

| Model | Expansion Range | Max. Input Aperture (mm) | Max. Output Aperture (mm) | O.D. (mm) | Max. length (mm) |
|---|---|---|---|---|---|
| 56-30-1-4X-λ | 1-4X | 10 | 30 | 37.6 | 180 |
| 56-30-2-8X- λ | 2-8X | 10 | 30 | 37.6 | 167 |
| 56-45-2-8X- λ | 2-8X | 10 | 45 | 66.7 | 163 |

## Large Output Beam Expanders

**Features:**

Adjustable Focus For Collimation At Various Wavelengths

Diffraction-Limited, Galilean Design

Large Output & Input Apertures

Broadband AR Coated For High Transmission

**Specifications:**

Wavefront Distortion............... < 1/2 Wave

Transmission............................... > 92%

Coating Damage Threshold... 500 MW/cm2

Useable Spectral Range.......... 400 - 1650nm

| Model | Expansion Ratio | Input Aperture (mm) | Output Aperture (mm) |
|---|---|---|---|
| 50-100-5X-λ | 5X | 20 | 100 |
| 50-100-10X-λ | 10X | 10 | 100 |
| 50-100-20X-λ | 20X | 5 | 100 |
| 50-100-40X-λ | 40X | 2.5 | 100 |



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## Single Line Objectives

**Features:**

Diffraction Limited Design

Air-Spaced for High Power Applications

Standard Models Available for UV Wavelengths

**Specifications:**

Wavefront Distortion................ < 1/4 Wave

Transmission............................... > 97%

Coating Damage Threshold... 500 MW/cm2

Surface Quality........................... 20-10

| Model | EFL (mm) | BFL (mm) | Aperture (mm) | F/# | Wavelength Range (nm) | O.D. (mm) |
|---|---|---|---|---|---|---|
| 54-15-15-λ* | 15 | 3.0 | 15.0 | 1.0 | 600-1550 | 28.58 |
| 54-18-15-λ | 15.1 | 4.2 | 18.0 | 0.8 | 780 - 1550 | 28.58 |
| 54-11-20-λ* | 20.2 | 12.8 | 11.0 | 1.8 | 500 - 1100 | 14.98 |
| 54-18-23-λ | 23 | 14.7 | 18.0 | 1.3 | 780 - 1100 | 31.75 |
| 54-17-30-λ* | 30.9 | 21.9 | 17.0 | 1.7 | 300 - 1100 | 31.75 |
| 54-18-52-λ | 50.6 | 42.3 | 18.0 | 2.8 | 750 - 900, 1300 | 25.40 |
| 54-25-60-λ* | 60.5 | 46.8 | 22.0 | 2.7 | 500 - 1100 | 31.75 |
| 54-25-71-λ | 70.1 | 60.0 | 27.5 | 2.6 | 750 - 900, 1300 | 31.75 |
| 54-25-87-λ* | 88.7 | 81.7 | 22.0 | 4.0 | 300 - 650 | 28.57 |
| 54-25-100-λ | 99.9 | 92.3 | 22.0 | 4.0 | 250-400 | 38.10 |
| 54-40-87-λ | 87 | 50.0 | 40.0 | 2.2 | 532 | 53.98 |
| 54-40-100-λ* | 99.9 | 84.1 | 40.0 | 2.5 | 532, 1064 | 57.15 |
| 54-40-180-λ | 180 | 163.8 | 40.0 | 4.5 | 1064 | 50.80 |
| 54-25-125-λ* | 127.2 | 121.9 | 23.0 | 5.5 | 500 - 1100 | 38.10 |
| 54-47-130-λ | 134.9 | 121.5 | 47.0 | 2.7 | 320 - 1100 | 57.15 |
| 54-75-175-λ | 174.8 | 163.8 | 75.0 | 2.3 | 1064 | 89.90 |
| 54-152-400-λ | 401.2 | 389.4 | 152 | 2.6 | 500-650 | 165.10 |

*All Fused Silica
Please replace λ in model number with working wavelength when ordering.

To calculate spot size:

| | | |
|---|---|---|
| To calculate spot size: | Gaussian Input Beam | $S = 1.27F\#\lambda$ |
| | Uniform Density Input Beam | $S = 2.44F\#\lambda$ |



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## Achromatic Objectives

| Model | EFL (mm) | BFL (mm) | Aperture (mm) | F/# | Wavelength Range (nm) | O.D. (mm) |
|---|---|---|---|---|---|---|
| 54-30-60 | 62.3 | 48.5 | 30 | 2.0 | 532/1064 | 41.3 |
| 54-37-117 | 117.4 | 109.4 | 37 | 3.2 | 532/1064 | 50.8 |
| 54-10-120 | 120.0 | 115.0 | 10 | 12.0 | 266/532 | 15.0 |
| 54-50-175 | 175.0 | 143.5 | 50 | 3.5 | 488/514 | 60.0 |
| 54-100-200 | 200.5 | 182.5 | 100 | 2.0 | 450/600 | 120.7 |
| 54-74-210 | 210.0 | 189.4 | 74 | 2.8 | 532/1064 | 88.9 |
| 54-75-250 | 250.0 | 210.6 | 75 | 3.5 | 488/514 | 88.6 |
| 54-120-260 | 258.0 | 231.5 | 120 | 2.2 | 450/650 | 152.4 |
| 54-106-370 | 370.0 | 305.2 | 106 | 3.5 | 488/514 | 119.4 |
| 54-100-576 | 575.5 | 563.5 | 100 | 5.7 | 480/650 | 120.7 |
| 54-200-1193 | 1192.7 | 1150.2 | 200 | 5.9 | 500/650 | 208.0 |
| 54-25-88N | -88.0 | 94.1 | 25 | -3.5 | 488/514 | 33.3 |
| 54-50-175N | -175.0 | 186.1 | 50 | -3.5 | 488/514 | 60.0 |

## Apochromatic Objectives

| Model | EFL (mm) | BFL (mm) | Aperture (mm) | F/# | Wavelength Range (nm) | O.D. (mm) |
|---|---|---|---|---|---|---|
| 54-2-7 | 7.1 | 5.9 | 2 | 3.6 | 400- 700 | 6.4 |
| 54-22-40 | 40.0 | 22.8 | 22 | 1.8 | 480- 550 & 1064 | 28.6 |
| 54-22-79 | 79.0 | 73.2 | 22 | 3.6 | 400 - 700 | 28.6 |
| 54-40-100 | 99.9 | 95.0 | 40 | 2.5 | 700 - 900 | 50.8 |
| 54-40-174 | 173.0 | 163.7 | 40 | 4.3 | 700- 900 | 50.8 |
| 54-12-180 | 179.2 | 173.5 | 12 | 15.0 | 300 - 365 | 25.4 |
| 54-25-350 | 369.2 | 362.0 | 24 | 15.0 | 250- 400 | 38.1 |
| 54-54-540 | 540.0 | 523.0 | 54 | 10.0 | 200- 400 | 60.0 |
| 54-8-35N | -34.6 | -35.9 | 8 | -4.3 | 700 - 900 | 12.5 |



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## Laser Diode Collimators

**Features:**

Diffraction Limited Design

Corrected for 5 to 10 mil Window

Long Back Working Distance

**Specifications:**

Wavefront Distortion................ < 1/4 Wave

Transmission............................... > 97%

Usable Wavelength Range...... 670 to 1550 nm

Field of View................................ 1.5 degrees


Laser Diode Objectives are designed to accommodate the large input angles associated with compact laser sources. Standard designs offer diffraction limited performance for numerical apertures as high as 0.6, making them useful for fiber optic coupling or collimating. The spectral range of our Diode Collimators is extended into the infrared region allowing for operations with most diodes within the 670 nm to 1550 nm wavelength range. Though designed for use with Diode Lasers, these lenses may be used with other lasers requiring highly corrected lenses within the visible and near infrared spectral range.

| Model | Aperture (mm) | N.A. | EFL λ = 835 nm | BWD λ = 835 nm | O.D. (mm) |
|---|---|---|---|---|---|
| 54-18-15-λ | 18.0 | 0.60 | 15.0 | 4.1 | 28.58 |
| 54-18-23-λ | 18.0 | 0.39 | 23.0 | 12.1 | 31.75 |
| 54-51-50-λ | 50.8 | 0.50 | 50.8 | 6.7 | 63.50 |

The five positive air-spaced doublets described below focus the collimated output of diode lasers operating within the 670 to 1550 nm spectral range. They may also be combined to expand the 18 mm output of either the Model 54-18-15 or 54-18-23 Collimating Objectives. The Model 54-18-76N negative doublets is designed to serve as the input element of a Galilean Beam Expander when mated with any of the 0.12 N.A. positive lenses. All six lenses are fully corrected aplanats, and can be mixed and matched in a focusing or non-focusing configuration to obtain the desired magnification. With the appropriate antireflection coating, each lens may also be used with visible wavelength lasers.

| Model | Aperture (mm) | N.A. | EFL λ = 835 nm | BWD λ = 835 nm | O.D. (mm) |
|---|---|---|---|---|---|
| 54-18-50-λ | 18.0 | 0.18 | 50.6 | 41.3 | 25.40 |
| 54-25-71-λ | 25.0 | 0.18 | 70.9 | 55.0 | 31.75 |
| 54-18-76-λ | 18.0 | 0.12 | 75.3 | 70.2 | 31.75 |
| 54-47-200-λ | 47.0 | 0.12 | 197.0 | 185.2 | 57.15 |
| 54-71-300-λ | 71.0 | 0.12 | 297.0 | 280.0 | 82.55 |
| 54-18-76N-λ | 18.0 | 0.12 | -75.9 | 87.6 | 31.75 |

Please replace λ in model number with working wavelength when ordering.



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## UV Objectives

**Features:**

Diffraction Limited Design

Air-Spaced for High Power Applications

Achromatic Design

**Specifications:**

Wavefront Distortion................ < 1/4 Wave

Transmission................................ > 97%

Coating Damage Threshold... 500 MW/cm2

Surface Quality............................ 20-10

| Model | EFL (mm) | BFL (mm) | Aperture (mm) | F/# | Wavelength Range (nm) | O.D. (mm) |
|---|---|---|---|---|---|---|
| 54-11-19-λ | 19.0 | 11.8 | 11 | 1.8 | 248 - 400 | 14.98 |
| 54-17-29-λ | 30.0 | 21.0 | 17 | 1.7 | 248 - 400 | 31.7 |
| 54-25-100-λ | 99.9 | 92.3 | 22 | 4.0 | 250 - 400 (apochromatic) | 38.1 |
| 54-10-120-λ | 120.0 | 115.0 | 10 | 12.0 | 266/532 (achromatic) | 15.0 |
| 54-12-180-λ | 179.2 | 173.5 | 12 | 15.0 | 300 - 365 (apochromatic) | 25.4 |
| 54-44-220-λ | 219.0 | 202.7 | 44 | 5.0 | 300 - 365 | 57.2 |
| 54-25-350-λ | 369.2 | 362.0 | 24 | 15.0 | 250 - 400 (apochromatic) | 38.1 |
| 54-54-540-λ | 540.0 | 523.0 | 54 | 10.0 | 200 - 400 (apochromatic) | 60.0 |

Please replace λ in model number with working wavelength when ordering.

## High N.A. UV Micro Objectives

**Features:**

Diffraction Limited Design

Air-Spaced for High Power Applications

Achromatic Design

**Specifications:**

Wavefront Distortion................ < 1/4 Wave

Transmission................................ > 97%

Coating Damage Threshold... 500 MW/cm2

Surface Quality............................ 20-10

| Model | Field Size (mm) | EFL (mm) | N.A. | Aperture (mm) | BWD | Wavelength (nm) | $1/e^2$ Spot Size (microns) 248nm | $1/e^2$ Spot Size (microns) 365nm |
|---|---|---|---|---|---|---|---|---|
| 54-10-5.5-λ | 0.10 | 5.5 | 0.90 | 10 | 0.15 | 248 or 365 | 0.17 | 0.25 |
| 54-10-6.7-λ | 0.12 | 6.7 | 0.75 | 10 | 0.28 | 248 or 365 | 0.21 | 0.31 |
| 54-10-10-λ | 0.18 | 10.0 | 0.50 | 10 | 0.30 | 248 or 365 | 0.31 | 0.46 |

Please replace λ in model number with working wavelength when ordering.



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## VIS - NIR Scanning Lenses

**Features:**

Diffraction Limited

Precision Manufacture and Assembly

Air Spaced Design

Achromatic Designs Available

| Model | Wavelength (microns) | Scan Field (mm) | EFL (mm) | Max Input Beam* (mm) | BWD (mm) | Deflection (degrees) | FWD (mm) | 1/e² Spot ** (microns) |
|---|---|---|---|---|---|---|---|---|
| 55-S70-30 | 1.064 | 30 | 63.4 | 8 | 70.0 | 13.6 | 17.0 | 10.7 |
| 55-S160-84T | 1.064 | 84 | 160.0 | 28 | 190.0 | 15.0 | 35.0 | 8.0 |
| 55-S112-90T | 1.064 | 90 | 112.2 | 13 | 155.6 | 23.0 | 27.6 | 11.7 |
| 55-S117-90 | 1.064 | 90 | 117.3 | 8 | 133.5 | 22.0 | 21.7 | 19.8 |
| 55-S181-90 | 1.064 | 100 | 181.3 | 19 | 229.0 | 15.8 | 35.8 | 12.9 |
| 55-S191-125 | 1.064 | 125 | 191.3 | 13 | 194.0 | 22.0 | 26.0 | 19.9 |
| 55-S236-150 | 1.064 | 152 | 236.8 | 25 | 298.0 | 18.4 | 55.4 | 12.8 |
| 55-S266-170 | 1.064/VIS | 170 | 266.0 | 15 | 275.0 | 18.0 | 370 | 24.0 |
| 55-S266-252 | 1.064 | 252 | 266.5 | 10 | 338.0 | 27.0 | 48.0 | 36.0 |
| 55-S295-250 | 1.064 | 250 | 295.4 | 25 | 355.0 | 25.0 | 37.6 | 16.0 |
| 55-S459-432 | 1.064 | 432 | 459.0 | 26 | 540.0 | 27.0 | 48.0 | 24.0 |
| 55-S700-450 | 1.064/VIS | 450 | 699.0 | 34 | 725.0 | 18.0 | 55.0 | 28.0 |
| 55-S700-560 | 1.064 | 560 | 699.0 | 35 | 580.0 | 23.0 | 35.0 | 27.0 |
| 55-S190-60-VIS | 0.45 - 0.65 (apochromatic) | 60 | 190.0 | 16 | 129.4 | 9.0 | 27.5 | 9.8 |
| 55-S190-100-VIS | 0.45 - 0.65 (apochromatic) | 100 | 190.0 | 16 | 161.0 | 15.0 | 24.0 | 9.8 |
| 55-S87-36T | 0.488 | 36 | 87.0 | 27 | 5.8 | 12.0 | 29.0 | 2.0 |
| 55-S223-77T | 0.632 | 77 | 223.0 | 22 | 231.5 | 10.0 | 33.0 | 8.1 |

* Single Axis Scanning
T denotes Telecentric
** Assumes a diffraction limited beam, spot size = 1.27λ F#



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## Confocal Microscopy Lenses

**Features:**

Diffraction Limited

Fully Apochromatic

Precision Manufacture and Assembly

| Model | Wavelength Range (nm) | Focal Length (mm) | Field Size (mm) | Max. Input* Aperture (mm) | FWD (mm) | BWD (mm) | Scan Angle (degrees) | Lateral Color (microns) | 1/e² Spot Size (microns) |
|---|---|---|---|---|---|---|---|---|---|
| 55-S28-3T | 530 - 590 | 28.6 | 3 | 28.6 | 16 | 2.8 | +/- 3 | < 1 | 0.5 |
| 55-S30-15T | 488 - 600 | 30.0 | 13 | 9.0 | 14 | 12.5 | +/- 13 | < 5 | 3 |
| 55-S80-25T | 450 - 650 | 80.3 | 25 | 8.0 | 16 | 53.0 | +/- 9 | < 3 | 6 |
| 55-S172-36T | 500 - 1100 | 172 | 36 | 20.0 | 49 | 86.0 | +/- 6 | < 8 | 10 |

* Single Axis Scanning
T denotes Telecentric
Model 55-S28-3 transmits 50% @ 365 nm

## Telecentric UV Scanning Lenses

**Features:**

Diffraction Limited

Precision Manufacture and Assembly

Air-Spaced Design

Achromatic Designs Available

| Model | Wavelength (microns) | Scan Field (mm) | EFL (mm) | Max Input Beam*(mm) | BWD (mm) | Deflection (degrees) | FWD (mm) | Spot Size (microns) |
|---|---|---|---|---|---|---|---|---|
| 55-S34-9UV-λ | 266 or 355 | 9 | 34 | 17 | 10 | 7 | 17 | 1.0 |
| 55-S50-20UV-λ | 266 or 355 | 20 | 50 | 10 | 15 | 12 | 23 | 2.5 |
| 55-S100-45UV-λ | 355 | 45 | 100 | 10 | 150 | 16 | 28 | 5.0 |
| 55-S100-55UV-λ | 266 or 355 | 55 | 100 | 10 | 135 | 16 | 28 | 5.0 |

Please replace λ in model number with working wavelength when ordering.

## Retardation Plates

**Features:**

No UV Cement Used in Construction
(Air-Spaced Design)

High Damage Threshold (500 MW/cm2)

Minimal Insertion Loss

**Specifications:**

Material.................................. Quartz

Retardation Tolerance ..... +/- 0.005 Waves

Parallelism............................ < 1 Arc Second

Wavefront Deformation... 1/8 Wave

AR Coatings........................ < 0.50 % Reflectance Per Surface

### Stock Wavelengths For Immediate Delivery

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 442 | 458 | 488 | 510 | 514 | 527 | 531 | 532 | 543 | 546 | 568 | 578 | 589 | 594 | 612 | 633 |
| 647 | 676 | 694 | 750 | 752 | 755 | 760 | 768 | 780 | 810 | 820 | 830 | 835 | 850 | 855 | 864 |
| 960 | 905 | 980 | 1047 | 1053 | 1060 | 1064 | 1150 | 1300 | 1310 | 1315 | 1320 | 1523 | 1550 | | |

### Zero and Multiple Order Waveplates

| Model[1] | Order | Retardance (degrees) | Aperture (mm) | *O.D. (mm) Unmounted | *O.D. (mm) Mounted | Thickness (mm) |
|---|---|---|---|---|---|---|
| 8-8008-1/4- λ | Zero | 90 | 8 | 11 | 12.7 | 6 |
| 8-8015-1/4- λ | Zero | 90 | 15 | 17.5 | 25.4 | 8 |
| 8-8025-1/4- λ | Zero | 90 | 25 | 27.3 | 31.8 | 8 |
| 8-8008-1/2- λ | Zero | 180 | 8 | 11 | 12.7 | 6 |
| 8-8015-1/2- λ | Zero | 180 | 15 | 17.5 | 25.4 | 8 |
| 8-8025-1/2- λ | Zero | 180 | 25 | 27.3 | 31.8 | 8 |
| 8-3015-1/4- λ | Multiple | 90 | 15 | 17.5 | 25.4 | 8 |
| 8-3025-1/4- λ | Multiple | 90 | 25 | 27.3 | 31.8 | 8 |
| 8-3015-1/2- λ | Multiple | 180 | 15 | 17.5 | 25.4 | 8 |
| 8-3025-1/2- λ | Multiple | 180 | 25 | 27.3 | 31.8 | 8 |

Please replace λ in model number with working wavelength when ordering.

### Achromatic Waveplates

| Model | Retardance (degrees) | Wavelength Range (nm) | Aperture (mm) | *O.D. (mm) Unmounted | *O.D. (mm) Mounted | Thickness (mm) |
|---|---|---|---|---|---|---|
| 8-9015-1/2 | 180 | 400-700 | 9 | 11 | 25.4 | 8 |
| 8-9012-1/4 | 90 | 600-900 | 9 | 11 | 25.4 | 8 |
| 8-9012-1/2 | 180 | 600-900 | 9 | 11 | 25.4 | 8 |
| 8-9014-1/4 | 90 | 700-1550 | 9 | 11 | 25.4 | 8 |
| 8-9014-1/2 | 180 | 700-1550 | 9 | 11 | 25.4 | 8 |

* Please request Mounted or Unmounted when ordering.



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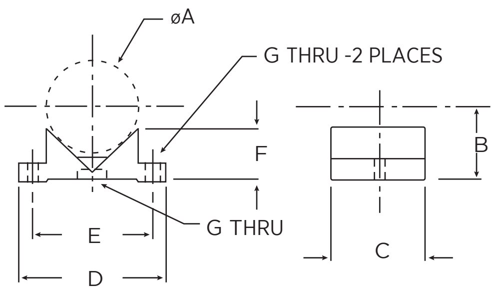
## Vee Block Mounts

The Vee Block Mounts are stable non-adjustable mounts which are used with the 50 and 52 Series Beam Expanders. Model 60-16-25 is suggested for barrel diameters between 25 and 45 mm, and Model 60-16-26 is suggested for diameters between 46 and 80 mm.

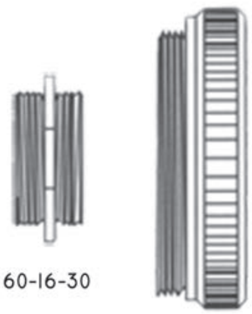



| Model | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| 60-16-25 | 1.25 | 1.00 | 1.25 | 2.00 | 1.63 | 0.716 | 0.147 |
| 60-16-26 | 2.25 | 1.63 | 2.25 | 3.25 | 2.75 | 1.13 | 0.187 |

## Threaded Adapters

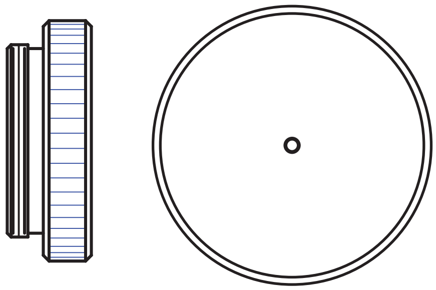
These Threaded Adaptors, compatible with 50-25 and 50-51 Series Beam Expanders, are useful for mounting the beam expander directly to the laser or other threaded optical components.

| Model | Thread (B.E. Side) | Thread (Laser Side) |
|---|---|---|
| 60-16-30 | 1″ - 32 TPI | 1″ - 32 TPI |
| 60-16-51 | 1″ - 32 TPI | 2″ - 32 TPI |




## Alignment Apertures

The Model 60-16-1.5 Alignment Aperture has a 1.5 mm central hole and screws into all 50-25 and 50-51 Series Beam Expanders. This removable aluminum plug is extremely useful in the initial centering and alignment of the beam expander.



| Model | T Thread (inches) |
|---|---|
| 60-16-1.5 | 1″ 32 TPI |
| 60-17-1.5 | 1.1/8 32 TPI |



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## In-Line Beam Steerer

In-Line Beam Steerers are convenient devices that precisely change the angle or alignment of optical beams without the use of mirrors. Unlike Risley prisms, In-Line Beam Steerers move the beams in a cartesian coordinate system rather than in a polar coordinate system. With a single adjustment, the In-Line Beam Steerer deflects the beam either horizontally or vertically. One In-Line Beam Steerer replaces typical two-mirror systems and makes adjustments easier. The In-Line Beam Steerer is an adjustable wedge formed by a plano-concave and a plano-convex lens that are connected to one another using a thin layer of index-matching fluid. Displacement of one lens with respect to the other changes the wedge angle, thereby steering the beam.

**Features:**

Independent two-axis Cartesian adjustments

Zero beam displacement

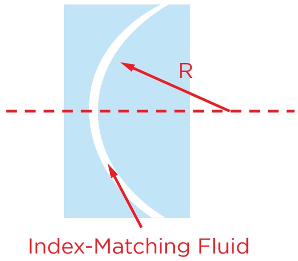
Mounts to 8-32 posts

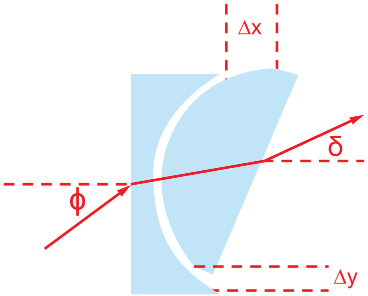
BK-7 (n = 1.52)

Broadband visible and IR coatings

| Model | Clear Aperture (mm) | Max. Deflection | Sensitivity | Dimensions (mm) | T (at 633 nm) | Adjustment |
|---|---|---|---|---|---|---|
| 12-4008-20 | 8 | ± 20 mrad | 14 μrad/deg | 25 x 25 x 14 | > 98% | Fine screw |
| 12-4010-25 | 10 | ± 25 mrad | 14 μrad/deg | 44 ø x 16 | > 98% | Fine screw |
| 12-4015-20 | 15 | ± 20 mrad | 14 μrad/deg | 60 ø x 22 | > 98% | Micrometer |

$$\delta \approx (n-1) \cdot \frac{\Delta y}{R} + \phi$$



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# Resources

- Custom Objectives
- Laser Beam Expander Theory
- Laser Focusing Objective Theory
- Laser Scanning Lens Theory
- Polarization Optics
- Metric Zoom

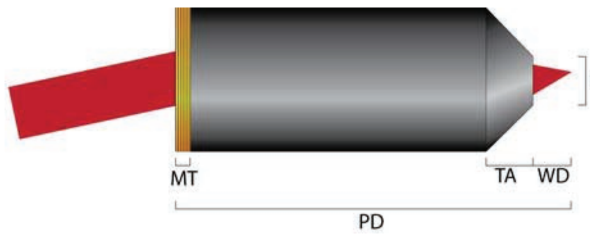
## Cutting-edge Research Requires State-of-the-art Optics

**A brief discussion on the increased demand for custom objectives and Special Optics' competitively priced solutions.**

As the scientific knowledge base expands and hypotheses become more specific, the requirement for equally specific tools increases proportionally. The number of investigators employing confocal, multi-photon, and other forms of laser scanning microscopy for specialized research applications has continually outpaced the rate at which affordable customized microscope objectives have been developed. The cost of specialized equipment coupled with a lack of qualified vendors forces investigators to perform complex research with less- than-ideal tools. Special Optics, a Navitar company, has emerged as a vendor of choice for investigators needing highly-customized microscope objective solutions at off-the-shelf cost without the limitations and bureaucracy of working with OEM microscope manufacturers.

### Customized Research Oftentimes Necessitates Custom Optics

Research in biomedical microscopy is inherently dynamic – today's investigations require different tools than what tomorrow's questions necessitate. However, researchers often feel trapped to stay within the catalogue of components offered by OEM microscope manufacturers because objective lenses are typically not universally compatible.




Many parameters of an objective lens may be customized according to the needs of a research project. The mounting threads (MT) and parfocal distance (PD) depend on the OEM microscope manufacturer. The housing tip angle (TA) and working distance (WD) can limit the types of peripheral instruments used during imaging. The working distance (WD) and field of view (FOV) are specific to the sample of interest and the protocol being followed.

This lack of flexibility in microscope component offerings leads to unique difficulties for investigators. Many factors influence the overall design of a microscope objective. The excitation and emission design wavelengths are oftentimes dictated by the fluorophores and biological systems under study. The design wavelengths can also be affected by the method of interrogation, such as through the use of uncaging or optogenetics. The WD is affected by the required depth of imaging, the necessary field of view, as well as the physical space required for peripheral experimental and vital instrumentation (micropositioners, pipettes, monitors, drug delivery systems, etc.). The overall design of the objective is also a function of excitation and transmission, resolution, and power requirements, and ideally must also compensate for optical aberrations induced by the particular sample of interest. It is impossible for any one objective, or even a reasonable series of objectives, to compensate for all of these factors and constitute a complete set adequate for biomedical microscopy.

As a result, commercial microscope manufacturers offer objectives that represent what they consider to be best compromises. Unfortunately, many current optical microscopy techniques require tolerances outside of the common one-size-fits-all catalog objective. The forefront of multiphoton microscopy is continually using wavelengths farther into the infrared spectrum and pushing the boundaries of transmission efficiency and chromatic aberration correction. Multifocal microscopies that use tunable lenses and acousto-optical deflectors require a large depth of field. Polychromatic techniques like single- and multi-photon stimulated emission depletion (STED) microscopy require broadband chromatic aberration correction across much of the visible and NIR spectrum. Simply stated, customized solutions are truly necessary to accomplish revolutionary research.

### The Special Optics Solution

For a similar cost to purchasing a stock objective from Nikon, Olympus, Zeiss, or Leica, a custom objective can be designed and built for a specific application by Special Optics - where competitive price and performance meets the flexibility of truly unique design. Our development team takes the time to fundamentally understand the specific research goals of each of our research partners to deliver the best possible microscope objective solution.



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## Laser Beam Expander Theory

### Diffraction

Perfect Gaussian Laser beams are often characterized by a parameter known as beam divergence. Divergence is the angular spreading of light waves as they propagate through space. Even a perfect unaberrated ray of light will experience some beam divergence due to diffraction effects. Diffraction is the effective bending of light rays caused by truncation from an opaque object such as a knife edge. The spreading arises from secondary wavefronts emitted from the edge of truncations. These secondary waves interfere with the primary wave, and also themselves, sometimes forming quite complicated diffraction patterns. Diffraction makes it impossible to perfectly collimate light, or to focus it to an infinitely small spot size. Fortunately diffraction effects can be calculated. Consequently theory exists which predicts the degree of collimation and spot size for any diffraction limited lens.

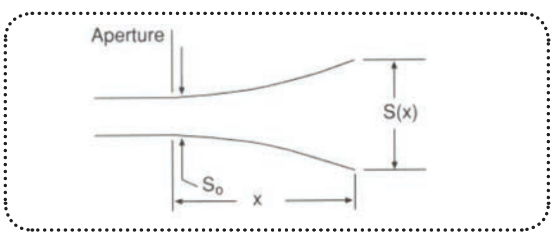


Fig. 1

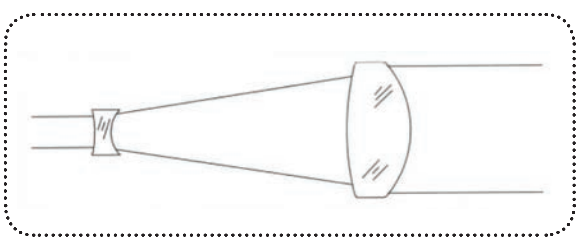

Fig. 2

### Improving Divergence

The far field beam divergence defines the best collimation for a given beam diameter. It also illustrates that zero beam divergence or perfect collimation can never be achieved, because doing so would require and infinite beam diameter. However this equation does suggest a means of improving divergence.

Consider a collimated beam of light with a beam divergence of **θ** and a beam diameter of $S_0$. Clearly, if the beam diameter were to be increased, the far field divergence would be decreased by the inverse proportion i.e. by 1/< where M is the expansion ration. This is precisely the advantage of expanding laser beams. In addition, lower divergence allows for better focusing of Gaussian beams (see Bestform Laser Lenses). With this improvement in mind we now describe several ways of expanding collimated light.

### Galilean Beam Expanders

The most common type of beam expander is derived from the Galilean telescope (figure 2) which usually has one negative input lens and one positive output lens. The input lens presents a virtual beam focus at the output. For lens expansion ratios (1.3x-20x) the Galilean telescope is most often employed due to its simplicity, small package size and low cost. Designs can usually be obtained having minimal spherical aberration, low wavefront distortion and achromaticity. Limitations are that it cannot accommodate spatial filtering or larger expansion ratios.

### Keplerian Beam Expanders

In cases where larger expansion ratios or spatial filtering is required, Keplerian design telescopes are employed. The Keplerian telescope has a positive input element presenting a real beam focus to the output elements. In addition, spatial filtering can be instituted by placing a pinhole at the focus of the first lens.



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# LASER FOCUSING OBJECTIVE THEORY

## Focusing Objective Theory

Some focusing applications may require a higher degree of aberration correction than can be achieved in single lenses such as Bestforms. Whether correction over larger apertures, several wavelengths or a wider field is needed, it may be necessary to use multi-element lens objective.

### Aberration Correction

A Bestform lens singlet is corrected for minimal spherical aberration. However, other aberrations will become prevalent in such a lens as field angles, aperture size, numerical aperture or wavelength bandwidth is increased. Coma and astigmatism are the two most important. Both are dependent on field angle. Using a combination of differing optical materials and computer controlled lens design software, many lens objectives can be made relatively aberration free. Depending on the F/# and degree of achromaticity, most on -axis focusing applications can be satisfied with objectives having three lenses or less.

### Single Line Objectives

All Special Optics Single Line Focusing Objectives are corrected for astigmatism and coma over the specified spectral range. However, they are not corrected for chromatic aberrations. These lenses are well suited for use with Solid State and Gas Lasers where only one wavelength is in use, or when shifts in focal length can be tolerated as the wavelength must be specified when ordering to indicate the appropriate anti-reflection coatings.

### Achromatic Objectives

An advantage of additional lens elements is the ability to combine lenses of different materials and optical properties to correct for chromatic aberrations. Achromatic Focusing Objectives are aberration corrected at two wavelengths simultaneously. A doublet consisting of two lenses of different materials can be designed such that the effective focal length and performance will be the same at two separate wavelengths.

### Apochromatic Objectives

Special low dispersion glasses allow for the design of lenses which are chromatically corrected for a range of wavelengths. Such lenses are referred to as having minimal secondary spectrum. Camera lenses are an extreme example of apochromatic lenses.



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## Scanning Lens Theory

Off axis deflection through a focusing lens system will, in general, form aberrated images in a curved plane as opposed to a more desirable flat surface. A flat field scanning lens is a specialized lens system in which the focal plane of a deflected laser beam is a flat surface. The most common uses of flat field scanning lenses are: Laser Machining, Pattern Generation, Laser Writing, Engraving and Marking. Additional subclasses of scanning lenses are F-theta lenses and Telecentric lenses.

### F-theta Lenses

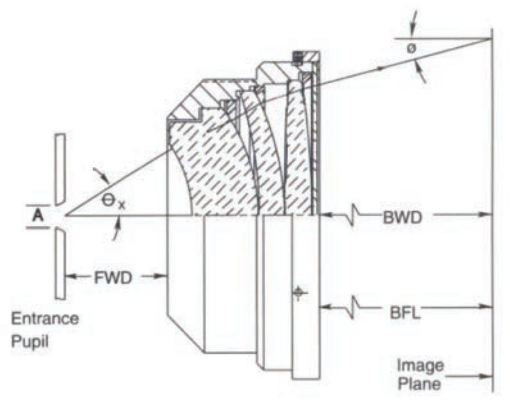
In the absence of distortion, the position of the focused spot is dependent on the product of the Focal Length (F) and the tangent of the deflection angle (θ). When the lens is designed with built-in barrel distortion, the position of the focused spot can then be made dependent on the product of F and θ, thereby simplifying positioning algorithms. Lenses designed in this way are called F-theta lenses.

### Telecentric Lenses

A significant feature of scanning lenses is the angle (ϕ) at which the focused beam strikes the work surface. In a typical lens, the beam will be normal to the surface only when the input beam is propagating along the lens axis. As the laser beam is deflecting off the axis, the angle moves off normal. This affects both the spot size, which becomes elongated, and the wall angle for cutting and drilling applications. At the cost of complexity and expense, the design of the lens can be such that the beam will strike normal to the work surface over the entire scanning field. This type of lens is defined as Telecentric. Telecentric lenses are almost always larger and more expensive than standard scanning lenses.

### Deflection Angle

Figure 1 is a diagram of the standard parameters used for describing and specifying scanning lenses. The angle between the input laser beam and the lens system axis is called the deflection angle. Theta (θ) is the maximum deflection angle allowed before the laser beam experiences vignetting through the lens system or before the diffraction limited point is exceeded.



## Entrance Pupil

The entrance pupil defines the origin of the laser deflection as well as the acceptable beam diameter and mirror size combination. If a single mirror system is used, the mirror is placed at the entrance pupil position and the maximum usable beam diameter is equal to the entrance pupil diameter. If a two mirror system is used for deflection in both the x and y directions, then the mirrors are placed on either side of the entrance pupil position and as close to each other as possible. Moving the origin of the beam deflection off of the pupil position and away from the lens system effectively reduces the allowable beam diameter and deflection angle.

## Front Working Distance

The Front Working Distance (FWD) is the distance from the entrance pupil to the lens housing. In a two axis system the physical working distance is less than the actual working distance since the entrance pupil position is between the two positioning mirrors.

## Scan Field Diameter

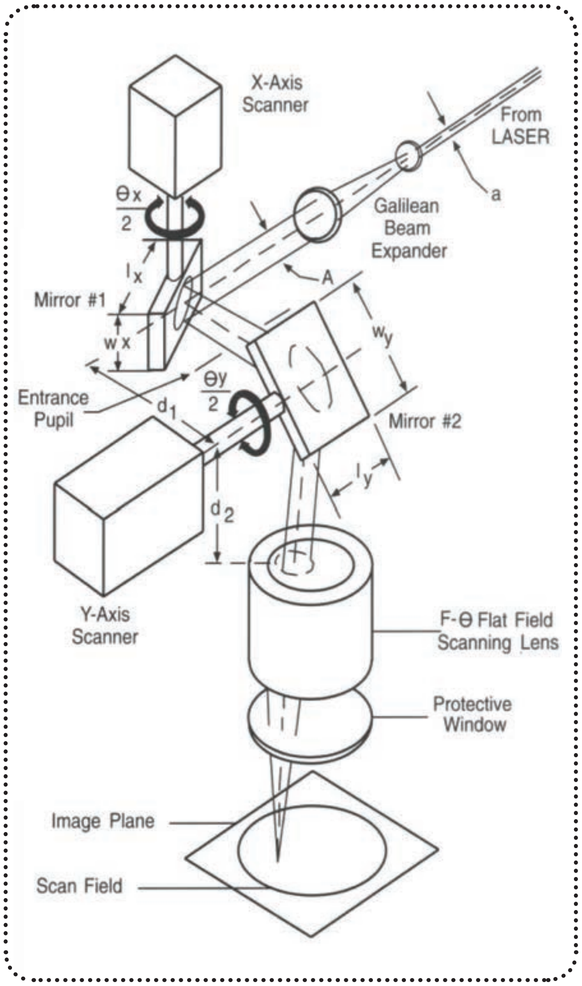
The scan field diameter determines many of the over-all lens specifications. Once a scan field diameter is determined, it is along with the focal length defines the deflection angle required, since the focus position is portional to the product of F x θ.

## Back Working Distance

The distance from the work surface to the output side of the lens housing is the Back Working Distance (BWD). Depending on lens complexity and the degree of telecentricity, the back working distance can usually be specified and controlled during lens design.

## Output Scan Angle

The angle between the normal to the image plane, or work surface, and the paraxial ray of the output beam is the output scan angle (ϕ). This angle is always zero for telecentric lenses. In general ϕ varies with the position of the focused spot across the work surface.



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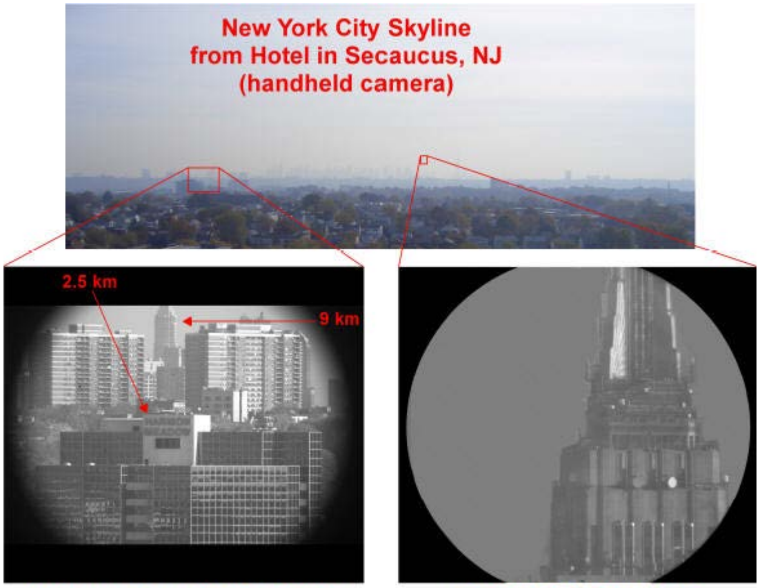
## Metric Zoom High Resolution Ultra-Long Range Surveillance / Imaging Lens

This Ultra-Long Range Surveillance lens provides continuous motorized zoom for tracking objects at a distance from .7km to over 100km. Ideal for weapons testing, shuttle tracking, and missile tracking, our Metric Zoom has the ability to image high speed events and conditions at locations that are far removed from the observer. Accurately imaging a moving target under changing conditions requires either multiple imaging systems with fixed focal lengths or a zoom lens system that is capable of changing its magnification to accommodate the variation in object distance. Our Metric zoom system offers significant advantages in that it eliminates the need for multiple imaging systems, the costly task of changing fixed imaging systems during operations, and thereby reduces the costs and logistics of carrying multiple surveillance systems in inventory.

## "Precision Metric Zoom Lens" from the U.S. Army White Sands Missile Range. (Phase I & Phase II )

Developed for the Army's White Sands Missile Range, this precision zoom lens consists of 16 refractive elements with three stationary lens groups and two moving lens groups. Using optical compensation, the focus and zoom are simultaneously maintained for focal lengths from 750 mm (f/4) to 3800 mm (f/14) at a resolution of 100 line pairs/mm (lp/mm) and an image field of 24 mm. The throughput of the lens is ~85%, and the lens is optimized over the visible waveband (485 nm to 650 nm). The zoom lens images objects at distances from 0.7 km to 100 km and is thermally compensated over a temperature range of 20 °F to 120 °F. Optical assembly was accomplished in about a week.




Secaucus, NJ (foreground) and New York City (background) (f = 1000 mm)

Empire State Building 8.9 km (f = 3600 mm)



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## Retardation Plate Theory

A retardation plate is an optically transparent material which resolves a beam of polarized light into two orthogonal components; retards the phase of one component relative to the other; then recombines the components into a single beam with new polarization characteristics.

### Birefringence

To better understand phase retardation, birefringence must first be discussed. Most optical materials are isotropic, i.e. having the same optical properties (and therefore one index of refraction) regardless of the direction of propagation through the material. An anisotropic material possesses different optical, electric, piezoelectric and elastic properties dependent on the orientation of the material. Crystal such as quartz, calcite and sapphire are common anisotropic materials. Polarized light propagating through such crystals will experience a different index of refraction for different directions of propagation and polarization orientations. This phenomenon is known as birefringence.

Within the material there exists a direction or axis with a unique optical property such that light propagating along it encounters only one index of refraction regardless of its polarization direction, and as such is called the optic axis.

Polarization components perpendicular to the optic axis encounter a refractive index known as the ordinary index ($n_o$), while parallel components encounter a refractive index known as the extraordinary index ($n_e$). Quantitatively, the birefringence value of a material is defined as($n_e$- $n_o$). If $n_e$>$n_o$ the crystal is called positive uniaxial and negative for the reverse. Often the axis which propagates the highest index value is called the fast axis.

### Retardation

We now consider the effect on polarized light due to birefringence. Polarization, being a vector quantity, can be resolved into two orthogonal components such that one experiences ne and the other no. Since the velocity of light within the crystal is inversely proportional to the index, one polarization will be traveling faster than the other.

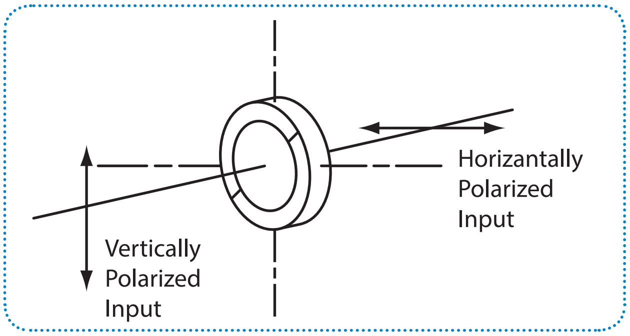
$n_e = c / v_{||}$ ; $n_o = c / v_{|}$

Where v is the velocity of light within the crystal, c is the velocity of light in a vacuum and n is the index of refraction.

As linear polarization enters a crystal, both polarization components are oscillating in phase with one another. As they propagate they begin to fall out of phase due to the velocity difference. Upon exiting, the resultant polarization is some form of elliptical polarization due to the phase difference. Special polarization cases can result if the overall phase difference is in multiples of π (linear polarization) or π/2 (circular).

### Example

As an example consider linearly polarized light incident on a birefringent crystal with the polarization at a 45 degree angle to the fast axis. In this case the magnitude of the $n_e$ and $n_o$ components are equal.




The change in phase due to the birefringence will be dependent on the plate thickness (d) of the material, as well as, the wavelength (λ) of the beam of incident light and the birefringence value. The resultant phase difference can easily be shown to be:

$\theta = 2\pi d(n_e - n_o)\lambda$

where the plate thickness and wavelength are both expressed in millimeters. If the thickness of the crystal is such that a phase change of π/2 is introduced, then the resulting exiting beam will be circularly polarized. This can be shown by carrying out the vector summation of both polarization components through the use of Jones calculus. Since π/2 is equivalent to a quarter of a wave, this retarder is referred to as a quarter waveplate. Note that a change in retardance of one wave (2π) is equivalent to no change in retardance and entrance beam. Moreover if the retardance is an odd multiple of π/2, i.e. [(M+1/2)π], quarter wave retardance is achieved once again.

## Multiple Order Waveplates

Using the previous equation, and given a required retardance value, the necessary thickness of the waveplate can be calculated. For standard waveplate materials, such as quartz and magnesium fluoride, the calculated thickness for a retardation value of a fraction of a wave would be on the order of 0.1 mm and too thin to manufacture. For this reason a higher multiple of the required retardation is use to place the thickness of the waveplate in a physically manufacturable range. These waveplates are called multiple-order waveplates and typically have values in the neighborhood of 10 to 12 whole waves plus the fractional retardation required.

## Temperature, Wavelength and Angle of Incidence Dependence

An important consideration in using multiple order waveplate is the dependence of the retardation value on temperature, wavelength and angle of incidence. The thicker the waveplate, the higher the retardation value, and the more the retardation value will change with temperature, wavelength and angle of incidence.

## Zero Order Waveplates

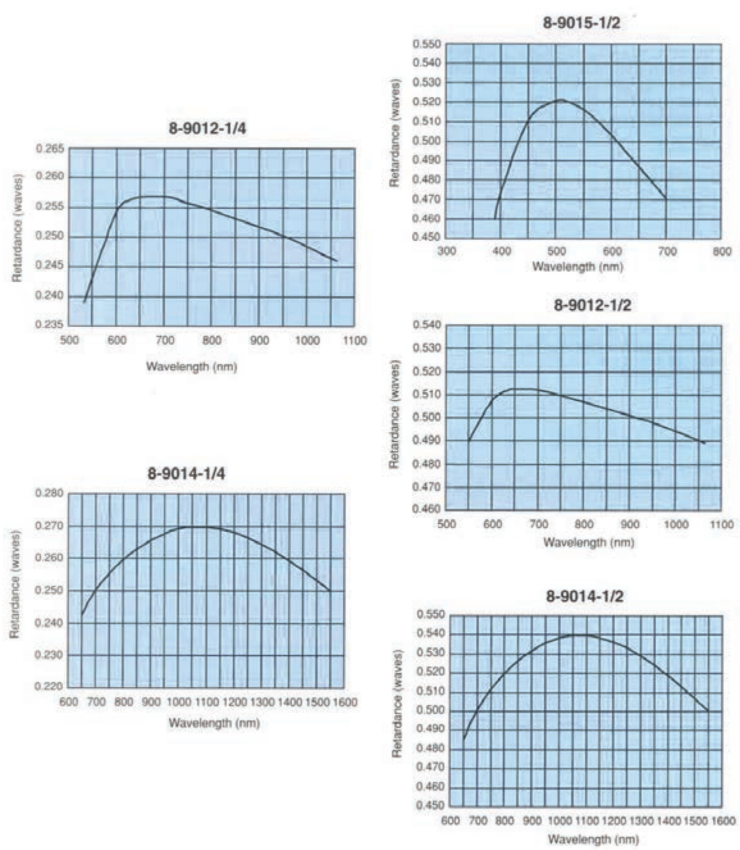
This can be achieved if the plate is constructed of two plate halves which have their fast axes crossed. The thicknesses are chosen so that the difference in retardation between the two plates is equivalent to the desired retardance. Any variation in temperature, wavelength, or angle of incidence dependence is greatly reduced. This type of waveplate is called a zero-order waveplate. Plate halves can be cemented, optically contacted or air-spaced.

## Achromatic Waveplates

The wavelength dependence of the birefringence dictates that the spectral range for the standard waveplate is approximately 10 nm. To accommodate tunable sources or sources with larger spectral widths, a waveplate that is relatively independent of wavelength is required This is accomplished with achromatic waveplates.

An achromatic waveplate is a zero-order waveplate utilizing two different birefringent materials. As a result of the dissimilar wavelength dependence value shifts in one plate due to the wavelength change will be compensated by the other plate. The resulting retardance can be fairly constant over a range of several hundred nanometers. The most common achromatic waveplates material combination is quartz/magnesium fluoride.

**Achromatic Waveplate Curves**



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