

Gradient-index (GRIN) lenses combine refraction at the plane end surfaces with continuous refraction within the rod. Made from SELFOC<sup>®</sup>, a radial gradient-index material, GRIN lenses are easy to use and are well suited to coupling the output of a diode laser into an optical fiber.

- Aberration correction can be achieved without complex multielement systems or aspherics.
- Real images are formed at the lens surface.
- An antireflection coating reduces reflection to less than 0.5 percent per surface.

### IMAGING THEORY IN GRADIENT-INDEX LENSES

The refractive index of SELFOC<sup>®</sup> material varies parabolically as a function of radius. The index variation may be expressed as

$$n_r = n_0 \left( 1 - \frac{A}{2} r^2 \right)$$

where  $n_r$  is the refractive index at a distance  $r$  from the optical axis,  $n_0$  is the design index on the optical axis, and  $A$  is a positive constant.

A ray incident on the front surface follows a sinusoidal path along the rod. The period of the sinusoidal path ("pitch" of the lens) is given by

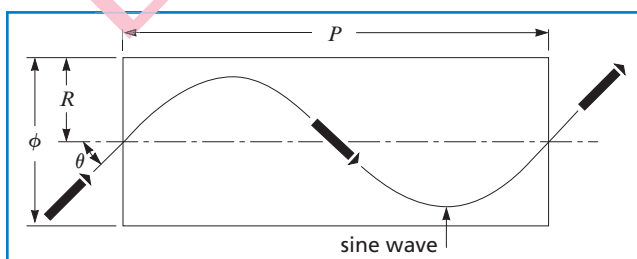
$$P = \frac{2\pi}{\sqrt{A}}$$

Another important parameter is the maximum acceptance angle

$$\theta = \sin^{-1} \left( n_0 R \sqrt{A} \right)$$

where  $R = \phi/2$ .

SELFOC<sup>®</sup> is a registered trademark of the Nippon Sheet Glass Company.

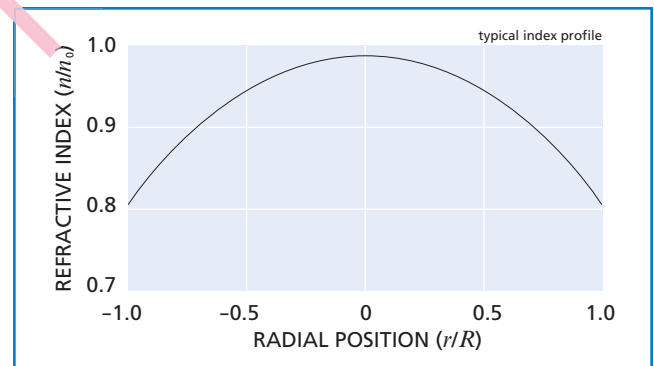


Ray path in gradient-index lenses

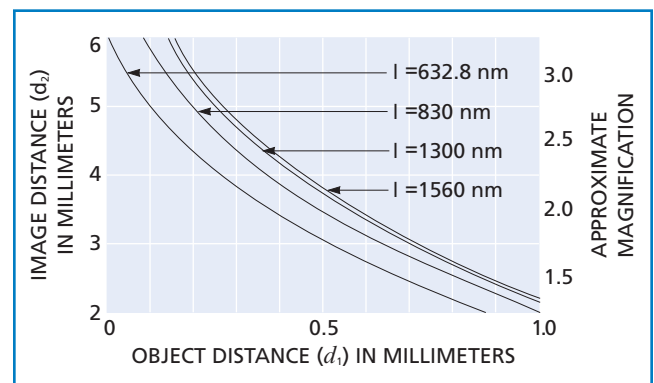
## Gradient-Index Lenses

### SPECIFICATIONS: Gradient-Index Lenses

Wavelength Options	633, 830, 1300, or 1560 nm
Gradient-Index Constant	$A^{1/2} \pm 2.5\%$
Working Distance for 0.23-Pitch Lenses	0.21 mm at 633 nm 0.21 mm at 830 nm 0.26 mm at 1300 nm 0.26 mm at 1560 nm
Working Distance for 0.29-Pitch Lenses	See graph
Coating	Multilayer metal oxide
Diameter	$\phi \pm 0.02$ mm (0.01 mm for $\phi=1.0$ mm)



Refractive index profile in SELFOC<sup>®</sup> gradient-index material



Object and image distance for 0.29 pitch lenses

## Gradient-Index Lenses

Fractional Pitch	NA	$\phi$ (mm)	$L$ (mm)	Maximum Acceptance Angle	Design Index (On Axis)	$A^{1/2}$	PART NUMBER	
							FORMER†	REPLACED BY
<b>Antireflection Coated for <math>\lambda = 632.8</math> nm</b>								
0.23	0.46	1.8	4.26 ± 0.12	55	1.608	0.339	06 LGT 114	LGT-0.23-1.8-4.26-633
0.25	0.46	1.0	2.58 ± 0.08	55	1.608	0.608	06 LGS 113	LGS-0.25-1.0-2.58-633
0.25	0.46	1.8	4.63 ± 0.13	55	1.608	0.339	06 LGS 114	LGS-0.25-1.8-4.63-633
0.25	0.46	2.0	5.17 ± 0.15	55	1.608	0.304	06 LGS 115	LGS-0.25-2.0-5.17-633
0.29	0.46	1.8	5.37 ± 0.16	55	1.608	0.339	06 LGE 114	LGE-0.29-1.8-5.37-633
0.50	0.46	1.0	5.17 ± 0.15	55	1.608	0.608	06 LGD 113	LGD-0.50-1.0-5.17-633
0.50	0.46	1.8	9.27 ± 0.27	55	1.608	0.339	06 LGD 114	LGD-0.50-1.8-9.27-633
0.50	0.46	2.0	10.33 ± 0.30	55	1.608	0.304	06 LGD 115	LGD-0.50-2.0-10.33-633
<b>Antireflection Coated for <math>\lambda = 830</math> nm</b>								
0.23	0.46	1.8	4.35 ± 0.13	55	1.600	0.332	06 LGT 214	LGT-0.23-1.8-4.35-830
0.25	0.46	1.0	2.61 ± 0.08	55	1.600	0.601	06 LGS 213	LGS-0.25-1.0-2.61-830
0.25	0.46	1.8	4.73 ± 0.14	55	1.600	0.332	06 LGS 214	LGS-0.25-1.8-4.73-830
0.25	0.46	2.0	5.27 ± 0.15	55	1.600	0.298	06 LGS 215	LGS-0.25-2.0-5.27-830
0.29	0.46	1.8	5.49 ± 0.16	55	1.600	0.332	06 LGE 214	LGE-0.29-1.8-5.49-830
0.50	0.46	1.0	5.23 ± 0.15	55	1.600	0.601	06 LGD 213	LGD-0.50-1.0-5.23-830
0.50	0.46	1.8	9.46 ± 0.28	55	1.600	0.332	06 LGD 214	LGD-0.50-1.8-9.46-830
0.50	0.46	2.0	10.54 ± 0.31	55	1.600	0.298	06 LGD 215	LGD-0.50-2.0-10.54-830
<b>Antireflection Coated for <math>\lambda = 1300</math> nm</b>								
0.23	0.46	1.8	4.42 ± 0.13	55	1.592	0.327	06 LGT 314	LGT-0.23-1.8-4.42-1300
0.25	0.46	1.0	2.63 ± 0.08	55	1.592	0.597	06 LGS 313	LGS-0.25-1.0-2.63-1300
0.25	0.46	1.8	4.80 ± 0.14	55	1.592	0.327	06 LGS 314	LGS-0.25-1.8-4.80-1300
0.25	0.46	2.0	5.32 ± 0.16	55	1.592	0.295	06 LGS 315	LGS-0.25-2.0-5.32-1300
0.29	0.46	1.8	5.57 ± 0.16	55	1.592	0.327	06 LGE 314	LGE-0.29-1.8-5.57-1300
0.50	0.46	1.0	5.36 ± 0.15	55	1.592	0.597	06 LGD 313	LGD-0.50-1.0-5.36-1300
0.50	0.46	1.8	9.61 ± 0.28	55	1.592	0.327	06 LGD 314	LGD-0.50-1.8-9.61-1300
0.50	0.46	2.0	10.65 ± 0.31	55	1.592	0.295	06 LGD 315	LGD-0.50-2.0-10.65-1300
<b>Antireflection Coated for <math>\lambda = 1560</math> nm</b>								
0.23	0.46	1.8	4.43 ± 0.13	55	1.590	0.326	06 LGT 414	LGT-0.23-1.8-4.43-1560
0.25	0.46	1.0	2.64 ± 0.08	55	1.592	0.596	06 LGS 413	LGS-0.25-1.0-2.64-1560
0.25	0.46	1.8	4.82 ± 0.14	55	1.592	0.326	06 LGS 414	LGS-0.25-1.8-4.82-1560
0.25	0.46	2.0	5.34 ± 0.16	55	1.592	0.294	06 LGS 415	LGS-0.25-2.0-5.34-1560
0.29	0.46	1.8	5.59 ± 0.16	55	1.592	0.326	06 LGE 414	LGE-0.29-1.8-5.59-1560
0.50	0.46	1.0	5.27 ± 0.15	55	1.592	0.596	06 LGD 413	LGD-0.50-1.0-5.27-1560
0.50	0.46	1.8	9.64 ± 0.28	55	1.592	0.326	06 LGD 414	LGD-0.50-1.8-9.64-1560
0.50	0.46	2.0	10.69 ± 0.31	55	1.592	0.294	06 LGD 415	LGD-0.50-2.0-10.69-1560

† Former Melles Griot part number is replaced by new CVI Melles Griot part number

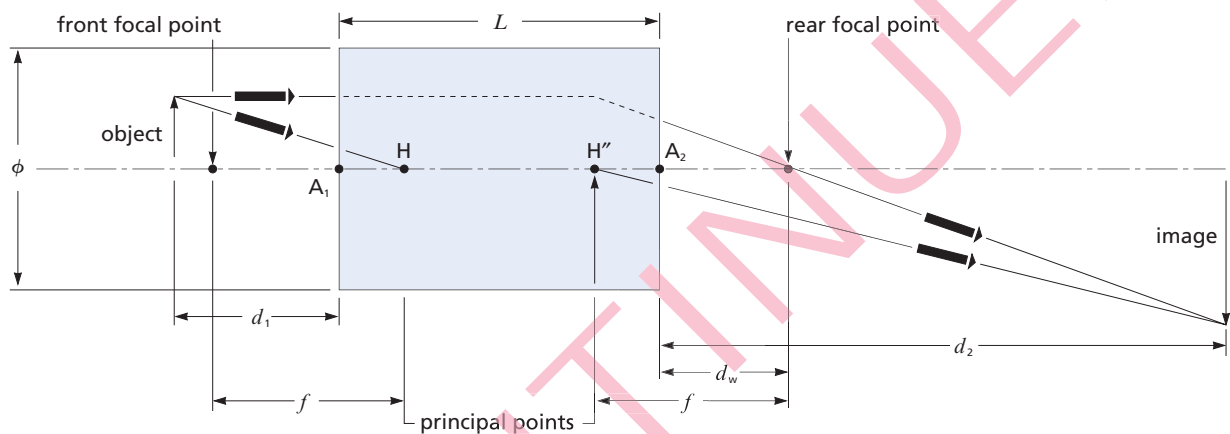
Do you need...

### GRADIENT-INDEX LENS HOLDERS

CVI Melles Griot offers a variety of holders designed specifically for 1- and 2-mm-diameter gradient-index lenses.

- 07 HGH 501 holder: Designed for use with the MicroLab™ 16-mm cell-mounting system
- 07 HGI 505 holder: Spring-clip holder with integral base
- 07 HGI 021 holder: Post mountable via M6 female thread





$\phi$  = Lens diameter

$d_w$  = Working distance (back focal length)

$L$  = Lens length

$$= \frac{1}{n_0 \sqrt{A}} \cot(L\sqrt{A})$$

$n_0$  = Refractive index on axis

$$A_2H'' = \text{Principal plane position} = \frac{1}{n_0 \sqrt{A}} \tan\left(\frac{L\sqrt{A}}{2}\right)$$

Gradient index constant =  $\sqrt{A}$

$$\text{Pitch} = \frac{2\pi}{\sqrt{A}}$$

$d_1$  = Object to lens distance

$d_2$  = Image to lens distance

Normalized lens length =  $L\sqrt{A}$

$$\text{Fractional pitch} = \frac{L\sqrt{A}}{2\pi}$$

$$= \frac{1}{n_0 \sqrt{A}} \times \frac{n_0 \sqrt{A} d_1 \cos(L\sqrt{A}) + \sin(L\sqrt{A})}{n_0 \sqrt{A} d_1 \sin(L\sqrt{A}) - \cos(L\sqrt{A})}$$

$$f = \text{Effective focal length} = \frac{1}{n_0 \sqrt{A} \sin(L\sqrt{A})}$$

$$m = \text{Magnification} = \frac{-1}{n_0 \sqrt{A} \sin(L\sqrt{A}) \left[ d_1 - \frac{\cot(L\sqrt{A})}{n_0 \sqrt{A}} \right]}$$

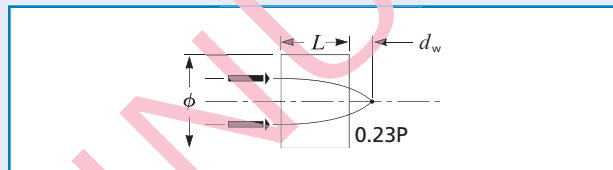
All angles are calculated in radians

### Imaging properties of a gradient-index rod lens at finite conjugate ratio

## APPLICATION NOTE

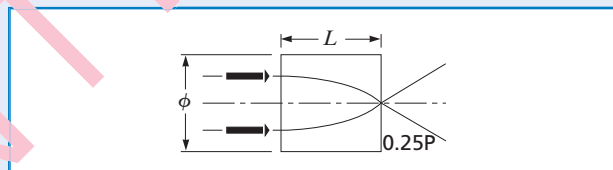
## Gradient-Index Lens Applications

- 0.23 pitch transfers collimated light to a focal point.
- Image is displaced from lens.



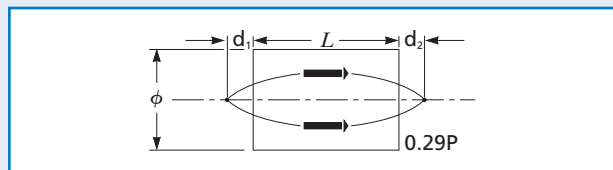
LGT gradient-index lens

- 0.25 pitch forms inverted, real image of an object at infinity on the opposite end of lens.



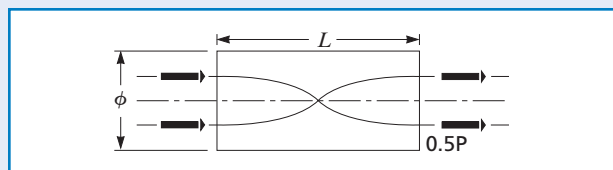
LGS gradient-index lens

- 0.29 pitch transfers light from a point source to a focal point.
- Image is displaced from lens.
- May be used over a range of magnification as shown in the figure at right.



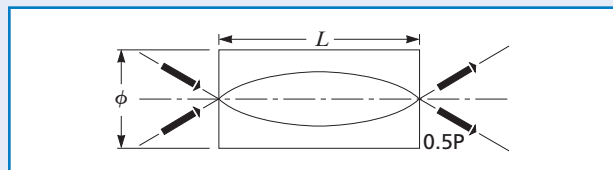
LGE gradient-index lens

- 0.5 pitch can also transfer collimated light from one end of the lens to the other.



LGD gradient-index lens

- 0.5 pitch transfers an inverted real image from one end of the lens to the other.



LGD gradient-index lens