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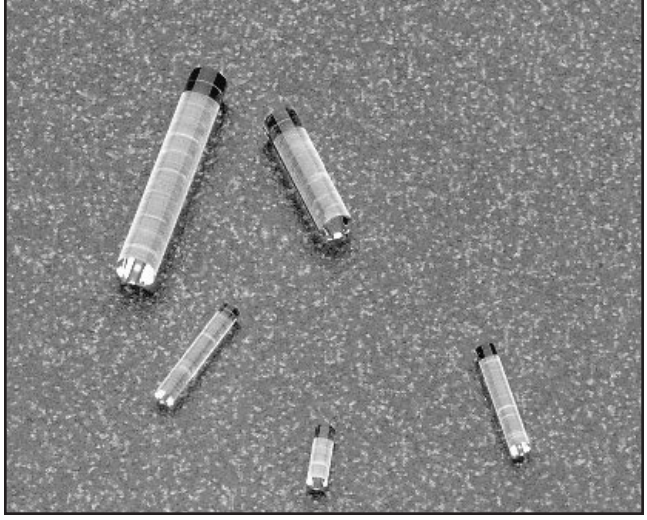
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Gradient-Index Lenses

Gradient-index (GRIN) lenses combine refraction at the plane end surfaces with continuous refraction within the rod. Made from SELFOC®, 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 1.5% per surface.

IMAGING THEORY IN GRADIENT-INDEX LENSES

The refractive index of SELFOC® 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 = refractive index at a distance r from the optical axis
n_0 = design index on the optical axis
A = 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

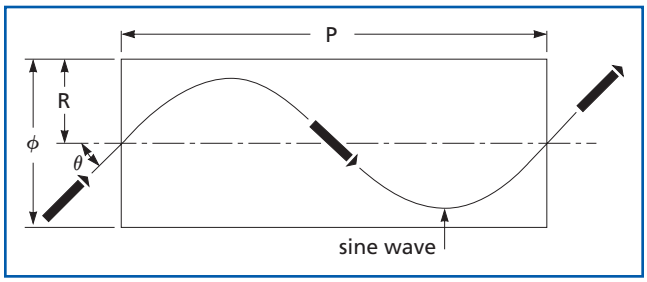
$$P = 2\pi/\sqrt{A}.$$

Another important parameter is the maximum acceptance angle,

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

where $R = \phi/2$.

SELFOC® is a registered trademark of the Nippon Sheet Glass Company.



Ray path in gradient-index lenses

SPECIFICATIONS: GRADIENT-INDEX LENSES

Design Wavelength: 632.8, 830, 1300, or 1560 nm

Gradient-Index Constant: $\sqrt{A} \pm 2.5\%$

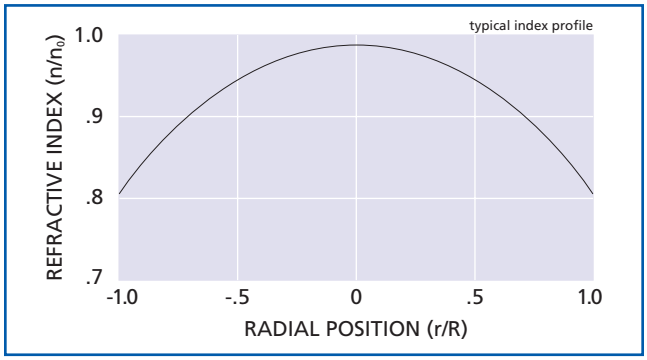
Working Distance (d_w): for 0.23 pitch lenses
0.21 mm at 633 nm
0.21 mm at 830 nm
0.26 mm at 1300 nm
0.26 mm at 1560 nm

Working Distance (d_1, d_2): for 0.29 pitch lenses – *see graph*

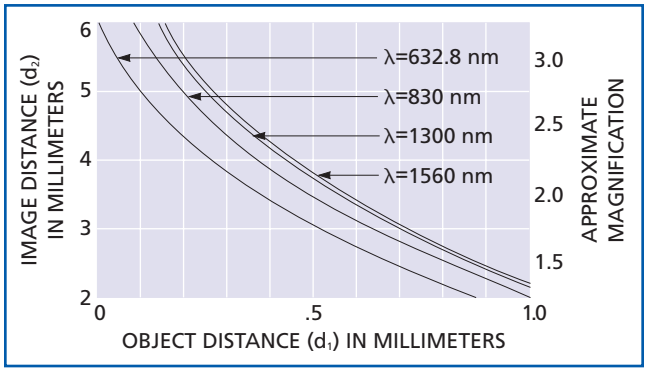
Length Tolerance: ±3%

Diameter (ϕ): 1.0 ± 0.01 mm, 1.8, and 2.0 ± 0.02 mm

Coating: Single-layer MgF_2

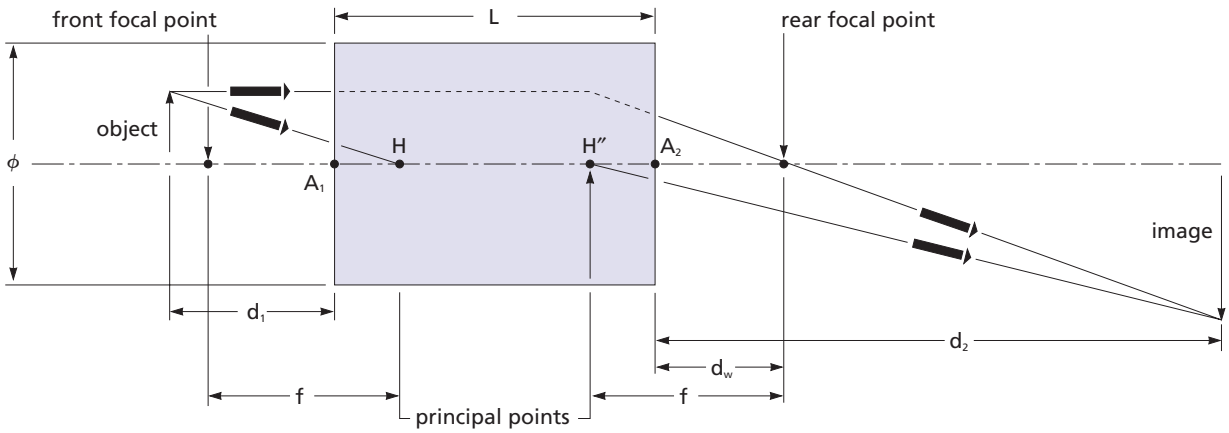


Refractive index profile in SELFOC® gradient-index material



Object and image distance for 0.29 pitch lenses

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ϕ = Lens diameter

L = Lens length

n_0 = Refractive index on axis

Gradient - Index Constant = $\sqrt{A}$

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

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

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

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

d_w = Working distance (back focal length)

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

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

d_1 = Object lens distance

d_2 = Image to lens distance

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

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

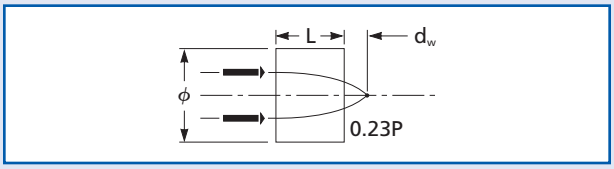
All angles are calculated in radians

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

APPLICATION NOTE

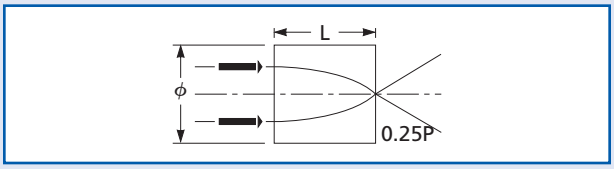
Gradient-Index Lens Applications

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



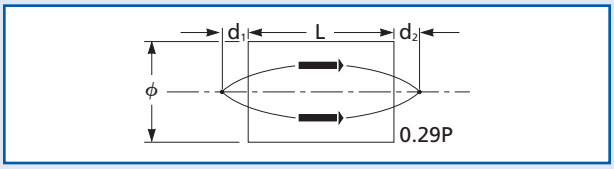
06 LGT gradient-index lens

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



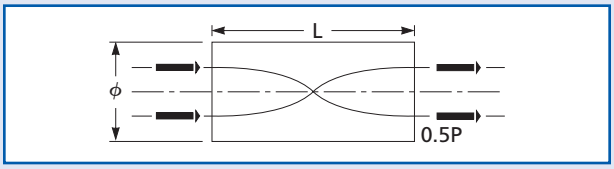
06 LGS gradient-index lens

- 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.



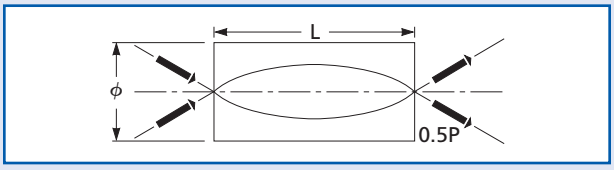
06 LGE gradient-index lens

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



06 LGD gradient-index lens

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



06 LGD gradient-index lens

Gradient-Index Lenses, Antireflection Coated, for λ = 632.8 nm

Fractional Pitch	NA	Diameter ϕ (mm)	Length L (mm)	Maximum Acceptance Angle, 2θ (degrees)	Design Index On-Axis n_0	Gradient-Index Constant $\sqrt{A}$	PRODUCT NUMBER
0.23	0.46	1.8	4.3	55	1.608	0.339	06 LGT 114
0.25	0.37	1.0	3.2	43	1.564	0.499	06 LGS 111
	0.37	2.0	6.4	43	1.564	0.247	06 LGS 112
	0.46	1.0	2.6	55	1.608	0.608	06 LGS 113
	0.46	1.8	4.6	55	1.608	0.339	06 LGS 114
	0.46	2.0	5.2	55	1.608	0.304	06 LGS 115
	0.60	1.8	3.7	72	1.658	0.428	06 LGS 116
0.29	0.46	1.8	5.4	55	1.608	0.339	06 LGE 114
0.50	0.37	1.0	6.3	43	1.564	0.499	06 LGD 111
	0.37	2.0	12.7	43	1.564	0.247	06 LGD 112
	0.46	1.0	5.2	55	1.608	0.608	06 LGD 113
	0.46	1.8	9.3	55	1.608	0.339	06 LGD 114
	0.46	2.0	10.3	55	1.608	0.304	06 LGD 115
	0.60	1.8	7.3	72	1.658	0.428	06 LGD 116

Gradient-Index Lenses, Antireflection Coated, for λ = 830 nm

Fractional Pitch	NA	Diameter ϕ (mm)	Length L (mm)	Maximum Acceptance Angle, 2θ (degrees)	Design Index On-Axis n_0	Gradient-Index Constant $\sqrt{A}$	PRODUCT NUMBER
0.23	0.46	1.8	4.4	55	1.600	0.332	06 LGT 214
0.25	0.37	1.0	3.2	43	1.557	0.489	06 LGS 211
	0.37	2.0	6.5	43	1.557	0.243	06 LGS 212
	0.46	1.0	2.6	55	1.600	0.601	06 LGS 213
	0.46	1.8	4.7	55	1.600	0.332	06 LGS 214
	0.46	2.0	5.3	55	1.600	0.298	06 LGS 215
	0.60	1.8	3.7	72	1.646	0.423	06 LGS 216
0.29	0.46	1.8	5.5	55	1.600	0.332	06 LGE 214
0.50	0.37	1.0	6.4	43	1.557	0.489	06 LGD 211
	0.37	2.0	13.0	43	1.557	0.243	06 LGD 212
	0.46	1.0	5.2	55	1.600	0.601	06 LGD 213
	0.46	1.8	9.5	55	1.600	0.332	06 LGD 214
	0.46	2.0	10.5	55	1.600	0.298	06 LGD 215
	0.60	1.8	7.4	72	1.646	0.423	06 LGD 216

Gradient-Index Lenses, Antireflection Coated, for λ = 1300 nm

Fractional Pitch	NA	Diameter ϕ (mm)	Length L (mm)	Maximum Acceptance Angle, 2θ (degrees)	Design Index On-Axis n_0	Gradient-Index Constant $\sqrt{A}$	PRODUCT NUMBER
0.23	0.46	1.8	4.4	55	1.592	0.327	06 LGT 314
0.25	0.37	1.0	3.2	43	1.551	0.483	06 LGS 311
	0.37	2.0	6.6	43	1.551	0.283	06 LGS 312
	0.46	1.0	2.6	55	1.592	0.597	06 LGS 313
	0.46	1.8	4.8	55	1.592	0.327	06 LGS 314
	0.46	2.0	5.3	55	1.592	0.295	06 LGS 315
	0.60	1.8	3.7	72	1.636	0.418	06 LGS 316
0.29	0.46	1.8	5.6	55	1.592	0.327	06 LGE 314
0.50	0.37	1.0	6.5	43	1.551	0.483	06 LGD 311
	0.37	2.0	13.2	43	1.551	0.283	06 LGD 312
	0.46	1.0	5.3	55	1.592	0.597	06 LGD 313
	0.46	1.8	9.6	55	1.592	0.327	06 LGD 314
	0.46	2.0	10.6	55	1.592	0.295	06 LGD 315
	0.60	1.8	7.5	72	1.636	0.418	06 LGD 316

Gradient-Index Lenses, Antireflection Coated, for λ = 1560 nm

Fractional Pitch	NA	Diameter ϕ (mm)	Length L (mm)	Maximum Acceptance Angle, 2θ (degrees)	Design Index On-Axis n_0	Gradient-Index Constant $\sqrt{A}$	PRODUCT NUMBER
0.23	0.46	1.8	4.4	55	1.590	0.326	06 LGT 414
0.25	0.37	1.0	3.3	43	1.550	0.481	06 LGS 411
	0.37	2.0	6.6	43	1.550	0.237	06 LGS 412
	0.46	1.0	2.6	55	1.592	0.596	06 LGS 413
	0.46	1.8	4.8	55	1.592	0.326	06 LGS 414
	0.46	2.0	5.3	55	1.592	0.294	06 LGS 415
	0.60	1.8	3.8	72	1.634	0.417	06 LGS 416
0.29	0.46	1.8	5.5	55	1.590	0.326	06 LGE 414
0.50	0.37	1.0	6.5	43	1.550	0.481	06 LGD 411
	0.37	2.0	13.3	43	1.550	0.237	06 LGD 412
	0.46	1.0	5.3	55	1.592	0.596	06 LGD 413
	0.46	1.8	9.6	55	1.592	0.326	06 LGD 414
	0.46	2.0	10.7	55	1.592	0.294	06 LGD 415
	0.60	1.8	7.5	72	1.634	0.417	06 LGD 416

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