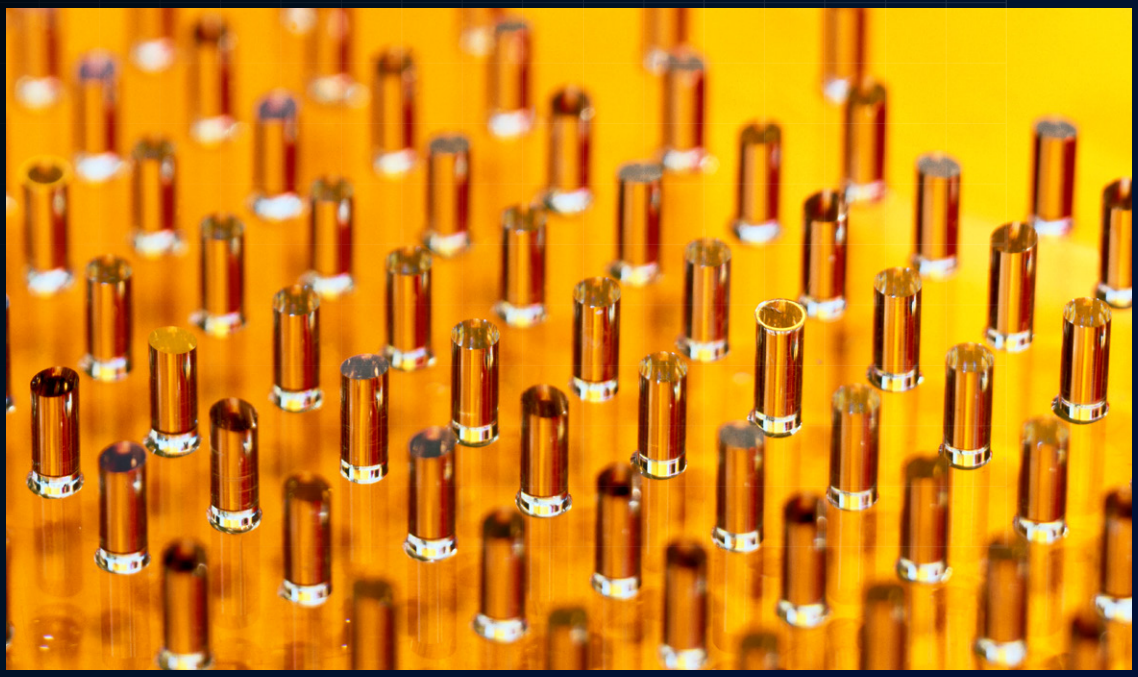
GRINTECH

Gradient Index Optics

GRIN Rod Lenses



www.grintech.de

Precision for every application

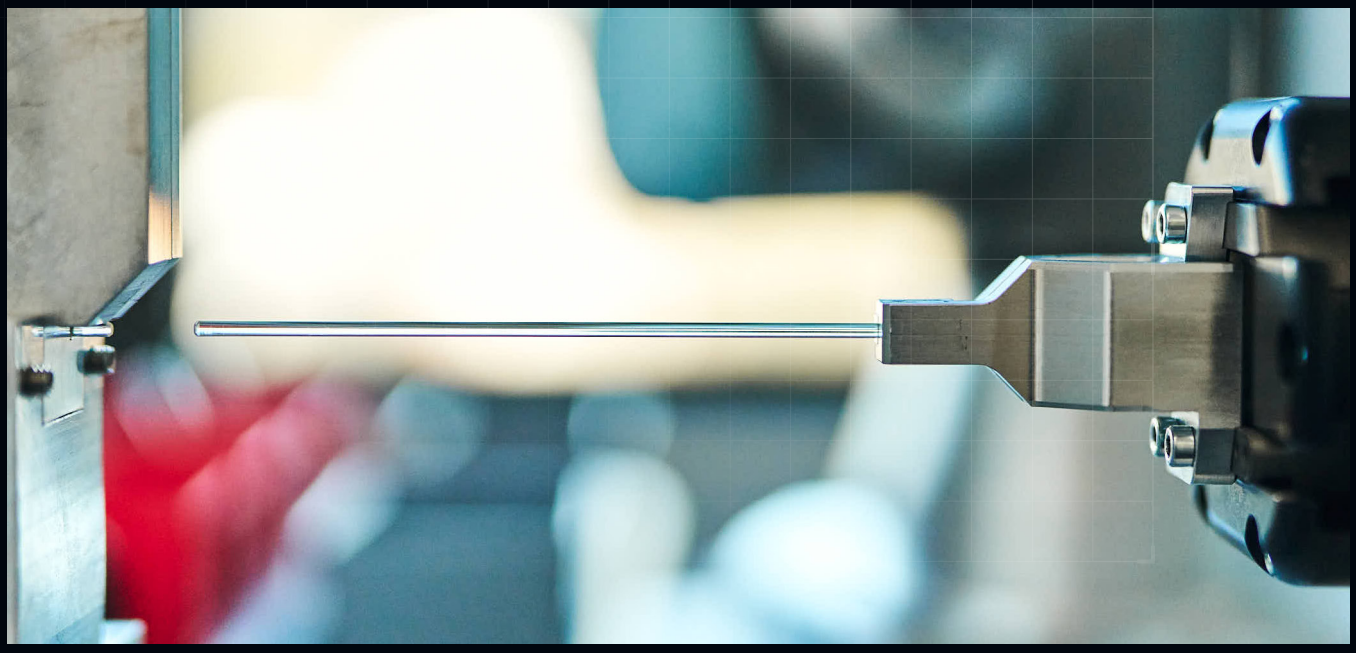
GRIN rod lenses are made of non-toxic glass material (biocompatibility according to EN ISO 10993-1). With standard diameters between 0.25 mm and 2.0 mm, they have plane surfaces and numerical apertures of 0.2 and 0.5. GRIN lenses with a numerical aperture (NA) of 0.5 are preferably used for fiber coupling and laser diode beam shaping. GRIN lenses with an NA of 0.2 have longer focal lengths and lens lengths. Optionally, we also offer these with better correction of spherical aberration (high performance).

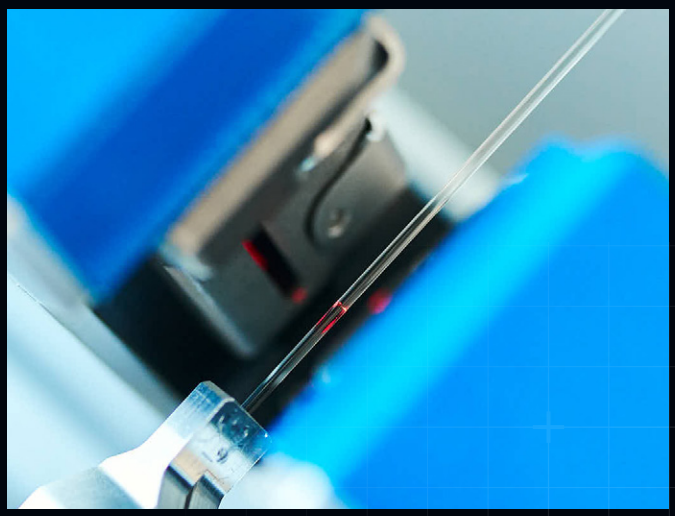
GRIN objective lenses with viewing angles of +/- 30° are mainly used for endoscopic applications, e.g. in conjunction with image guide bundles or GRIN relay lenses.

Customizable at the customer's request

On request, the following are possible:

- Working distance and lens length changes
- Change of design wavelength
- Anti-reflective coatings
- 8° facet polishing
- Other diameters, e.g. 0.25, 0.35, 0.6 and 0.85 mm



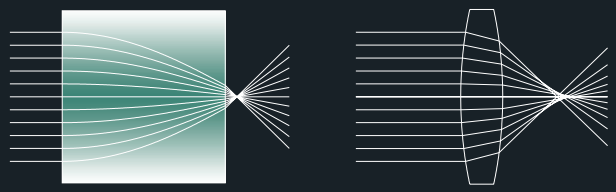


Gradient Index (GRIN) Lenses – An Introduction

GRIN lenses represent an interesting alternative to conventional spherical lenses since the lens performance depends on a continuous change of the refractive index within the lens material. Instead of curved shaped surfaces only plane optical surfaces are used. The light rays are continuously bent within the lens until finally they are focussed on a spot.

Types and Properties

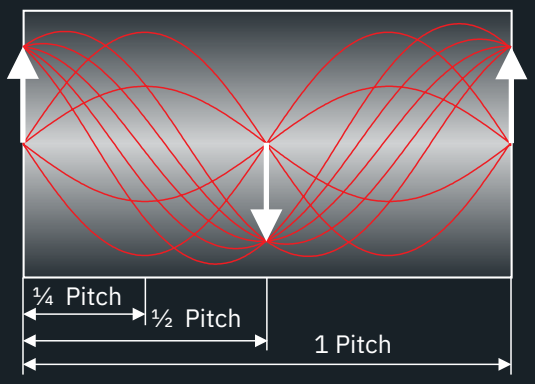
- GRIN rod lenses for fiber coupling
- Easy to assemble due to the plane surfaces
- Good off- and on-axis performance
- Non-toxic silver and lithium ion exchange



GRIN lens | Conventional spherical lens

The GRIN lenses are produced by silver ion exchange in a special glass. In contrast to the conventionally used technology this is a non-toxic process and bears no health and environmental risks for both the producer as well as the user of these products. This process is performed in rods (and can also be offered in slabs) resulting in rod lenses and optionally in cylindrical lenses with plane optical surfaces.

A radial refractive index profile of nearly parabolic shape $n(r) = n_0 \operatorname{sech}(gr)$ realizes a continuos cosine ray trace within a GRIN focussing lens, the period length $z_{1\text{-}P}$ of the lens is given by $z_{1\text{-}P} = 2\pi/g$ and does not depend on the entrance height and the entrance angle of the light ray. n_0 represents the refractive index at the center of the profile, r the radius and g the gradient constant.



Ray traces within a GRIN focussing lens of different pitch lengths

The geometrical length of the particular lens z_l is calculated from the characteristic pitch of the lens P,

$$z_l = \frac{2\pi}{g} P$$

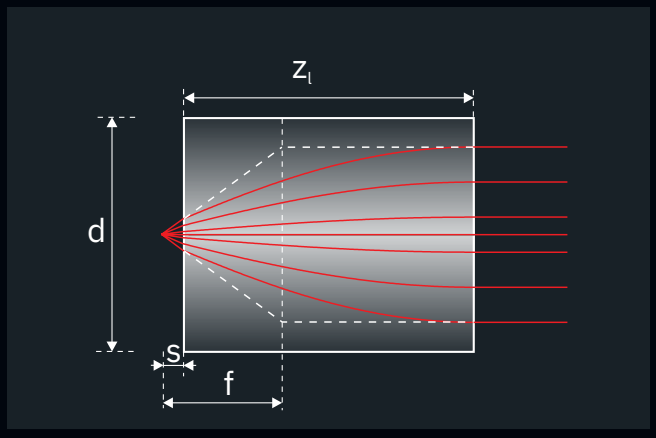
Various imaging designs can be realized using the same index profile by choosing different lens lengths:

A 1- (2, 3, or more, respectively)-pitch lens reproduces an object placed in the entrance surface of the lens identically into the exit surface.

A half-pitch lens images an object on the entrance surface inverted to the exit surface of the lens.

A quarter-pitch lens images a point source on the entrance surface of the lens into infinity or collimates it, respectively. This configuration is usually applied to the collimation of single-mode and multi-mode optical fibers and laser diodes.

A 0.23-pitch lens images a point source placed in the working distance s into infinity or collimates it.



GRIN rod lens

The geometrical gradient constant g and the lens length z_l determine the focal length f and the working distance s of the lens,

$$f = \frac{1}{n_0 g \sin(g z_l)} \quad , \quad s = \frac{1}{n_0 g \tan(g z_l)}$$

Various imaging problems can be solved by choosing different lens lengths z_l.

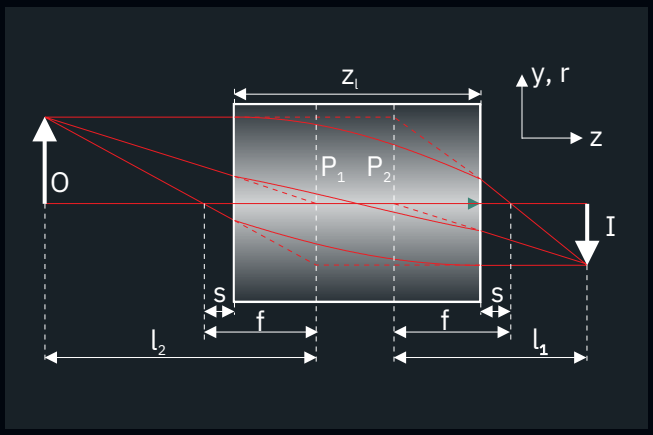


Image formation by a GRIN focusing lens

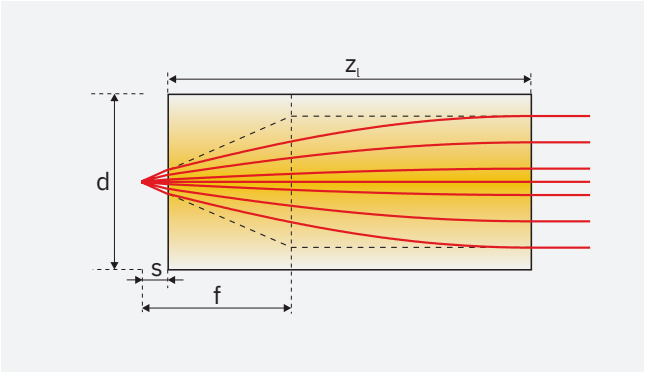
The maximum acceptance angle of a GRIN collimating lens ϑ is determined by the numerical aperture NA. As in fiber optics, it is derived from the maximum index change of the GRIN profile,

$$\sin(\vartheta) = NA = \sqrt{n_0^2 - n_R^2} = n_0 \sqrt{1 - \operatorname{sech}^2(gd/2)} \ .$$

n_R is the refractive index at the margin of the profile, and d is the lens diameter or the lens thickness, respectively.

GRIN lenses with a high numerical aperture (NA ≈ 0.5) are produced by silver ion exchange in a special glass which avoids any coloration in the visible spectral range. The absorption edge of the silver containing glass occurs at a wavelength of $\lambda_{0.5}$ = 370 nm. GRIN lenses with low numerical aperture (NA ≤ 0.2) are fabricated via lithium ion exchange. The absorption edge of the glass being used is at a wavelength of $\lambda_{0.5}$ = 235 nm.

GRIN Rod Lenses – Numerical Aperture 0.5



Gradient index lenses for fiber coupling and beam shaping of laser diodes

- Working distance, design wavelength and lens length deviating from these standards are available on request
- 8° angled facet / other diameters (0.25 mm, 0.35 mm, 0.60 mm and 0.85 mm) are available on request
- ZEMAX files can be downloaded from our website

Diameter d (mm)	**Pitch** P	**Working distance** s (mm)	**Lens length** z_l (mm)	**Focal length** f (mm)	**Gradient constant** g (mm^{-1})	**Refractive index at the center of the profile** n_0	**Wavelength** λ (nm)	**Product code**
0.50	0.25	0	1.10	0.43	1.427	1.629	670	GT-LFRL-050-025-50-NC (670)
	0.25	0	1.11	0.44	1.418	1.624	810	GT-LFRL-050-025-50-NC (810)
	0.25	0	1.12	0.44	1.406	1.616	1550	GT-LFRL-050-025-50-NC (1550)
	0.23	0.06	1.00	0.44	1.427–1.406*	1.629–1.616*	670–1550	GT-LFRL-050-023-50-NC
1.00	0.25	0	2.26	0.89	0.695	1.629	670	GT-LFRL-100-025-50-NC (670)
	0.25	0	2.27	0.89	0.691	1.624	810	GT-LFRL-100-025-50-NC (810)
	0.25	0	2.29	0.91	0.685	1.616	1550	GT-LFRL-100-025-50-NC (1550)
	0.23	0.12–0.11*	2.07	0.90	0.695–0.685*	1.629–1.616*	670–1550	GT-LFRL-100-023-50-NC
1.80	0.25	0	4.34	1.70	0.362	1.629	670	GT-LFRL-180-025-50-NC (670)
	0.25	0	4.36	1.72	0.360	1.624	810	GT-LFRL-180-025-50-NC (810)
	0.25	0	4.40	1.74	0.357	1.616	1550	GT-LFRL-180-025-50-NC (1550)
	0.23	0.25–0.21*	3.98	1.74	0.362–0.357*	1.629–1.616*	670–1550	GT-LFRL-180-023-50-NC
2.00	0.25	0	4.92	1.93	0.319	1.629	670	GT-LFRL-200-025-50-NC (670)
	0.25	0	4.95	1.94	0.317	1.624	810	GT-LFRL-200-025-50-NC (810)
	0.25	0	4.99	1.97	0.314	1.616	1550	GT-LFRL-200-025-50-NC (1550)
	0.23	0.27–0.23*	4.53	1.96	0.319–0,314*	1.629–1.616*	670–1550	GT-LFRL-200-023-50-NC

* depending on wavelength

As standard, GRIN rod lenses are provided without antireflection (AR) coatings. However, AR coatings can be offered as described at the end of this brochure. Please find here also further important information on tolerances, handling, and cleaning.

GRIN Rod Lenses – Numerical Aperture 0.2

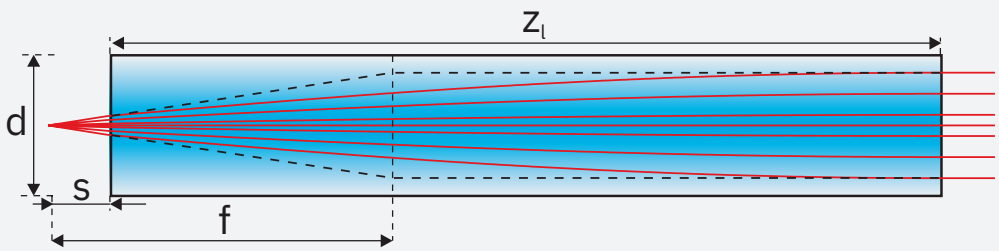
Gradient index lenses for fiber coupling and beam shaping of laser diodes with 0.2 NA. Two types of these lenses are offered: The **Standard LFRL**-type with first-order correction of spherical aberration is recommended for multimode beam applications. The **High-performance CFRL**-type with higher-oder correction of spherical aberration is recommended for singlemode Gaussian beam applications ($M^2 \leq 1.1$).

- Working distance, design wavelength and lens length deviating from these standards are available on request
- Other diameters (0.25 mm and 0.35 mm) are available on request
- ZEMAX files can be downloaded from our website

Standard LFRL lenses – recommended for multimode applications

Diameter d (mm)	**Pitch** P	**Working distance** s (mm)	**Numerical Aperture** NA	**Lens length** z_l (mm)	**Focal length** f (mm)	**Gradient constant** g (mm^{-1})	**Refractive index at the center of the profile** n_0	**Wavelength** λ (nm)	**Product code**
0.50	0.25	0	0.20	3.05	1.28	0.515	1.524	670	GT-LFRL-050-025-20-NC (670)
	0.25	0	0.20	3.06	1.28	0.513	1.521	810	GT-LFRL-050-025-20-NC (810)
	0.25	0	0.19	3.16	1.32	0.497	1.515	1550	GT-LFRL-050-025-20-NC (1550)
	0.24	0.09 – 0.07*	0.19	3.06	1.33	0.515 – 0.497*	1.524 – 1.515*	670 – 1550	GT-LFRL-050-024-20-NC
1.00	0.25	0	0.20	6.12	2.56	0.260	1.524	670	GT-LFRL-100-025-20-NC (670)
	0.25	0	0.20	6.13	2.57	0.259	1.521	810	GT-LFRL-100-025-20-NC (810)
	0.25	0	0.19	6.32	2.65	0.248	1.515	1550	GT-LFRL-100-025-20-NC (1550)
	0.24	0.18 – 0.16*	0.19	6.08	2.68	0.260 – 0.248*	1.524 – 1.515*	670 – 1550	GT-LFRL-100-024-20-NC
1.80	0.25	0	0.20	11.15	4.66	0.141	1.524	670	GT-LFRL-180-025-20-NC (670)
	0.25	0	0.20	11.17	4.68	0.140	1.521	810	GT-LFRL-180-025-20-NC (810)
	0.25	0	0.19	11.38	4.78	0.138	1.515	1550	GT-LFRL-180-025-20-NC (1550)
	0.24	0.31 – 0.26*	0.19	10.99	4.79	0.141 – 0.138*	1.524 – 1.515*	670 – 1550	GT-LFRL-180-024-20-NC

* depending on wavelength



First order parameters of a GRIN lens with 0.2 NA: diameter, working distance, focal length, lens length.

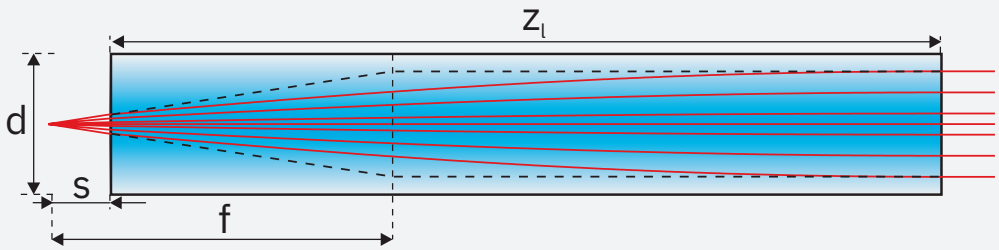
GRIN Rod lenses – Numerical Aperture 0.2

High-performance CFRL lenses – recommended for singlemode applications

Diam-eter d (mm)	**Pitch** P	**Working distance** s (mm)	**Numerical Aperture** NA	**Lens length** z_l (mm)	**Focal length** f (mm)	**Gradient constant** g (mm^{-1})	**Refractive index at the center of the profile** n_0	**Wave-length** λ (nm)	**Product code**
1.00	0.25	0	0.20	6.04	2.52	0.260	1.524	670	GT-CFRL-100-025-20-NC (670)
	0.25	0	0.20	6.05	2.53	0.259	1.521	810	GT-CFRL-100-025-20-NC (810)
	0.25	0	0.19	6.32	2.65	0.248	1.515	1550	GT-CFRL-100-025-20-NC (1550)
	0.24	0.18–0.16*	0.19	6.08	2.66	0.260–0.258*	1.524–1.515*	670–1550	GT-CFRL-100-024-20-NC (1550)
1.80	0.25	0	0.19	11.06	4.62	0.141	1.524	670	GT-CFRL-180-025-20-NC (670)
	0.25	0	0.19	11.08	4.64	0.140	1.521	810	GT-CFRL-180-025-20-NC (810)
	0.25	0	0.19	11.38	4.78	0.138	1.515	1550	GT-CFRL-180-025-20-NC (1550)
	0.24	0.31–0.26*	0.19	10.99	4.79	0.141–0.138*	1.524–1.515*	670–1550	GT-CFRL-180-024-20-NC (1550)

* depending on wavelength

As standard, GRIN rod lenses are provided without antireflection (AR) coatings. However, AR coatings can be offered as described at the end of this brochure. Please find here also further important information on tolerances, handling, and cleaning.

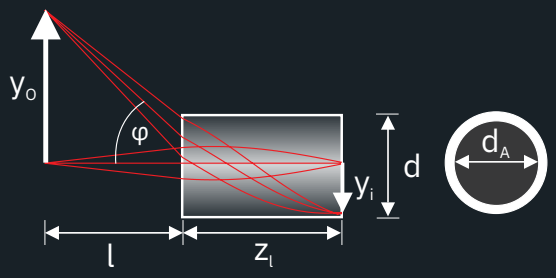


First order parameters of a GRIN lens with 0.2 NA: diameter, working distance, focal length, lens length.

Gradient Index Imaging Optics – An Introduction

Types and Properties

- GRIN rod lenses and systems
- Endoscopic and other miniaturized imaging applications
- Easy to assemble due to the plane surfaces
- Good off- and on-axis performance
- AR-coating on both sides possible
- Non-toxic silver and lithium ion exchange
- Low chromatic aberration



GRIN Objective Design

GRINTECH objective lenses are produced by non-toxic silver ion exchange in glass and are suited for medical applications. The large view angle of 60 degrees (± 30°) is obtained by a strong index change within the glass material. The objective lenses image the object plane in a working distance l into the end surface of the lens on a reduced scale.

The lenses are specified by the rod diameter d and the working distance l (see the respective data sheet). The corresponding magnification M and the necessary lens length zl are calculated by

$$M=\sqrt{\frac{1}{n_0^2 g^2 l^2+1}} \quad ; \quad z_l=\frac{\arctan(-n_0 l g)+\pi}{g} \quad ,$$

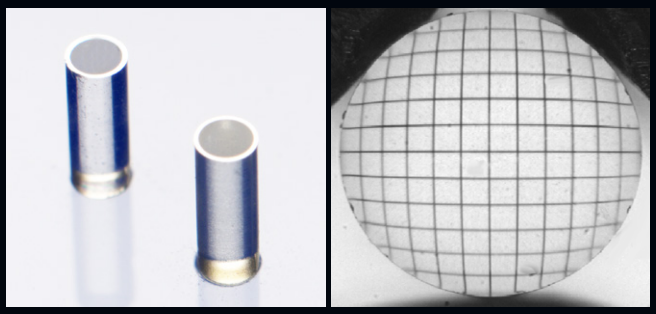
where n_0 is the center index of the lens, and g is the gradient constant of the lens. For each diameter, g can be calculated by using the lens length of the respective lens type with infinite working distance,

$$g=\frac{1}{2z_l^{inf}} \quad .$$

Beside standard working distances, customized lens designs can be provided on request.

The dispersion of the index gradient causes a relative change of the focal length as function of the wavelength. In the visible range, the focal length of lenses with NA of 0.5 increases by approx. 0.017 % per nm with rising wavelength. For objective lenses of 1.0 mm diameter, the image plane of the blue light part (440 nm) is located approx. 18 µm inside the lens. The image plane of the red light part (650 nm) is located approx. 18 µm outside the lens exit plane. For lenses of 0.5 mm diameter for example, half of this image shift values is valid.

GRINTECH objective lenses are characterized by a small field curvature. The image field is slightly bent inwards. For lenses of 1.0 mm diameter the field curvature is – 40 µm maximum at 90% of the aperture, for 0.5 mm diameter – 20 µm maximum.



The barrel shaped distortion of the image increases up to approx. 14% of the image height at the lens margin (see CCD-image above).

The resolution limit of the objective lenses is on-axis approx. 400 lines per mm in white light.

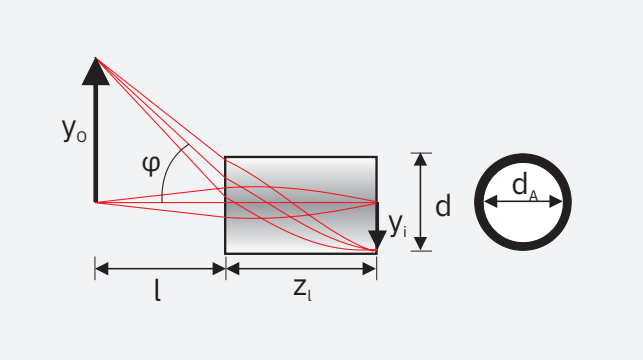
GRIN Imaging Systems

Complete imaging systems for endoscopes and other applications are fabricated by combining GRINTECH objective lenses, GRIN relay lenses of customized pitch lengths, and prisms. Please contact GRINTECH for customized solutions.

GRIN Objective Lenses for Endoscopy

Gradient index lenses for endoscopic imaging optics

- Non-toxic silver-based glass material
- View angle φ +/- 30° (numerical aperture 0.5)
- Plane surfaces, low chromatic aberration
- Combination with prisms and beam splitter cubes on request
- Aperture and field stops (black chromium coating ring on lens surface generated by photolithography) are available on request
- Certification: Biological safety – toxicology (EN ISO 10993-1)
- Design wavelength: 570 nm



Diameter d (mm)	**Working distance** s (mm)	**Lens length** z_l (mm)	**Parax. Magnification** $M = y_o/y_i$	**Refractive index at the center of the profile** n_0	**Product code**
2.0	Infinity	4.86	–	1.635	GT-IFRL-200-inf-50-NC
	20	5.14	-10.56	1.635	GT-IFRL-200-020-50-NC
	10	5.42	-5.35	1.635	GT-IFRL-200-010-50-NC
	5	5.94	-2.81	1.635	GT-IFRL-200-005-50-NC
1.8	Infinity	4.29	–	1.635	GT-IFRL-180-inf-50-NC
	20	4.51	-11.94	1.635	GT-IFRL-180-020-50-NC
	10	4.72	-6.04	1.635	GT-IFRL-180-010-50-NC
	5	5.14	-3.14	1.635	GT-IFRL-180-005-50-NC
1.0	Infinity	2.23	–	1.635	GT-IFRL-100-inf-50-NC
	20	2.29	-22.85	1.635	GT-IFRL-100-020-50-NC
	10	2.35	-11.46	1.635	GT-IFRL-100-010-50-NC
	5	2.47	-5.80	1.635	GT-IFRL-100-005-50-NC
0.85	Infinity	1.89	–	1.635	GT-IFRL-085-inf-50-NC
	10	1.96	-13.61	1.635	GT-IFRL-085-010-50-NC
	5	2.05	-6.86	1.635	GT-IFRL-085-005-50-NC
0.6	Infinity	1.31	–	1.635	GT-IFRL-060-inf-50-NC
	10	1.35	-19.47	1.635	GT-IFRL-060-010-50-NC
	5	1.39	-9.77	1.635	GT-IFRL-060-005-50-NC
0.5	Infinity	1.09	–	1.635	GT-IFRL-050-inf-50-NC
	10	1.12	-23.47	1.635	GT-IFRL-050-010-50-NC
	5	1.14	-11.77	1.635	GT-IFRL-050-005-50-NC
0.35	5	0.80	-16.67	1.635	GT-IFRL-035-005-50-NC
0.25	5	0.56	-23.16	1.635	GT-IFRL-025-005-50-NC

General Information & Customization

- Working distance and lens length deviating from these standards are available on request
- ZEMAX files can be downloaded from our website
- As standard, GRIN rod lenses are provided without antireflection (AR) coatings. However, AR coatings can be offered as described at the end of this brochure. Please find here also further important information on tolerances, handling, and cleaning.

Coating Options

GRIN rod lenses are produced without antireflection coatings as standard. Antireflection coatings (for incidence angles of 0°–30° corresponding to measurements on a reference substrate) can be offered:

Coating Code:

NC: no coating (reflection loss approx. 12%) – standard

C1: λ = 400 ... 700 nm, R < 1.0%

C2: λ = 800 ... 1000 nm, R < 0.5%

C5: λ = 1310 ... 1550 nm, R < 0.5%

One - sided coatings are available on request. Variations due to modifications of the production process are possible. It is the user's responsibility to determine suitability for the user's purpose.

If AR coating is needed, please replace in the product code NC by C1, C2 or C5.

Please note our partnership with Inscopix as our exclusive distributor for the field of neuroscience applications in non-humans. If you wish to order GRIN lenses of this brochure for these applications, please visit www.inscopix.com or contact order.inscopix@bruker.com.

Tolerances and Handling Instructions

For of our single lenses we have the following fabrication tolerances and quality criteria:

Tolerances

- Lens length z_l: ± 5% due to variations of the gradient constant
- Working distance s: ± 0.02 mm (only LFRL- and CFRL lens series)
- Diameter d: + 0 / -0.01 mm
- Tighter diameter tolerances on request

Surface quality

- 5 / 3 × 0.025; L 3 × 0.005; E 0 (defined by DIN ISO 10110-7:2000-02).
- The surface quality is defined within 90% of the lens diameter. Outside of this area defects are allowed.

Storage

GRIN lenses and lens systems should be stored in a dry environment. For short term storage, the plastic box or foam packing in which the lenses are shipped will provide adequate storage. Recommended storage temperature: -20°C – 80°C.

Storage boxes should ensure that the lenses do not touch each other to prevent chipping and scratches. Best is to use the original box.

Handling

Lenses should be carefully handled with plastic tweezers, preferably those with a tapered end. Lenses should be picked up out of their individual compartments by firmly holding each on its side cylinder surface (not the polished ends). Especially small sized lenses may stick to the lens box material and can be lost during removal.

Cleaning

If it is necessary to clean the lens surfaces due some dust or other contaminant which may impair the optical performance. GRINTECH generally recommends the use of ethyl alcohol as a cleaning solvent, maybe combined with some smooth lintfree lens cleaning tissue.

Acetone may also be used, but it should be pure enough, otherwise it might leave some residue on the lens surface.

GRINTECH

Gradient Index Optics

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