Gradient Index (GRIN) Lenses

- GRIN rod lenses for fiber coupling
- GRIN cylindrical lenses for beam shaping of high power laser diode bars and high brightness diodes
- easy to assemble due to the plane surfaces
- good off- and on-axis performance
- non-toxic silver and lithium ion exchange

Gradient Index Optics

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.

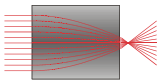
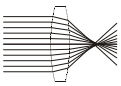


Fig. 1 GRIN lens



Conventional spherical lens

The GRIN lenses are produced by silver ion exchange in a special glass. The composition of the glass is protected by a patent. 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 slabs resulting in rod lenses and 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

$$z_{1\text{-}p} = \frac{2\pi}{g}$$

and does not depend on the entrance height and the entrance angle of the light ray (see Fig 2). n_0 represents the refractive index at the center of the profile, r the radius and g the gradient constant.

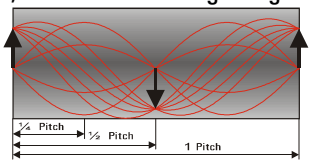


Fig. 2. Ray traces within a GRIN focussing lens of different pitch lengths

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 (see Fig. 3).

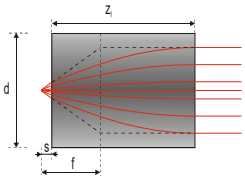


Fig. 3. GRIN rod lens

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

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

Various imaging problems can be solved by choosing different lens lengths z_l (see Fig.4).

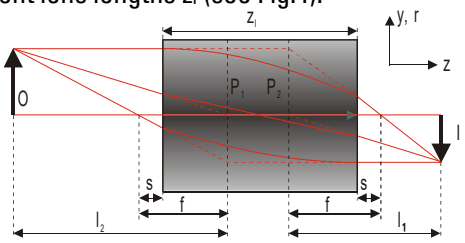


Fig. 4. Image formation by a GRIN focusing lens

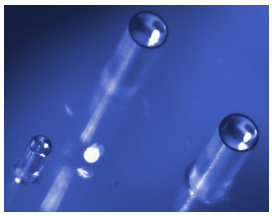
The maximum acceptance angle of a GRIN collimating lens ϑ is determined by the numerical aperture NA. As in fiber optics, it is derived from the maximum index change of the GRIN profile,

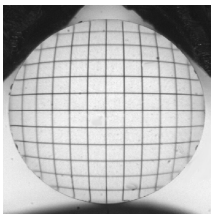
$$\sin(\vartheta) = NA = \sqrt{n_0^2 - n_R^2} = n_0 \sqrt{1 - \operatorname{sech}^2(gd/2)}\,.$$

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.

Gradient Index Imaging Optics

- 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 (see Fig. 1) into the end surface of the lens on a reduced scale.

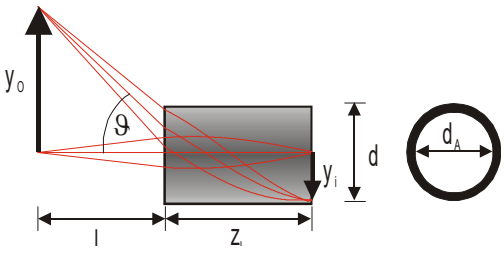


Fig. 1 Image formation by a GRIN objective lens

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 z_l are calculated by

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

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,

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

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 these 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.