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.

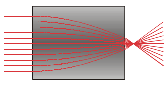
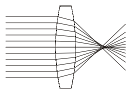


Fig. 1 GRIN lens



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

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

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.

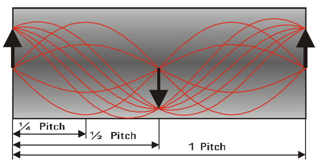


Fig. 2. Ray traces within a GRIN focussing lens of different pitch lengths

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. For high-power laser diodes, GRIN cylindrical lenses are used for the Fast-Axis-Collimation.
A 0.23-pitch lens images a point source placed in the working distance s into infinity or collimates it (see Fig. 3).

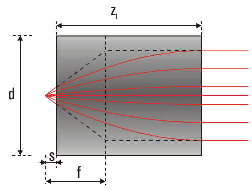


Fig. 3. GRIN rod lens

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).

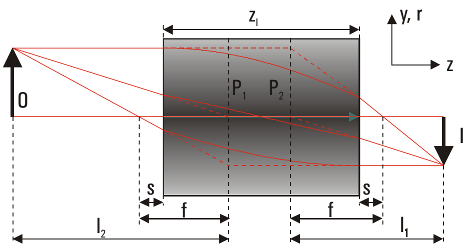


Fig. 4. Image formation by a GRIN focusing lens

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 $\approx$ 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 $\leq$ 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.

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