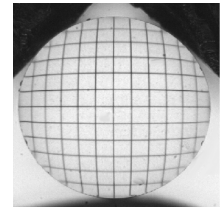
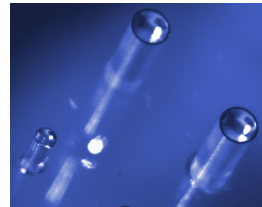


## Gradient Index Imaging Optics

- 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 ( $\pm 30^\circ$ ) 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.

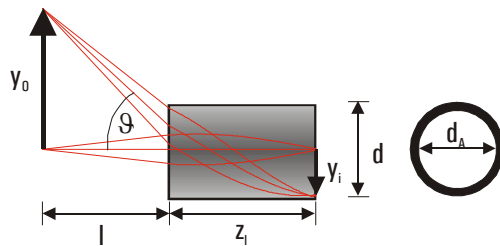


Fig. 1 Image formation by a GRIN objective lens

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  $z_1$  are calculated by

$$M = \sqrt{\frac{1}{n_0^2 g^2 l^2 + 1}} ; z_1 = \frac{\arctan(-n_0 l g) + \pi}{g},$$

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,

$$g = \frac{\pi}{2z_1^{\text{inf}}}.$$

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  $\mu\text{m}$  inside the lens. The image plane of the red light part (650 nm) is located approx. 18  $\mu\text{m}$  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  $-40 \mu\text{m}$  maximum at 90 % of the aperture, for 0.5 mm diameter  $-20 \mu\text{m}$  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.