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Fabrication of Gradient-Index Lens by Ion-Exchange in Glass

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Abstract

GRIN lenses have been fabricated using $Ag^+ <--> Na^+$ ion-exchange in glass. The fabrication process and characterization of GRIN lenses are discussed. The refractive index profile was studied on the Mach-Zehnder interferometer and the results are presented.

Key words: Gradient-Index lens, ion-exchange, optical fabrication

Introduction

Gradient-index materials have variety of applications in optical imaging and fibre optic systems (Houde-Walter 1988; Moore 1980). GRIN elements have been used in camera lenses and binocular objectives to achieve better aberration correction with fewer lens elements. GRIN rod lenses of 1-3 mm diameter are used for coupling light from source to the fibre, fibre to fibre, etc. (Tomlinson 1980).

Ion-exchange in glass is the most widely used technique for fabrication of GRIN rod lenses (Houde-Walter 1988). It requires simple instrumentation and is easier to control. In this technique, monovalent ions in glass are exchanged with monovalent ions from a salt melt to obtain the desired refractive index profile in the glass rod. The reaction can be expressed in general as:

$$(A^+)_{glass} + (B^+)_{melt} <--> (B^+)_{glass} + (A^+)_{melt}$$

The ion-exchange process is governed by the Fick's laws of diffusion (Frischat 1975). It is given below for the one dimensional case:

$$J = -D\frac{\partial C}{\partial x} \tag{1}$$

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}\left[D\frac{\partial C}{\partial x}\right] = D\frac{\partial^2 C}{\partial x^2} \tag{2}$$

where J is flux of ions through unit area in unit time, C is the concentration of the ions, D is the diffusion coefficient and x is co-ordinate in the direction of diffusion.

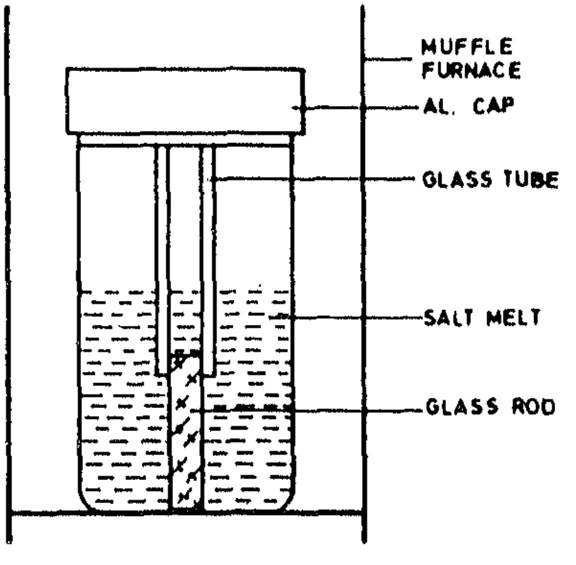

Figure 1. Experimental arrangement.

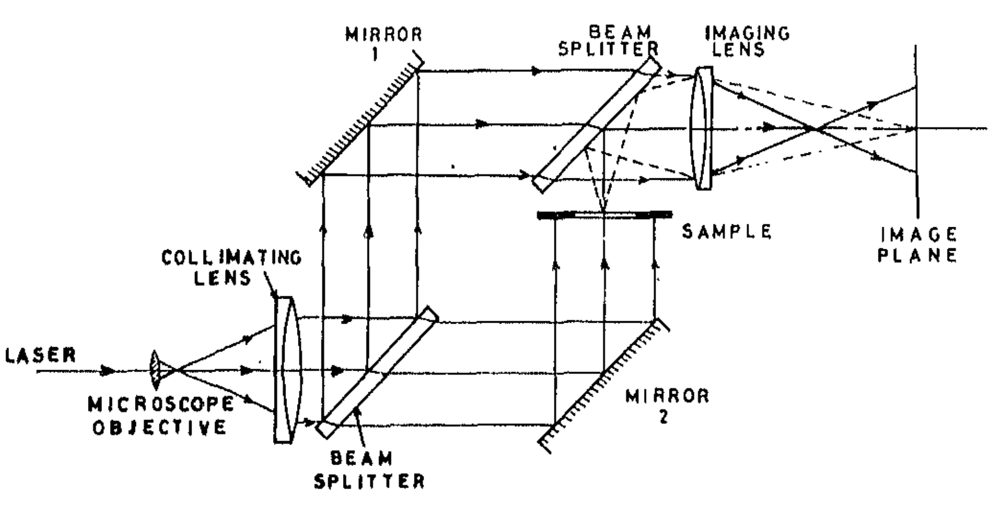

Figure 2. Mach-Zehnder interferometer for testing grin samples.

Experiment

Cylindrical rods of diameter 4.5 mm were made from HC 517606 glass. The rods were ground and then polished on all surfaces. They were immersed in a molten eutetic mixture of $AgCl$ and $ZnCl_2$ (57 mol % of $ZnCl_2$). The experimental arrangement is as shown in Fig.1. One rod was kept in the melt at 500^o C and the other at 520^0 C for 248 hours each. They were then cleansed and cut into pieces of 4 mm in length and their faces ground and polished to better than $\lambda/4$ surface accuracy. The refractive index profile in these rods was observed on the Mach-Zehnder interferometer as shown in Fig.2. In order to observe the effect of annealing on refractive index profile, one piece annealed at 520^o for 248 hours was studied in the interferometer.

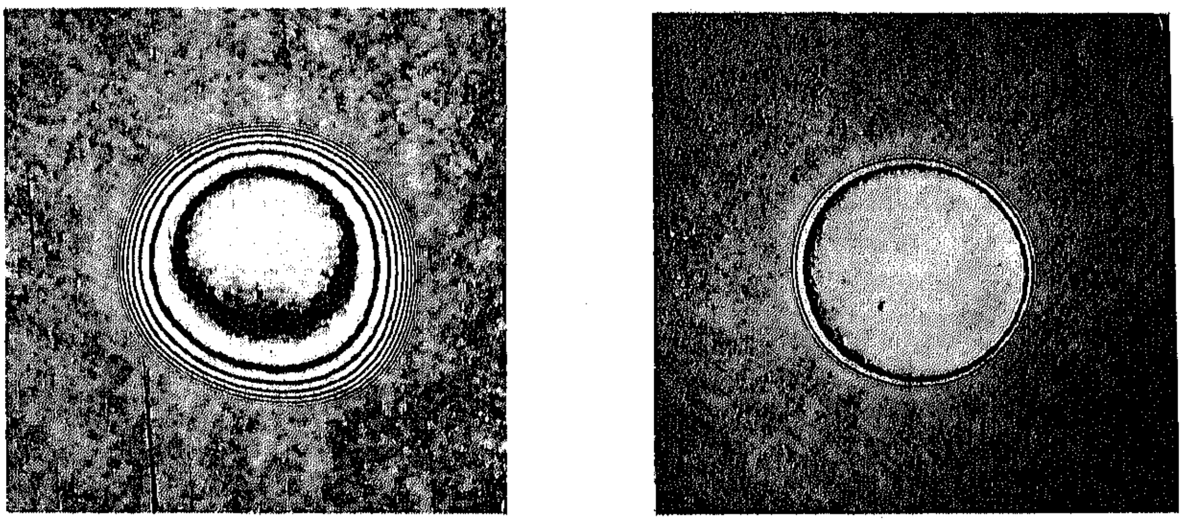

Figure 3. (a) Fringe pattern obtained after ion-exchange at 520^0C for 248 hours (GRIN rod No. 1). (b). Fringe pattern obtained after ion-exchange at 500^0C for 248 hours (GRIN rod No. 2).

Results

After the diffusion, the glass rods retained the shape but the surface of the rod kept at 520^o C deteriorated significantly. This reduced its efective diameter to 3.2 mm. The rod kept at 500^o C had little surface deterioration but the diffusion depth achieved in it was small as seen in Figs 3(a) and 3(b). The change in refractive index $\Delta\mu$ which corresponds to n fringes is given by

$$\Delta\mu = (\mu - \mu_0) = \frac{n\lambda}{l} \tag{3}$$

where $\mu_0 = 1.517610$ is the refractive index of the base glass. $\lambda = 0.633$ μm is the wavelength of the Helium-Neon Laser and l is the thickness of the slice of GRIN rod being observed on the interferometer. The variation of refractive index in the radial direction in these rods is shown in Figs 4(a) and 4(b).

Annealing of glass was found to flatten the refractive index gradient.

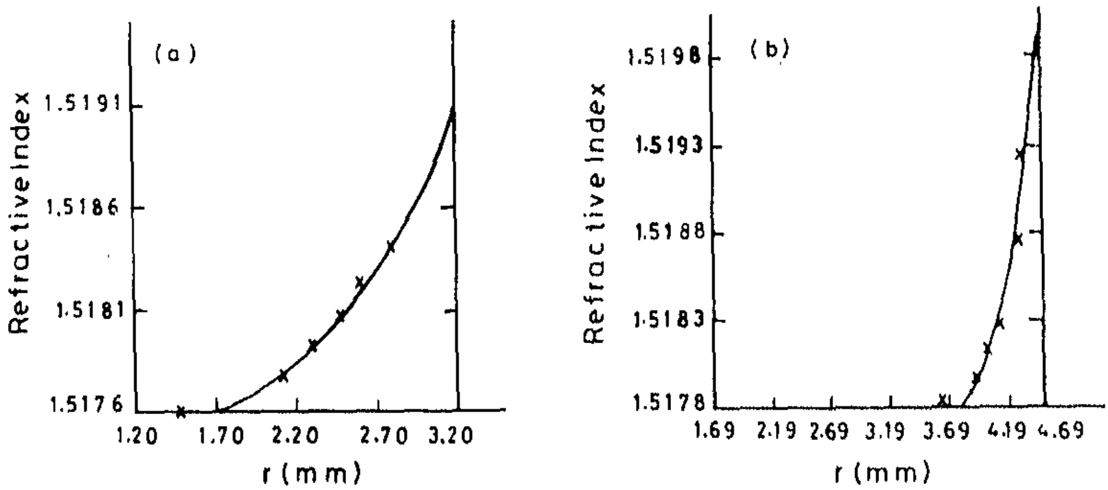

Figure 4. (a) Refractive index profile for GRIN rod No. 1. (b) Refractive index profile for GRIN rod No. 2.

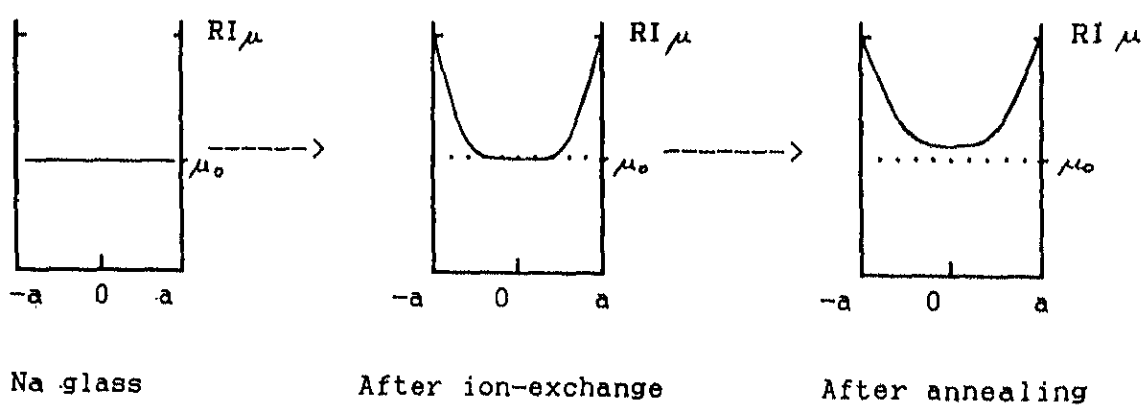

Figure 5. Refractive index profiles at various stages.

Discussion

The process is schematically depicted in Fig. 5. as the Na^+ ions from glass exchange with the Ag^+ ions from the salt melt. After ion-exchange the concentration of Ag^+ near the surface of the rod is higher hence the refractive index there is higher.

HC 517606 was chosen for the experiment because it has a relatively higher Na_2O content. Its composition by weight is: SiO_2 68%, Na_2O 13%, K_2O 5%, BaO 10%.

$AgCl$ salt is diluted with $ZnCl_2$ to make melt more economical. $ZnCl_2$ also reduces the effect of poisoning of the melt by the outdiffused Na^+ ions (Houde-Walter 1987).

The GRIN rod lenses to be used in fibre-optic systems require a refractive index profile given approximately by:

$$\mu^2(r) = \mu_0^2[1 - g^2 r^2] \tag{5}$$

where μ is the refractive index at r, μ_0 is the refractive index at the centre and g is a constant. This type of profile can be generated by first stuffing the glass with Ag^+ ions and then destuffing it to reduce the concentration of Ag^+ near the surface (Ohmi et al. 1988).

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