Mechanical stresses in rare-earth doped fiber preforms

Florian Just, Hans-Rainer-Müller, Hartmut Bartelt
Institute of Photonic Technology Jena
mailto:florian.just@ipht-jena.de

Mechanical stresses depending on doping differences in the glass material of preforms for active optical fibers are determined. Changes in the refractive index induced in this manner are calculated and the thermal expansion coefficient of Yb-doped fused silica is estimated for the first time.

1 Introduction

Mechanical stresses can significantly influence the optical and mechanical properties of fibers. Here, we present a nondestructive measurement method for doping related stresses in active optical fiber preforms.

Besides the estimation of stress induced index changes, that are relevant for the propagation of light in optical fibers, the thermal expansion coefficient of Yb-doped fused silica could be evaluated to the best of our knowledge for the first time. These results are of practical importance especially for so called "large-mode-area" fibers with very low index contrasts.

2 Measuring system

In a fully automated method [1, 2] (setup see Fig. 1) we measure the phase shift δ of the sample. This is caused by the birefringence between the light polarized in the y- and z-direction and is determined by compensating it using different phase influencing elements (LC-R, $\lambda/4$ & Pol). A high spatial resolution of about 10 µm is obtained.

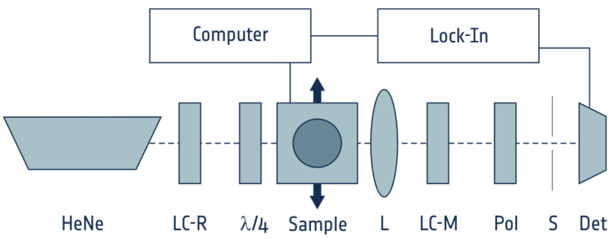

Fig. 1 *Illustration of the optical arrangement for the measurement of the stress induced phase shift.*

3 Data analysis

It is possible to calculate the component s_z of the mechanical stress from the profile of the phase shift in the preform by applying an Abel-like integral transformation.

$$s_z(r) = \frac{\lambda}{2(B_1 - B_2)\pi^2} \int_r^R dy \frac{d\delta/dy}{\sqrt{y^2 - r^2}} \qquad (1)$$

This transformation is based on the cylindrical symmetry of the preform. The $\mathrm{B}_1\,(= 4.2 \cdot 10^{-6}\,\mathrm{MPa}^{-1})$ and $\mathrm{B}_2\,(= 6.5 \cdot 10^{-7}\,\mathrm{MPa}^{-1})$ are the elasto-optic constants [3].

Using other relations for residual stresses [1] it is possible to calculate the other components of the mechanical stresses and the resultant induced index changes for light polarized along the coordinates axes of the preform (used coordinate system see Fig. 2).

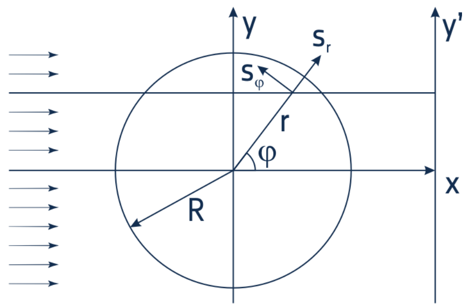

Fig. 2 *Definition of the used coordinate system;* s_r, s_φ *- stress components.*

4 Results and Discussion

We made measurements on a series of preforms of the same type and dimensions, but with different Yb_2O_3-concentrations in the core (Fig. 3).

Using the linear correlation between the maximum mechanical stress in the core and the Yb-content (Fig. 4), we were able to estimate the relation between the thermal expansion coefficient of silica glass and the Yb_2O_3 doping concentration. The result is a much higher dependancy on the concentration $(\beta_{\mathrm{Yb}} = \mathrm{d}\alpha/\mathrm{dc}_{\mathrm{Yb}} = 4.1 \cdot 10^{-7}\mathrm{K}^{-1}\mathrm{mol\%}^{-1})$ than for other common dopants in lightwave technology like phosphorus $(\beta_{\mathrm{P}} = 1.51 \cdot 10^{-7}\mathrm{K}^{-1}\mathrm{mol\%}^{-1})$ or aluminum $(\beta_{\mathrm{Al}} = 0.53 \cdot 10^{-7}\mathrm{K}^{-1}\mathrm{mol\%}^{-1})$ [4].

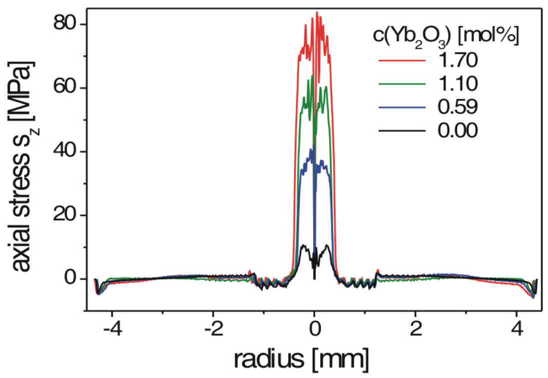

Fig. 3 *Axial stress component s_z of four samples with different Yb_2O_3-doping.*

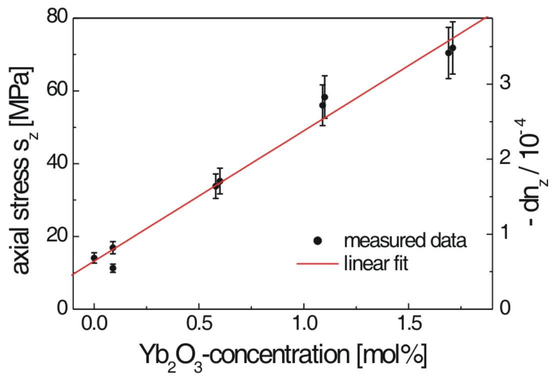

Fig. 4 *Maximum mechanical stress in the core for different Yb_2O_3-concentrations.*

By calculating the induced index change for radial polarized light, which is an important parameter to evaluate the guiding properties for light propagating along the fiber axis, we found that the change is even higher than for the axial index.

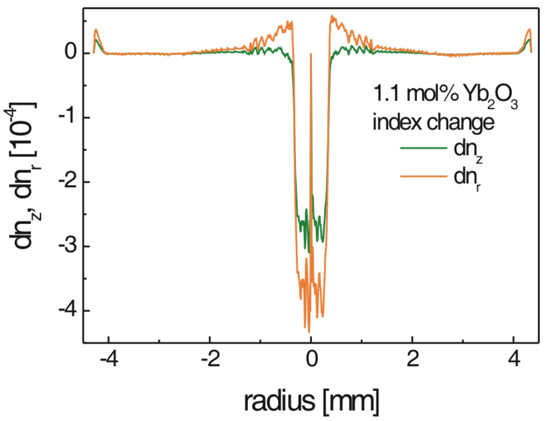

Fig. 5 *Calculated radial index shift dn_r in comparison to the axial dn_z.*

So the stress induced change in the refractive index is a parameter that has to be considered carefully, especially when the differences in the index between the core and cladding are quite small like for example in "'large mode area"' fibers [5].

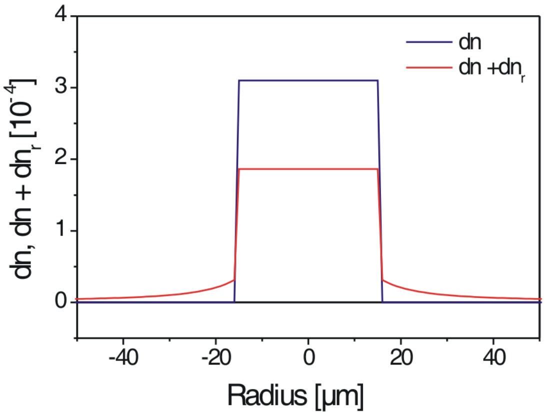

Fig. 6 *Step index profile with an NA of 0.03 (blue line) and the calculated stress changed index profile (red line)*

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