Anomaly of Thermal Stresses in Aluminum and Phosphorus Codoped Active Optical Fiber Preforms

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

We report on measurements of intrinsic stress in preforms for high-power fiber-lasers to investigate material properties. In contrast to simple stress models we found no additive superposition concerning the generated stress by doping the core with aluminum and phosphorus. This is also in agreement with measurements of the refractive index profile, which also shows no additive properties.

1 Introduction

It is well known that thermal stress influences the properties of optical fibers. This stress is caused by variations of the thermal expansion coefficient of the differently doped regions in the fiber, like core and cladding. Simple stress models assume an additive superposition of thermal stress for each dopant in multiple doped glasses. In these simple models both aluminum and phosphorus cause an increase in the thermal expansion coefficient. That means that samples doped with one of these elements in the core develop tensile stress in the core against the fused silica cladding after cooling down to room temperature during the fabrication process.

We used a non-destructive polarimetric measurement method to investigate the mechanical stress properties of fiber preforms. In this method, the measured stress induced birefringence is used to calculate the thermal stress in the samples [1].

2 Experiments

The active optical fiber preform samples were prepared by a combination of MCVD and solution doping technique. In this process codoping with aluminum or phosphorus increases the solubility of ytterbium in the SiO_2 glass matrix. Using a combined codoping with Al and P it is possible to realize Yb doped laser fibers with a high laser efficiency, a low numerical aperture and low photodarkening [2].

To investigate the influence of such an Al and P codoping on the stress properties a series of preforms with nearly constant Yb and Al and variation of P content was prepared (Tab. 1). The active core is surrounded by five slightly phosphorous doped cladding layers. Fig. 1 shows the radial doping profile of Yb, Al and P of sample #P1. The radial P doping profiles of the series are shown in Fig. 2.

sample	#P1	#P2	#P3	#P4
$c(Yb_2O_3)$ [mol%]	0.47	0.46	0.45	0.43
$c(Al_2O_3)$ [mol%]	4.7	4.6	4.5	4.3
$c(P_2O_5)$ [mol%]	0.5	1.4	2.0	4.3

Tab. 1 *Yb, Al, P content of different investigated samples.*

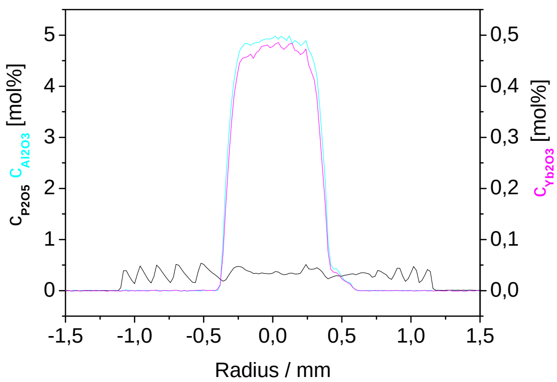

Fig. 1 *Radial profile of the dopant concentration (Al, P, Yb) of sample #P1.*

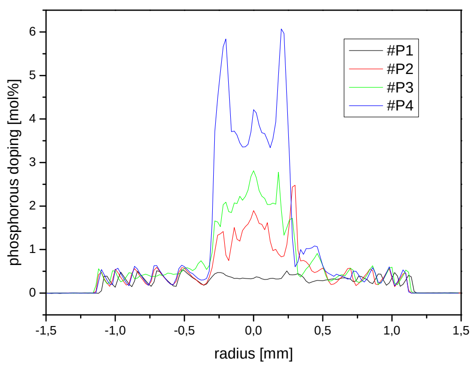

Fig. 2 *Radial P doping profile of different samples.*

3 Results

First we discuss the refractive index profiles of the samples (Fig. 3). In the graph one can clearly see a decrease in the refractive index of the core by adding phosphorus. That means that there is no additivity of the indices for combined doping with aluminum and phosphorus [2].

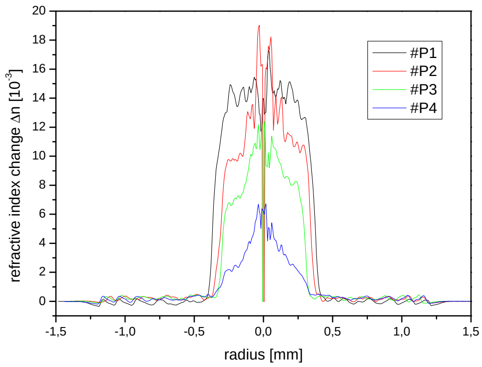

Fig. 3 *Radial profiles of the refractive index of different samples.*

Additionally, we compare the axial stress profiles of the preforms (Fig. 4). In the graph one can clearly see the differently doped areas in the preform like the core, the cladding layers and the fused silica cladding. We find that the core is under tensile stress against the slightly phosphorus doped cladding layers, which are under compressive stress. On the surface of the samples we find another area of compressive stress that is caused by OH impurities resulting from OH diffusion during the deposition and collapsing process with an O_2/H_2-Burner.

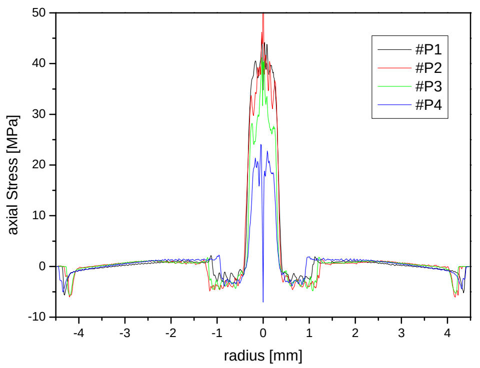

Fig. 4 *Axial stress profile of differnt samples.*

Again, one can see a decrease of the axial stress in the core by raising the phosphorus content toward the amount of aluminum. It can be observed that also for axial stress the effects of different dopants are not combined additively. That means that doping with either aluminum or phosphorus increases the coefficient of thermal expansion, but combining both dopants leads to a thermal expansion coefficient that is closer to the value of fused silica than expected from an additive model.

4 Conclusion

We found that adding phosphorus to an aluminum doped core leads to decreasing intrinsic stress in the glass material. The thermal expansion coefficient of the aluminum doped core changes toward the fused silica level by adding phosphorus. This is in contrast to simple stress models where an additive correlation of the thermal expansion coefficient for several dopants is assumed. This gives us the possibility to generate highly doped samples with very low thermal stress.

5 Acknowledgment

This work was supported by the German Federal Ministry of Education and Research (BMBF) under the contract 13N9555.

References

[1] F. Just, H.-R. Müller, S. Unger, J. Kirchhof, V. Reichel, H. Bartelt, "Ytterbium-Doping related Stresses in Preforms for High-Power Fiber-Lasers," in *IEEE Journal of Lightwave Technology* **27**(12), 2111 (2009).

[2] S. Jetschke, S. Unger, A. Schwuchow, M. Leich, J. Kirchhof, "Efficient Yb laser fibers with low photodarkening by optimization of the core composition," in *Optics Express* **16**, 15540 (2008).