Analysis of residual thermal stress in an aluminosilicate core and silica cladding optical fiber preform

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1. Introduction

As silica based optical fibers and preforms are processed at a high temperature, residual stresses are bulit in the strucure when cooled down to the room temperature. The magnitude of the residual stress depends on the difference in the thermal expansion coefficients between core and cladding glass as well as on the temperature difference. Residual stress distribution determines the intrinsic strength and could affect the long term reliability of optical fibers. And furthermore, stress can introduces anisotropy into optical fibers by photoelastic effects. The analysis of thermal stress has been intensively studied for multimode fibers[1]and the authors and co-wokers recently reported the stress distribution in a depressed inner cladding structure[2]. The compositions of the glass in the previous studies, however, have been restricted to conventional glass formers, such as GeO2, B2O3, P2O5, Fluorine.

Since the development of erbium doped fiber amplifier, various glass host material have been studied to improve gain characteristics. Among the glass compositions, high Al_2O_3 concentration, more than 10 mole %, was found to be beneficial for a wide band gain. Thermal stress distribution in an erbium doped aluminosilicate glass fiber is mainly determined by the characteristics of aluminosilicate glass due to very low concentration of Er ions in the order of few hundred ppm. Nevertheless detailed information of stress distribution of thermal stress in a high Al_2O_3 concentration silica optical fibers has not been available, which will affect the strength and reliability of rare earth doped amplifiers and fiber lasers.In this letter we report, for the first time to the best knowledge of authors, thorough analysis of thermal stress distribution in a silica optical preform whose core is doped with Al_2O_3.

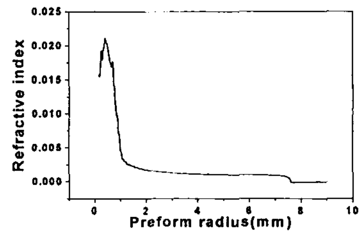
2. Measurement of refractive index and stress profiles

The optical fiber preform with the silica core with a high Al_2O_3 concentration were made using modified chemical vapor deposition (MCVD) process along with a vapor halide delivery technique[3]. The refractive index profile of the preform is shown in Figure 1. The index of the core was raised by doping only Al_2O_3 and the refractive index difference was 0.02, which is comparable to those of commercially available erbium doped fibers used in optical amplifiers. The core and the cladding radii of the preform were 1 mm and 7.8 mm, respectively. The aluminum concentration in the core was estimated as 13 mole % using the previously reported mole fraction versus refractive index relation[4].

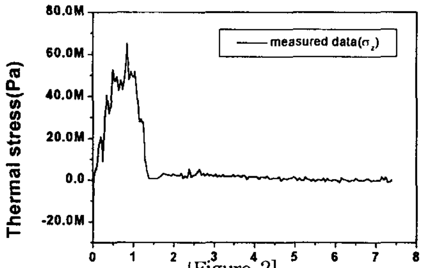
The axial thermal stress in the preform was measured using a modified plane polariscope and the set-up was described in detail elsewhere[2]. Resolutions in the measurement of the rotation angle and the linear position step were 0.008 and is 50 m, respectively. A second order polynomial is fitted to the data by least square method. The measured profile is shown in Figure 2. Note that the peak value of stress of the preform is about 50 Mpa which is significantly less than that of a preform with GeO2 doped core, ~100 MPa of a similar refractive index difference.

3. Analysis of thermal stress based on measured axial stress

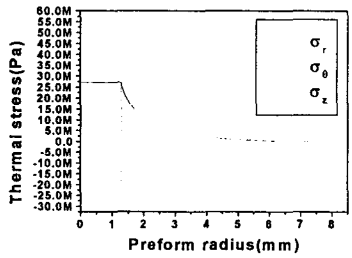
The residual stresses in an optical fiber preform with an axially symmetric dopant concentration can be written as(5),thermal expansion coefficient coefficients of the core glass was estimated to minimize the difference between the measurement and calculation. The thermal expansion coefficient was estimated as $11.4\times10^{-7}C$ which showed an excellent agreement with the value estimated from the relation between the mole fraction and thermal expansion coefficient(6). From the estimated thermal expansion coefficient, radial and circumferential stress profiles were calculated using the above formulae. The results of simulation are shown in the Figure 3. Notice the compressive and tensile stress built at the core-cladding interface for the circumferential and radial components, respectively.



[Figure 1]



[Figure 2]



[Figure 3]

Conclusion.

Using an automated modified plane polariscope, the axial thermal stress of 50 MPa in an optical fiber preform whose core is heavily doped with Al2O3 was measured. The magnitude of the stress in the Al2O3 doped core was found to be significantly less than that of GeO2 doped core with the comparable refractive index difference of 0.02. Lower stress in the preform strongly indicates that Al2O3 glass hosts could be of benefit in the long term reliability in optical amplifiers and lasers. We also demonstrated an optical technique to estimate the thermal expansion coefficient of core glass using refractive index and stress profile measurement, which showed a good agreement with previously reported data.

Reference

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