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PD2.1

Growth Characteristics of Fiber Gratings

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The physical mechanism responsible for UV-induced index of refraction change in the core of optical fiber is not well understood. We have conducted a series of measurements to characterize this effect for continuous-wave (cw) UV exposure and contrast these results with those for pulsed UV exposure. We have measured the growth rate of Bragg gratings in germanium-doped, germanium-boron-codoped, and hydrogen-loaded optical fiber. The measurements were made by observing the grating reflectance at various times during exposure to cw 244 nm light. We have also measured the change in blue fluorescence during exposure to UV light for these same fibers. Finally, we measured the effect of annealing the gratings at a variety of temperatures and compared this behavior for the different fiber types. We compare our measurements with the predictions of competing theories of the origin of photoinduced refractive index change.

A simple model of grating growth arising from the depletion of a homogeneously broadened defect population by one-photon absorption does not explain the time and intensity dependence we observe.[1] That model predicts an exponential growth of the index to a maximum value corresponding to the complete depletion of the defects. Instead, we observe a power law dependence of index change Δn on both time and intensity. Also, the model predicts that the dependence of Δn on time and intensity should be the same, whereas we obtain an exponent b of about 0.3 for the time dependence ($\Delta n = Ct^b$) and an exponent of 0.5 for the intensity dependence ($\Delta n = CI^b$) in a germanium-doped fiber.[2] A power-law dependence of Δn on time with an exponent of about 0.4 was observed for pulsed UV exposure of the same type of fiber.[3] Another problem with the one-photon model is the prediction of similar writing efficiencies for pulsed or cw light with the same average power. Although we can produce high reflectance gratings using cw UV light, we find that cw light produces a smaller index change than pulsed light for the same type of fiber and comparable UV fluence.[1]

The blue fluorescence that occurs during exposure of the fiber to UV light may be related to the UV-induced index change. If this were the case, the fluorescence intensity would change during the exposure due to the change in the number of defects. There are contradictory reports as to whether this fluorescence intensity changes with time during UV exposure. With A. Lidgard,[4] we have measured the fluorescence intensity during exposure of germanium-doped and germanium-boron-codoped fiber to cw or pulsed 244 nm light. We see a pronounced reduction of the fluorescence during the exposure. For a given fiber, the reduction is only a function of UV fluence and does not differ between the cw and the pulsed case. Furthermore, the boron-doped fiber shows a larger decrease of fluorescence than the germanium-doped fiber. The side-collected fluorescence from the germanium-doped fiber decreased to 60% of its initial value after exposure to 3600 J/cm^2 fluence, while

the fluorescence from the germanium-boron-codoped fiber decreased to 40% of its initial value after the same fluence.

We also observed a difference between the temporal behavior of the fluorescence radiated transversely to the exposed region and that seen at the end of the fiber. The difference in results between side and end detection can be explained by photodarkening that takes place when germanium-doped silica is exposed to UV light. We found that the transmittance of the fiber at 488 nm dropped very rapidly when an exposure to cw UV light began and slowly recovered during the exposure. Since the blue fluorescence detected at the end of the fiber will be a convolution of the fluorescence propagating down the core of the fiber and the change in transmittance in the exposed region, we postulate that photodarkening masks the true temporal features of the fluorescence. The fluorescence emitted radially and detected from the side of the fiber does not suffer from this effect.

Our concurrent measurements of the fluorescence intensity and grating reflectance during cw UV exposure show that the changes in fluorescence occur on the same time scale as the refractive index changes and follow nearly the same power-law function. The faster fluorescence decrease in the boron-codoped fiber was accompanied by faster index changes in this fiber. This points to a connection between the fluorescence and the refractive index change in the case of cw exposure. Our observations support theoretical models such as that given by Atkins et al.,[5] where the UV light ionizes a neutral oxygen vacancy (NOV) defect and produces a Ge(E') center. In this model, blue fluorescence is emitted when the ionized electron recombines with the Ge(E') center, reforming the NOV. Permanent index change occurs if the electron does not recombine with the Ge(E') center, but is instead trapped by a nearby electron acceptor.

We are conducting studies of the fluorescence and the refractive index change in hydrogen-loaded fiber. In addition, we are characterizing the annealing behavior of gratings in hydrogen-loaded and non-hydrogen-loaded germanium-doped and germanium-boron-codoped fiber.

References

1. H. Patrick and S.L. Gilbert, Opt. Lett. **18** 1484 (1993).
2. The fiber used was AT&T Accutether, which contains 9 mol. % germanium doping and is single-mode at 1500 nm. We use the trade name to describe the experimental procedure adequately and do not imply endorsement by the National Institute of Standards and Technology.
3. D.Z. Anderson, V. Mizrahi, T. Erdogan, and A.E. White, Electron. Lett. **29**, 566 (1993).
4. H. Patrick, S.L. Gilbert, and A. Lidgard, to be published in Optical Materials (August, 1994).
5. G.R. Atkins, Z.H. Wang, D.R. McKenzie, M.G. Sceats, S.B. Poole and H.W. Simmons, IEEE J. Lightwave Tech. **LT-11**, 1793 (1993).