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MJ3 Enhanced photorefractivity in germanosilicate fibers: effects of bleaching with 488-nm light

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Permanent index changes, Δn, of the order of 10^{-4} at 633 nm are induced in germanosilicate optical fibers by exposure to light at 488, 266, and 240 nm.[1-3] This photorefractivity has great potential in the fabrication of efficient grating-based devices for a wide range of WDM and lasing applications. It has been explained[2] in terms of alterations in the UV absorption spectrum yielding (through the Kramers–Kronig relation) almost dispersion-free Δn values between 500 nm and 1.5 μm. The predominant cause is the movement of electrons from broken oxygen deficient Ge–Si bonds (associated absorption peak at 240 nm) to Ge(2) traps (when occupied by an electron an absorption peak appears at 213 nm) (see Fig. 1). The Ge–Si bonds can be broken by single-photon absorption of 240-or 266-nm light (permitting gratings of any period to be fabricated by side writing), or (much more slowly) by two-photon absorption (TPA) of 488-nm light. However, an undesirable side effect of 266-nm treatment is that the absorption induced for approximately the same Δn value is some two orders of magnitude larger than that obtained with 488-nm light (30 dB/m at 633 nm). This absorption is attributed to the creation of Ge(1) color centers,[4] with a broad absorption peak centered at 281 nm and extending into the visible (Fig. 1). Because the balance between bleaching and trapping at Ge(1) and Ge(2) dopant sites is different for 266-nm light, it seemed possible that the population of Ge(1) centers could be depleted by 488-nm light, perhaps even enhancing the induced Δn.

We have confirmed experimentally that the absorption induced by 266-nm light does indeed substantially bleach out. Furthermore, using an interferometric measurement technique developed earlier[1] (Fig. 2), we have been able to measure a 2-fold increase in the induced index change from 0.8×10^{-4} to 1.5×10^{-4}. It is unlikely, however, that the Ge(1) bleaching process is responsible for this enhancement of Δn. It is more likely that TPA at 488 nm breaks a subpopulation of Ge–Si bonds that are not susceptible to 266-nm exposure. Therfore 488-nm light coupled into the core is unlikely to increase the Δn modulation depth of gratings that are side written with UV light. It has, however, two beneficial effects: the induced absorption is bleached out by a factor of 100 and a 100% increase in the average Δn is obtained.

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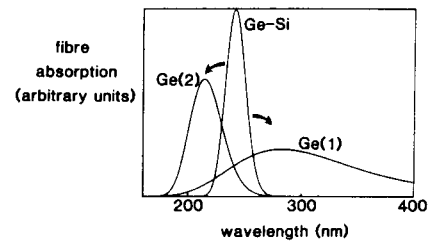

Fig. 1. Fiber absorption spectrum (qualitative only). The intrinsic 240-nm absorption is bleached out by blue/UV light. Released electrons are trapped at Ge(1) and Ge(2) sites, giving absorption peaks at 281 and 213 nm, respectively, the relative intensities of which are dependent on excitation wavelength.

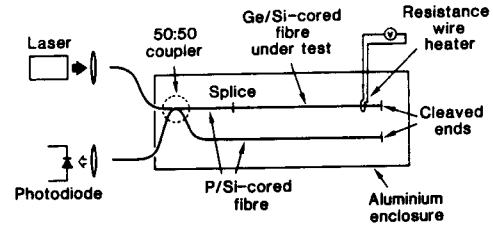

Fig. 2. Experimental arrangement: backreflected light from the cleaved ends interferes on recombination at the coupler. Any index change in the test fiber results in a shift of the interference fringes, as monitored by the photodiode.

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MJ4 Color-center model for second-order optical nonlinearities in germanosilicate optical fibers

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Second-order nonlinearities can be induced in germanosilicate (GS) glass fibers in a variety of ways: by coherent superposition of pump and second-harmonic light (a third-order dc polarization P_{dc}[3] is induced that breaks the inversion symmetry[1]); by excitation poling with blue light and an external dc field,[2] E_{pol}; and by strong E_{pol}'s in the absence of light.[3] There is as yet no satisfactory agreement over the nature of the underlying alignment process. From related detailed studies of color-center behavior in GS fiber,[4] we have formulated a self-consistent model as developed in the following points.

(1) If (as has been proposed[5]) $\chi^{(2)}$ is caused by a built-in space-charge field, then in excitation poling it should start large (being initially $\chi^{(2)} = 3E_{pol}\chi^{(3)}$), gradually falling off to zero as the core region charges up. Upon switching off E_{pol}, it should immediately reappear at its initial level, with its sign reversed. In practice $\chi^{(2)}$ simply increases continuously, tending asymptotically toward a steady level; this strengthens the case for color-center alignment.

(2) Breakage of oxygen deficient Ge–Si bonds by two-photon absorption in the blue (or by $E_{pol} \sim 500$ V μm^{-1} in the absence of light) creates GeE' centers and positively charged $\equiv Si^{+}$ hole traps, releasing electrons that drift off through the glass matrix and are captured at Ge(1) and Ge(2) precursor sites to form negatively charged color centers $Ge^{-}(1)$ and $Ge^{-}(2)$ (Fig. 1).