Monday MORNING
May 11, 1992 CMG
CONVENTION CENTER ROOM B2

10:30 am **Guided-Wave Photorefractivity**

Charles L. Woods, *U.S. Air Force, Presider*

10:30 am Invited
CMG1 Photorefractive thin films and waveguides

Robert W. Eason, *Optoelectronics Research Centre University of Southampton, Southampton, U.K.*

The fabrication of photorefractive waveguides for use in holographic processors, integrated-optic applications, and optical memory devices is a particularly desirable goal. To date, small diameter (≤100 μm) crystal fibers of materials such as SBN have successfully been grown, but their bulk and surface optical quality can be poor, and clad fibers are not readily available. Planar guides of Ti indiffused photorefractive $LiNbO_3$ are more easily fabricated, but the materials of most interest to the photorefractive community, such as $BaTiO_3$, SBN or BSO, have not been produced as low-loss waveguide structures, apart from a few reports on highly multimode thin cleaved crystal wafers.[1]

The use of guided wave structures in photorefractive media has the obvious advantage of optical confinement and its consequent reduction in material response times. For planar structures of typical guiding dimension 1–5 μm, this reduction is expected to be two or three orders of magnitude. Thin film optical materials have been produced previously using various evaporation or sputtering techniques, but the single crystal oriented nature of such films is often poor or irreproducible. We discuss here the three techniques of laser ablative growth, ion-beam implantation, and indiffusion for fabrication of planar guides in $BaTiO_3$, SBN:Ce, and BSO/BGO.

Laser ablation is a relatively simple and convenient method for thin film optical growth. Provided attention is paid to such deposition parameters as substrate temperature, and incident laser flux, ~1-μm thick single crystal epitaxial layers can be grown on suitable lattice matched substrates. So far, we have had success with BGO grown on ZrO_2,[2] for which single crystal growth of the correct phase $Bi_{12}GeO_{20}$ was achieved. The growth chamber used is illustrated in Fig. 1. $BaTiO_3$ on LiF has also been reported,[3] but waveguide quality films were not produced as the substrate was cleaved rather than polished. There is also the problem of postpoling these ferroelectric films. We are currently growing $BaTiO_3$/LiF thin films on polished substrates.

Ion-beam implantation via 2–3 MeV He^+ and H^+ ions has also been used to form guides in $BaTiO_3$, SBN:65, SBN:52, and BSO. Typical guide dimensions produced fall in the region of 2–20 μm, but so far the guide losses are rather high (~30 dB/cm), and the material's photorefractive response is minimal. Postannealing typically reduces these losses, but oxidation/reduction treatments may be required to restore the material's photorefractive response. Finally we are also starting work on indiffused (Ti and Cr) guides in BSO and BGO.

We discuss our progress so far in waveguide growth techniques, loss measurements, photorefractive characteristics, and prospects for the future.

1. K. Kitayama, F. Ito. *Photorefractive Materials, Effects and Devices III*, Vol. 14, 1991 OSA Technical Digest Series (Optical Society of America, Washington, DC, 1991), paper MC14-1.
2. K. E. Youden, R. W. Eason, M. C. Gower, N. A. Vainos, Appl. Phys. Lett. **59**, 1989 (1991).
3. G. M. Davis, M. C. Gower, Appl. Phys. Lett. **55**, 112 (1989).

11:00 am
CMG2 Temporal evolution of the photorefractive effect in annealed proton-exchanged $LiNbO_3$ waveguides

Takumi Fujiwara*, Xiaofan Cao, Ramakant Srivastava, Ramu V. Ramaswamy, *Photonics Research Laboratory, Department of Electrical Engineering, University of Florida, Gainesville, FL 32611*

Waveguides based on proton exchange (PE) in $LiNbO_3$ substrates are of significant interest for integrated photonic applications; in particular, they are useful for efficient second-harmonic generation,[1,2] because of their strong nonlinearity, large optical confinement, and simple fabrication process.

Recently, restoration of the nonlinear coefficients of the PE $LiNbO_3$ waveguides by thermal annealing was reported.[3,4] Although it is known that the PE $LiNbO_3$ waveguides have higher resistance to the photorefractive effect than Ti-diffused $LiNbO_3$ waveguides,[5,6] quantitative measurements of the effect in annealed proton-exchanged (APE) waveguides as well as the PE waveguides have not been reported to date.

In this paper, we report on the quantitative measurements of the photorefractive effect at irradiation wavelengths (λ_{ir}) of 532 and 633 nm in APE $LiNbO_3$ waveguides by using a technique similar to that used for Ti-diffused waveguides.[7] From measurements of the temporal behavior of the photo-induced index change caused by irradiation for several hours, the saturated-index change, buildup time constant, and photorefractive sensitivity in APE $LiNbO_3$ waveguides were determined and compared to Ti-diffused waveguides.

Figure 1 shows the experimental setup to measure the photorefractive effect. The APE waveguides were fabricated by proton exchange at 220°C for 20 min in benzoic acid, and subsequent annealing at 350°C for 6 h. They guide only the lowest-order mode at 1.3 μm. Irradiation light produces an optical phase retardation between the two interferometer arms due to the photo-induced index change which results in a change in the modulated output intensity of the 1.3-μm probe.

By measuring the time dependence of the probe power, we obtain the photo-induced index change $\Delta n(t)$. No measurable index change was observed at λ_{ir} = 633 nm for intensity of up to 7.1 W/cm^2. However, the photorefractive effect caused the index to change when exposed to the 532-nm light, as shown in Fig. 2. The buildup of the index change is exponential and is governed by

$$\Delta n(T) = \Delta n_s(1 - E^{-t/\tau}), \quad (1)$$

where Δn_s is the saturated index change, and τ is the time constant.[7] Figure 2 shows the time dependence of the photo-induced index change for two irradiation intensities fitted to Eq.(1) for 220 min of exposure.

The results are summarized in Table 1 where we have also listed the photorefractive sensitivity S (cm^2/J) defined by $S = \Delta n_s / I_{ir}\tau (I_{ir}$ is the irradiation intensity). For comparison, we have also listed the results on Ti-diffused waveguides.[7] The photorefractive sensitivity S for APE waveguides, while immeasurable at λ_{ir} = 633 nm, is at least three orders of magnitude smaller at λ_{ir} = 532 nm than that of Ti-diffused waveguides at λ_{ir} = 633 nm. A comparison of the time constants indicates that the conductivity of the APE $LiNbO_3$ waveguides is lower than that of Ti-diffused waveguides. However, based on Glass's model, the smaller saturated index change Δn_s in the APE waveguides indicates that the absorption coefficient, the electro-optic coefficient, and Glass's constant may be smaller to account for the reduction in the sensitivity S, because S is independent of the conductivity.

**permanent address: Electronics Materials Laboratory Sumitomo Metal Mining Co., Ltd., Tokyo, Japan*

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11:15 am
CMG3 Photorefractivity in doped nonlinear polymers

W. E. Moerner, C. A. Walsh, J. C. Scott, D. M. Burland, G. C. Bjorklund, R. J. Twieg, *IBM Research Division, Almaden Research Center, San Jose, CA 95120-6099*

Photorefractive polymer materials offer a number of potential advantages over