HOLOGRAPHIC STORAGE, ELECTRICAL FIXING AND ERASING IN DOPED BaTiO3 CRYSTALS

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Abstract. — We have demonstrated that holographic storage by optical damage in BaTiO₃ crystals is enhanced by doping with Fe³⁺ and Ni²⁺, while doping by Nb⁵⁺ produces the inverse effect. Stable holograms have been obtained, by applying a pulsed electric field of amplitude slightly smaller than the coercitive field. Erasure is achieved by applying a saturation field.

Creation of phase holograms in electrooptic and ferroelectric materials have been demonstrated by many research groups since Ashkin et al. [1] found the effect of « optical damage ». This effect occurs in crystals that contain photoexcitable electrons and deep traps. When photoexcited, electrons drift under the influence of internal or external fields, as demonstrated by Chen [2], or diffuse in the crystal along the polar axis as suggested by Johnston [3] and Amodei [4]. They are trapped in the adjacent dark regions; the new electronic distribution causes local changes of birefringence via the electrooptic effect. Holographic patterns may be recorded in these crystals by interference of two coherent laser beams.

The recorded hologram is not stable, since thermal lattice vibrations or uniform illumination (to allow reading of the hologram) of the crystal cause ionization and redistribution of the trapped electrons [5].

Such experiments have been carried out by Townsend [6] on nominally pure BaTiO₃ crystals. Thermal erasure occurs at room temperature in less than 1 s. We felt that doping BaTiO₃ crystals with electron donors would create traps, and enhance the optical damage process. One carried out experiments to verify this assumption.

Doped Fe³⁺ and Ni²⁺ BaTiO₃ crystals were grown by the flux method by Arend, Coufova and Novak [7], [8]. 100 µ thick plates were poled by 10 kV/cm field either normal or parallel to the faces of the plates. Recording the holograms was achieved in « c domain » plates, with the polarization of the two Ar laser beams, (λ = 4880 Å), making a 45° angle with the bisectrix B of the two beams (Fig. 1a). In « a domain » crystals, recording is achieved with c axis normal to the bissectrix (Fig. 1b).

Diffraction efficiency of the created hologram was monitored by measuring the diffracted part of a low power HeNe laser beam.

Figure 2 shows experimental results of diffraction efficiency measurements versus doping concentration, and light density power.

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At room temperature, the time constant of thermal erasing (in the dark) is 300 s for 0.24 Wt % Fe$^{3+}$ doped crystals and 100 s for 0.30 Wt % Ni$^{2+}$ doped crystals, i.e. higher by two orders of magnitude than for nominally pure crystals. Similar experiments were performed on Nb$^{5+}$ doped crystals [9]. Poor diffraction efficiency was measured (10$^{-3}$ at 500 W/cm²) and the time constant of thermal erasure was lower than 0.1 s. With higher concentration than 0.1 mole % of Nb$_2$O$_5$ in the flux, the grown crystals show no measurable diffraction efficiency.

Later experiments have been carried out in order to fix the recorded holograms. In 0.1 Wt % Fe doped BaTiO$_3$, the storage time is less than 5 s, when it is uniformly illuminated by a 50 W/cm² Ar Laser beam. Recently, Amodei [10] has demonstrated that fixation of the holographic pattern occurs when thermally stimulated ions drift under the influence of the local internal field. Heating a LiNbO$_3$ crystal to 100 °C for 30 mn, during or after recording the hologram gives rise to high diffraction efficiency and stable holographic patterns, when reilluminated at room temperature.

Ionic drift has cancelled the local changes of the internal field, produced by the trapped photoelectrons. At room temperature, this new ionic distribution is frozen, and uniform illumination of the crystal causes a uniform drift of electrons that leave behind the uncompensated ionic pattern. Such a pattern is stable since ions are not photoexcitable.

In ferroelectric crystals, such as BaTiO$_3$ and KNbO$_3$, high ionic drift rates can be obtained by the application of a field close to the coercitive field $E_c$. By applying such a field, one should be able to fix the holograms using the electric field in place of the heating used by Amodei. Experiments were performed which verified this hypothesis.

The experiments were performed in Fe 0.1 Wt % doped crystals, in which holographic patterns have been recorded. We have observed that after applying during 0.1 s a field $E$ with $E/E_c = 0.9$ and returning to $E = 0$, the storage time was about 5 hours when the crystal was illuminated with a light density power of 50 W/cm². The gain in time storage is then higher than 10$^3$. Erasure of the holographic pattern is achieved by applying field high enough to saturate the polarization (10 kV/cm during 3 s).

In summary, we believe that doping BaTiO$_3$ crystals with donors like Fe$^{3+}$ or Bi$^{3+}$ creates traps deep enough to enhance optical damage. These traps would be the oxygen vacancies. Doping with Nb$^{5+}$ creates traps compensated by electrons that are not photoexcitable at $\lambda = 4$ 880 Å. Drift of ions or vacancies occurring while applying an electric field smaller than the coercitive field is responsible of the creation of stable holographic patterns. More information about the nature of drift carriers must be found by conductivity, thermo and photocurrent measurements, and transmission optical spectra analysis when applying the previously mentioned electrical fields. Proper doping may decrease the writing, fixation and erasure times and allow use of ferroelectric crystals and thin films for new optical memories.

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References