E. P. Harris
M. L. Dakss

Optical Damage to $LiNbO_3$ from GaAs Laser Radiation

Abstract: We have observed optical damage to $LiNbO_3$ at room temperature from focused cw GaAs laser radiation at a wavelength of 8450 Å. Visible damage was apparent after a 20-sec exposure corresponding to an energy flux of about 1.2×10^5 J/cm^2 and was observed by changes in the diffraction pattern of the crystal. This is believed to be the first report of such damage in the potentially useful wavelength range of 0.8 to 0.9 μm. No damage was observed at a wavelength of 9030 Å in a similar but pulsed-laser experiment.

It is known that $LiNbO_3$ can develop refractive index inhomogeneities when subjected to intense radiation in the visible spectrum.[1] For example, 4880-Å laser light focused to an intensity of 1 W/cm^2 can cause the development of visible damage in seconds.[2] The damage is thought[2] to be caused by the photoexcitation of electrons from traps in the crystal. The electrons drift in the internal electric field of the spontaneous ferroelectric polarization and set up a space charge that modifies the local electric field. Through the electro-optic effect these changes in the local field produce changes in the refractive index.

Potential applications such as deflection and modulation exist for $LiNbO_3$ in conjunction with GaAs laser radiation in the near-infrared radiation spectrum (0.8 to 0.9 μm). Although exposure of $LiNbO_3$ to 1.06-μm and 1.15-μm radiation has been found[1] not to cause optical damage, equivalent optical damage measurements in the wavelength range 0.8 to 0.9 μm do not seem to have been reported previously.

We have observed optical damage in $LiNbO_3$ following its exposure to cw GaAs laser radiation in a 20-Å band centered at 8450 Å (laser operating at 27 K). The unpolarized beam was collimated and focused into the sample (at room temperature, a $LiNbO_3$ crystal grown by Union Carbide) so that it propagated perpendicular to the *c* axis of the crystal. The focused spot was observed visually through a microscope (with an image converter) and was photographed by refocusing the microscope objective onto photographic film. A beam splitter was placed between the focusing lens and the $LiNbO_3$ so that the crystal could be examined for radiation-induced damage with collimated, low-power, unpolarized, 6328-Å He-Ne laser light. A schematic diagram of the experimental setup is shown in Fig. 1.

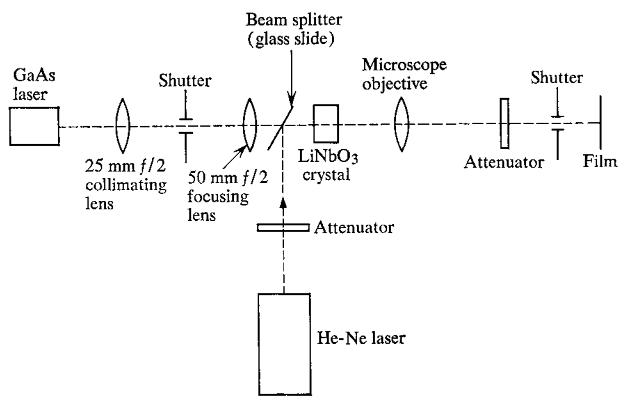

Figure 1 Schematic diagram of the experimental setup.

After exposures of several seconds each to 8450-Å radiation, the $LiNbO_3$ crystal was photographed with 6328-Å illumination. There was apparent damage to the $LiNbO_3$, evidenced by diffraction of the He-Ne light at the damaged area, after a total exposure time of about 20 seconds. Several photographs of the diffraction pattern, corresponding to increasing 8450-Å exposure times, are shown in Fig. 2. These photographs were taken with the microscope objective in the position that yielded maximum visibility of the diffraction fringes. The contrast of the diffraction fringes increased with exposure time and did not appear to saturate in the first six minutes of exposure. The damage annealed out at room temperature over a period of a few months.

The power incident on the crystal during the exposures was determined to be approximately 120 mW. From this value we estimated the energy flux required to produce

The authors are located at the IBM Thomas J. Watson Research Center, Yorktown Heights, New York 10598.

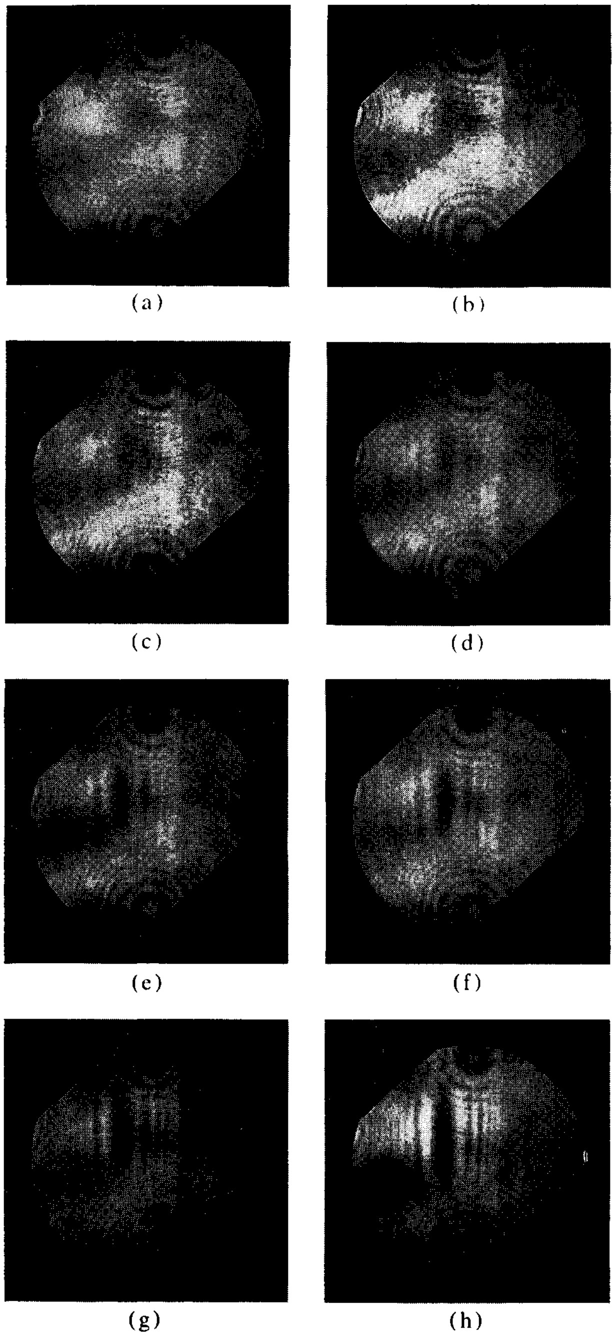

Figure 2 Diffraction pattern photographs (in He-Ne laser light) of the $LiNbO_3$ sample before and after exposure to 8450-Å GaAs laser radiation: before exposure (a) and after exposure of (b) 20 sec, (c) 50 sec, (d) 80 sec, (e) 120 sec, (f) 160 sec, (g) 330 sec and (h) 720 sec.

observable damage to be about 1.2×10^5 J/cm^2, with corresponding power density about 6×10^3 W/cm^2. Similarly, we estimated the energy flux for saturation[2] to be greater than 2×10^6 J/cm^2. For order-of-magnitude comparison, Chen et al.[2] determined that, with laser radiation of 4880 Å wavelength focused to an intensity of about 1 W/cm^2, an energy flux of the order of 100 J/cm^2 is required to produce saturation, but damage is clearly observable after exposure to a flux of less than or approximately 1 J/cm^2. Detailed comparison is not possible, however, because optical damage in $LiNbO_3$ at visible wavelengths is known to depend on beam intensity and often varies from sample to sample.

A similar experiment was done using pulsed GaAs laser radiation at 9030 Å wavelength. The laser was operated at room temperature with a repetition rate of 2 kHz and the exposure times were scaled relative to the cw experiment to account for the duty cycle of the pulsed laser. The average power entering the $LiNbO_3$ was 440 μW and the peak power was 1.6 W. At the end of 100 hours of exposure there was no damage that affected the diffraction pattern. The total energy flux during this exposure was about 4.7×10^6 J/cm^2, 40 times greater than the minimum energy flux required to observe damage in the cw 8450-Å experiment.

It is possible that the spot drifted over the long exposure time, but we estimated from observations of the focused spot at different times during the exposure that the maximum effect of drift would be to reduce the energy flux by a factor of six; thus the energy flux in the pulsed experiment was at least six times that in the cw experiment. We cannot rule out the possibility that differences exist between the susceptibilities of $LiNbO_3$ to pulsed- and cw-radiation damage. However, as far as differences in heating effects are concerned, a simple calculation shows that the temperature rise due to local heating during a pulse is several orders of magnitude less than the rise that would cause annealing of damage between pulses.

In summary, we observed optical damage to $LiNbO_3$ from exposure to a focused, 120-mW, 8450-Å, cw GaAs laser beam. The radiation produced visible damage in about 20 seconds and the damage increased with time for at least six minutes. The minimum energy flux required to produce observable damage is estimated to be about 10^5 J/cm^2. The $LiNbO_3$ crystal was found to be significantly less damageable by radiation of wavelength 9030 Å, but the results at this wavelength are less conclusive.

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