the reference beam mirror is optically flat and the object beam mirror has a scattering surface.

Figure 3 is the interferogram of the glass slide by the conventional Mach-Zehnder interferometer when $2\theta \neq 0$. The fringes of Fig. 2 are similar in shape to those of Fig. 3.

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Pulsed Writing of Solid State Holograms

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Optically induced refractive-index changes in lithium niobate have previously been utilized for recording volume holograms.[1] These holograms are produced directly (without processing) by the interference of laser beams of the appropriate wavelength intersecting in the crystal. Iron doped lithium niobate has subsequently been shown to exhibit higher sensitivity to light induced changes in index of refraction than those observed in nominally pure crystals of lithium niobate.[2] These previous experiments have been performed with cw lasers. The writing of holograms on a pulsed basis is reported here.

A 1-mm thick poled single-domain $LiNbO_3$ crystal doped with 0.05 mole % iron was used as the recording medium in the experimental configuration shown in Fig. 1. The laser beam was divided by a beam splitter, and the two resultant beams were made to intersect in the crystal. The interference pattern produced by these beams was then recorded in the crystal as index of refraction changes thus forming a thick diffraction grating. The crystal was oriented with its b-face surface perpendicular to the bisector of the writing beams and with the c-axis in the plane of the writing beams as shown in Fig. 1. The angle between the writing beams was 8.8°.

Two pulsed laser systems were used to write holograms in the lithium niobate. The Nd:YAG system was acoustooptically Q-switched and frequency doubled as shown in Fig. 1. The resultant 5300Å pulses had an average energy of 0.50 μJ/pulse and an approximately Gaussian shape as shown in Fig. 2. A pulse repetition rate of 1 KHz was used. The pulse width was about 200 nsec (full width at half maximum). A frequency doubled Nd:Glass laser was also used in these experiments. This was used in a folded cavity configuration[3] and was Q-switched with a Pockels cell as shown in Fig. 1. These 5300 Å pulses that were available at 10-sec intervals had an average energy of 4.9 mJ/pulse and a Gaussian shape as shown in Fig. 2. The pulse width was approximately 20 nsec (full width at half maximum). The 200-nsec and 20-nsec pulses were monitored using an RCA 7102 photomultiplier tube and an ITT F4000(S-1) photodiode, respectively.

Both the 200-nsec and 20-nsec pulses were used to write holograms. In each case a beam diameter of 2 mm was used. For both the 200-nsec and 20-nsec pulses, the effect of a single pulse was not observable with this experimental equipment. Thus a series of pulses was used in each case, and the diffraction efficiency was monitored using a He–Ne laser operating at 6328 Å and aligned to its corresponding Bragg angle. The writing curve of diffraction efficiency

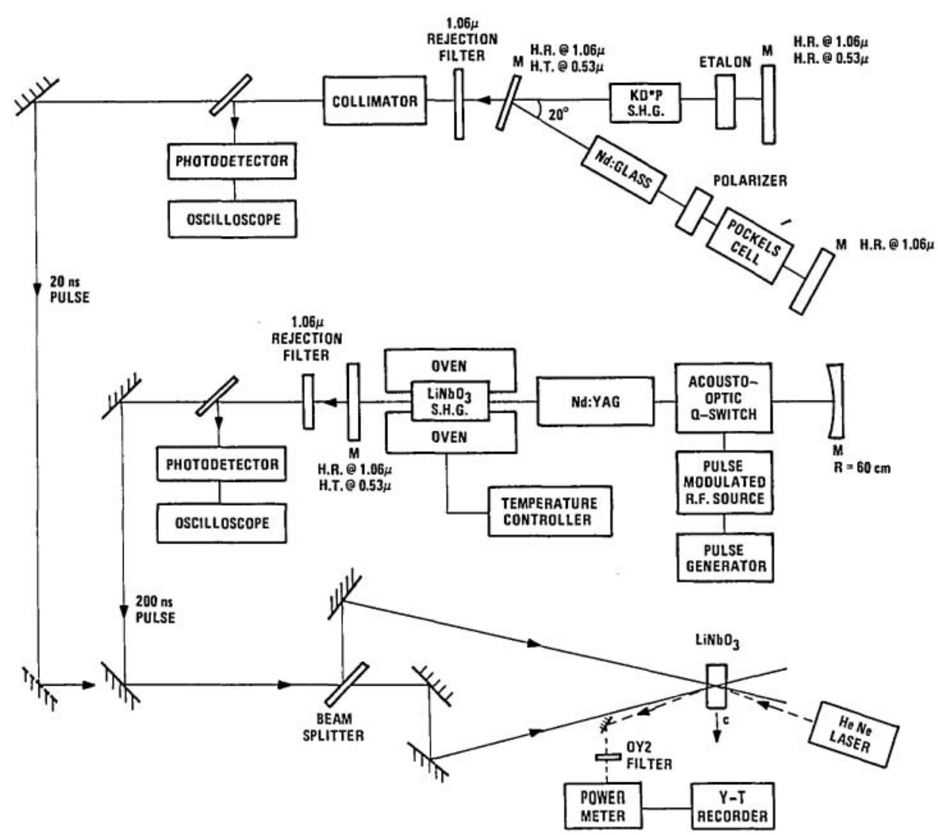

Fig. 1. Experimental configurations used for pulsed writing of $LiNbO_3$ holograms.

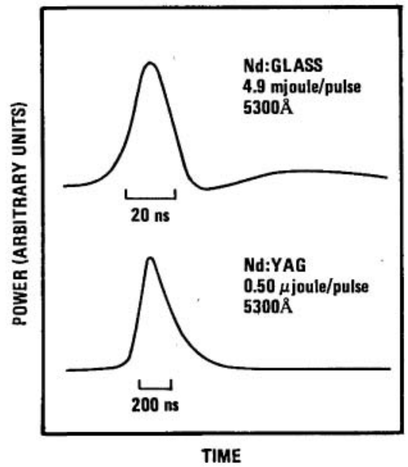

Fig. 2. Q-switched frequency doubled laser pulses from the Nd:Glass and the Nd:YAG lasers used in these experiments.

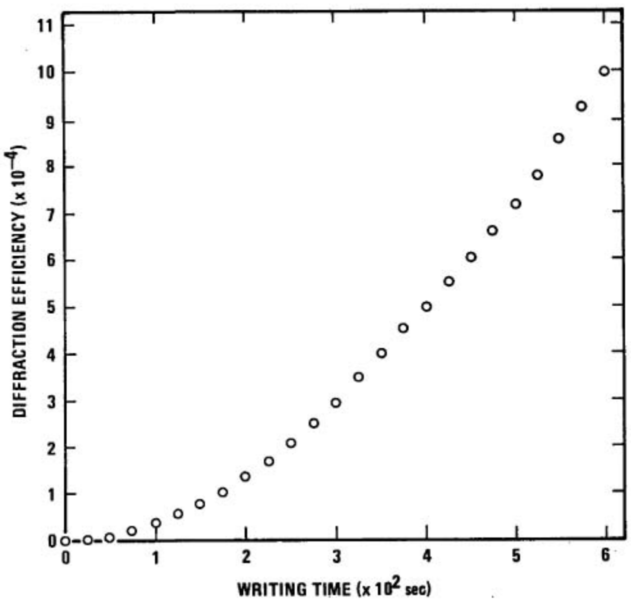

Fig. 3. Writing curve for iron-doped lithium niobate using repetitively Q-switched (1-KHz repetition rate) frequency doubled Nd:YAG laser (0.50 μJ/pulse).

as a function of writing time for this sample of iron-doped lithium niobate is shown in Fig. 3 as obtained using the 1000-pulses/sec frequency doubled Nd:YAG laser. Starting with two unwritten regions of the crystal, holograms were written with 200-nsec pulses at one location and with 20-nsec pulses at the other. In each case the number of pulses required to produce a diffraction efficiency of 5×10^{-4} was noted. Using 200-nsec pulses, a total energy of 0.201 J was required while an energy of 0.183 J was required when 20-nsec pulses were used. Thus to within 10% (which is of the order of the experimental error) the energy required to produce a given level of diffraction efficiency was the same for the two pulse lengths.

For the physical processes producing the index of refraction changes the range of optical intensities used here is dependent only on the amount of incident energy down to times of 20 nsec. This would indicate that the process or processes involved do not require the presence of light for over 20 nsec in order to be completed. Detailed dynamic response curves could not be obtained because of the inadequate sensitivity of the photodetectors that were used to detect the diffracted beam.

In summary, the pulsed writing of volume holograms in $LiNbO_3$ is reported, both with 200-nsec and 20-nsec duration pulses. This information is of particular interest in high capacity information storage applications since it indicates that writing times at least as short as 20-nsec are readily possible.

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Multiplex Image Plane Hologram

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An image plane hologram is recorded by the interference with a focused image and a reference beam. It can be reconstructed by an extended white light source.[1,2] All its reconstructed light bundles pass through a common area off the hologram, which is a reconstructed image of an exit pupil of the imaging lens. When an opening is placed on the area, it shuts off the other light bundles without sacrificing the angle of view.[3] The radius of the opening can be small for a two-dimensional object, so that it is easy to separate one of the multiply recorded images by changing the position of the reference light source. Furthermore, it was found that the reconstructed image of the image plane hologram had a higher contrast ratio than that of other type holograms, because the self-interference in the object beam[4] was absent, and the dark part of the reconstructed image was not illuminated by the scattered light from other parts of the hologram (Fig. 1).

In this Letter, we will describe a method of recording and reconstructing an image plane hologram multiplexed tenfold in a small area.

The multiplex image plane hologram was recorded by an arrangement shown in Fig. 2. The offset angle of the reference beam was about 30 degrees of arc, and the carrier frequency was about 1100 lines/mm using He–Cd laser.

An object transparency was placed at O. Lenses L_1 and L_2 form a uniform illumination on a hologram plane H. In order to shut out the higher order diffracted light and the scattered light from the transparency, a small opening P', the diameter of which corresponded to the bandwidth of the object, was placed at the focal plane of L_1, where the spatial frequency spectra were formed. L_2 imaged the real image of O on a photographic plate at H. The shutter was opened, and the interference fringes with the reference beam were recorded. The mean exposure period was about 10 sec using a 50-mW cw laser. After the first transparency was recorded on H, the shutter was closed, and the object was changed by a new one. Then, O and H planes were rotated 18 degrees of arc around the optical axis. This is equivalent to rotating the direction