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# Radiation Studies of Optical Interferometric Modulators with Fast Neutrons and High Energy Gamma-rays

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ABSTRACT

The possibility of using Ti : $LiNbO_3$ and single mode fibers for nuclear particle detection and transmission in large-scale machines, such as Superconducting Super Collider, calls for a detailed radiation damage study. In this report, we present radiation studies on Ti : $LiNbO_3$ Mach-Zehnder interferometric optical modulators with fast neutrons and high energy Gamma-rays.

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Preliminary results using optical modulators to detect and transfer signals generated by high energy particles are very promising.[1] Successful operation of these devices in the radiation hazard environment requires a detailed radiation damage study. There have been extensive studies on $Ti : LiNbO_3$ waveguides and directional couplers exposed to a variety of ionization radiation.[2] However, data concerning irradiation of an operational device with fast neutrons and high energy Co-60 Gamma-rays are lacking but are essential when the $Ti : LiNbO_3$ Mach-Zehnder modulators are used in nuclear particle detection. The change of the optical properties (transmission or photorefractive-like properties) would affect the operational characteristics of the device.

A total of 27 interferometric modulators[3] were fabricated in x-cut y-propagating $Ti : LiNbO_3$, without a buffer layer, at the Naval Research Laboratory. The waveguide branching angle is $1.2^o$ with electrodes of length 14 mm and arm spacing of 60 $\mu$m. The interferometer loss, as compared to the straight channel, is $3 - 4$ dB. The interferometric fringe intensity has an extinction ratio of $\sim 26$ dB with a $V_\pi$ voltage of $\sim 2.0$ volt and an input capacitance of a few pF. These modulators, and 2 straight channel waveguides for transmission test, were separated into three batches and then exposed to total doses of $4.3 \times 10^{13}$, $0.82 \times 10^{13}$, and $0.31 \times 10^{13}$ neutrons/cm$^2$, respectively, in 5 hours. Another 6 modulators and one straight channel were not exposed to neutrons and are used as a reference. Fast neutrons are generated via the $^7Li(p,n)^7Be$ reaction by bombarding a thick metallic Li target with protons from the CN Van de Graaff accelerator at the University of Lowell. The energy of the fast neutrons is $> 10$ keV and the ratio of Gamma-rays to neutrons production in this facility is only 1:12,[4] therefore, minimum effects caused by gamma-rays are avoided. Because the devices are not pigtailed with fibers, the transient behavior can not be obtained in-situ. However, several tests of the optical characteristics were performed immediately (within 1 hour) after the irradiation, therefore, any annealing effect would have been observed. We examine the optical transmission at the wavelength of 1.3 $\mu$m, the extinction ratio, the modulation voltage $V_\pi$, and the magnitude and stability of the zero voltage phase bias point $\phi_o$, on all interferometers including the reference. Figure 1 shows a typical transfer characteristic of a modulator before and after fast neutron irradiation. The channel transmission was $-4.0 \pm 0.1$ dB before and after neutron radiation. Within experimental error, there was no change in optical transmission (in contrast to electron ionization where color centers are usually formed),[2] modulator phase bias angle $\phi_o$, modulator $V_\pi$ or the extinction ratio, see Table 1. In an actual detector situation, the signal charge applied to the electrode of the modulator will generate an optical signal output. The optical signal is then transfered through a fiber to a fast preamp-shaper receiver at a remotely located and electrically noise-free environment. Figure 2 shows a typical result of the charges detected by a modulator-receiver after fast pulse shaping technique is applied.[5]

Another batch of similar single-channel devices has been fabricated by NRL. Radiation damage experiments, to be performed at BNL, using high energy gamma-rays Co-60 source are in progress. With pigtailed fibers attached to one device, the transient behavior may be obtained during the irradiation in this experiment. We will present the details of the results at the conference.

## Figure Captions

**Figure 1.**

Transfer characteristics of a Mach-Zehnder modulator before and after receiving a total dose of $\sim 4.3\text{x}10^{13}$ n/cm$^2$ fast neutrons.

**Figure 2.**

A typical modulator-receiver response at the shaping time of $\tau_i = \tau_d = 3$ ns with $2.5\text{x}10^5$ electrons injected to the modulator.

## References

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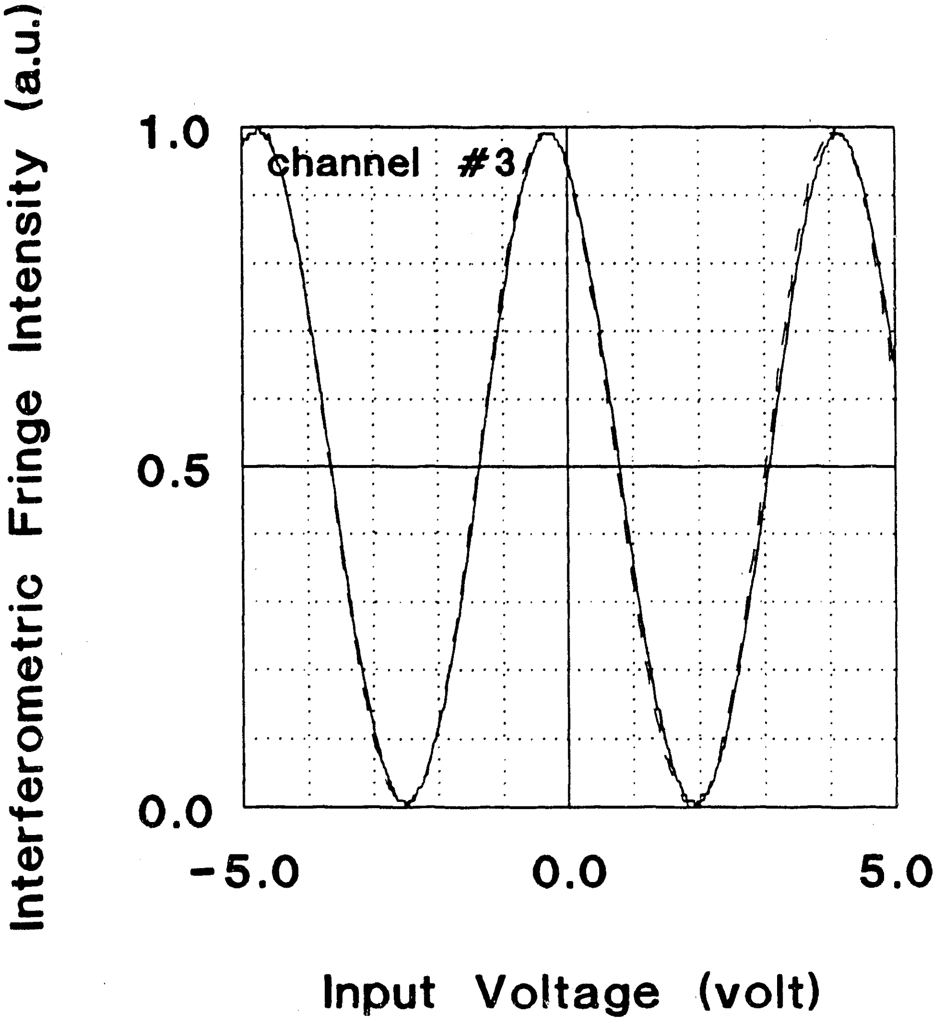
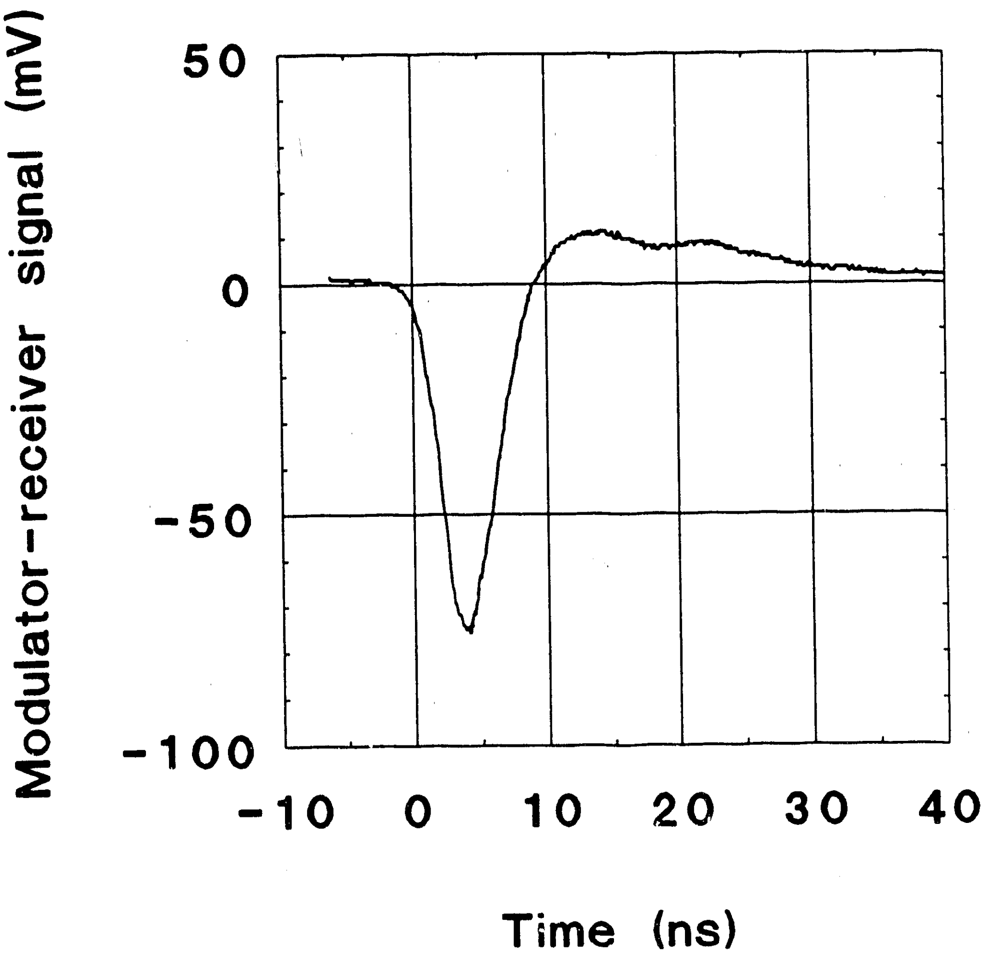
**Table 1: Summary of the fast neutron irradiation**

| @NRL | Before radiation | | After radiation | |
|---|---|---|---|---|
| modulator # | $V_\pi$ (volt) | $\phi_o$ (degrees) | $V_\pi$ (volt) | $\phi_o$ (degrees) |
| 3 | 2.00 | -29.4 | 2.06 | -29.7 |
| 4 | 2.06 | 22.7 | 2.06 | 22.7 |
| 6 | 1.98 | -45.5 | 1.98 | -45.5 |
| 7 | 2.00 | -131.4 | 2.01 | -131.6 |
| 8 | 2.03 | -84.4 | 2.02 | -84.7 |
| 9 | 2.02 | -50.8 | 2.02 | -51.7 |
| 10 | 2.04 | 165.4 | 2.05 | 166.0 |
| 12 | 2.09 | -159.3 | 2.07 | -158.6 |
| 13 | 1.99 | -123.9 | 2.03 | -124.3 |
| 14 | 2.03 | -69.2 | 2.03 | -69.2 |


Interferometric Fringe Intensity (a.u.)
1.0
0.5
0.0
channel #3
-5.0
0.0
5.0
Input Voltage (volt)


50
0
-50
-100
-10
0
10
20
30
40
Modulator-receiver signal (mV)
Time (ns)

# END

DATE
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