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Bulk optical Bragg deflectors at 1.064μm based on an electro-optically induced grating in periodically poled lithium niobate

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Abstract: We report the first demonstration of a bulk optical Bragg deflector based on an electro-optically induced grating in z-cut periodically poled $LiNbO_3$ (PPLN) operating at a wavelength of at 1.064μm. Discussions on the reduction of photorefractive damage by control of the grating period are presented.

Many solutions exist for making laser modulators including acousto-optic (AO) and bulk electro-optic (EO) devices. However, another class of modulators based on Bragg diffraction in periodically poled materials offers the potential to overcome disadvantages inherent in the more conventional types, such as low efficiency in the infra-red and high drive voltages. These devices are an extension of early work on grating based EO devices for example those by Hammer [1] and Barros & Wilson [2], but by making use of periodic poling they allow additional design freedom. This in turn allows fast switching, high efficiency and simple construction as demonstrated in periodically poled lithium niobate at 633nm [3], [4].

In this paper we present the first results on Bragg EO modulators operating at 1.064μm, describe their fabrication and present an investigation into the design considerations for such devices. We also report our findings on the optimisation of modulator designs for shorter wavelengths. Problems are usually encountered at visible and blue wavelengths due to the strong photorefractivity of lithium niobate at these wavelengths. However in a poled device the poling is known to reduce the photorefractive effect [5], giving a degree of flexibility not present in other modulator designs.

The first order diffraction efficiency of a thick Bragg grating is given by [6]:

$$\eta = \sin^2\left(\frac{\pi \Delta n d}{\lambda \cos\theta_{\text{int}}}\right) \qquad \text{\{Eqn 1\}}$$

where η is the diffraction efficiency, λ is the wavelength in free space, θ_{int} is the internal angle between the incident light and y-axis of the crystal, d is the length of the grating and Δn is the change in refractive index due to the applied field. This efficiency equation only holds if the Bragg relation;

$$\sin\theta_{\text{int}} = \frac{\lambda}{2n\Lambda} \qquad \text{\{Eqn 2\}}$$

is simultaneously satisfied, where Λ is the period of the grating. For a given grating period a large range of wavelengths may be used by altering the launch angle, with the only constraints being set by the device geometry. This means that for a given wavelength it is possible to design the device to give high diffraction efficiency whilst taking into consideration fabrication constraints and the need to reduce photorefractive damage.

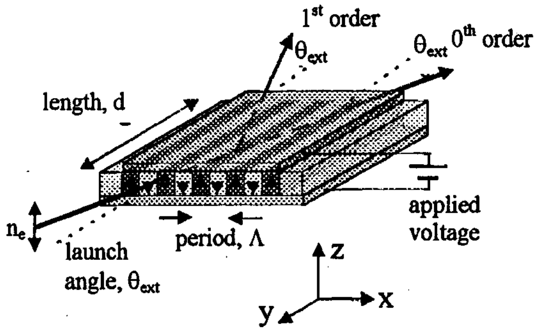

Figure 1: Schematic diagram of the periodically poled $LiNbO_3$ modulator device

The design of the modulator devices is shown in Figure 1. It consists of an area of periodically domain inverted regions forming a grating of length d and period Λ with grating k-vector parallel to the x-axis of the crystal. By applying a uniform electric field, E, between the ± z faces a periodic refractive index change with an amplitude of:

$$\Delta\left(\frac{1}{n^2}\right)_{ij} = \sum r_{ijk} E_k \qquad \text{\{Eqn 3\}}$$

is induced. The largest electro-optic coefficient in lithium niobate is accessed by extraordinary or z polarised light as shown by n_e in Figure 1, with a value of $r_{33} = 32.2 \times 10^{-12}$ mV^{-1} [7].

The devices were fabricated using 500μm thick, z-cut lithium niobate. Using a reactive ion beam etcher we created alignment marks on the samples allowing us to accurately line up the electrodes with the gratings. The grating was then photolithographically patterned on the –z face and poled using liquid electrodes [8]. To lower the capacitance of the device, the top electrodes were reduced to strip electrodes matching the dimensions of the grating. The electrodes were patterned using a lift off process by which 500nm of aluminium was deposited. The same thickness of aluminium was deposited to form a ground plane on the opposite face. The y faces were then end polished to optical flatness.

Initial optical measurements were performed with a 70mW Nd:YAG laser at 1.064μm and a device with period 70μm and length 30mm. This corresponded to an internal angle of 0.19 degrees and an external launch angle of 0.44 degrees. The laser was focussed to give a beam waist of 100μm at the centre of the crystal and a confocal parameter greater than the crystal length. The zeroth and first order fractional diffraction efficiencies were measured as a function of applied voltage, V, between the top and bottom electrodes. Results are shown in Figure 2, with the solid lines indicating the theoretical efficiencies as described by Equation 1 with an offset relating to the effect of higher order diffraction, and the points indicating the data taken. We can see that these give a good agreement.

From Figure 2 it can be seen that the effective zero field point occurs at 32 V and not 0 V. We believe that this is due to a residual refractive index grating after poling. The total diffraction efficiency is reduced by parasitic higher order spots, an effect which is minimised at 100V where the maximum power transfer occurs between zeroth and first orders. The higher order spots are believed to be due to the relatively low grating Q factor and non-sinusoidal grating components present in our PPLN grating. Numerical simulations of this effect will be presented. The effect of device temperature and annealing history on the device bias will also be presented.

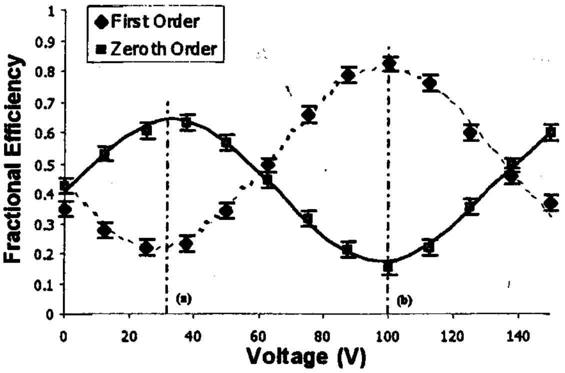

Figure 2: Fractional efficiency of first and zeroth orders with applied voltage. (a) shows the effective zero field point and (b) shows the highest efficiency offset bias.

The freedom in device design allows us to alter the poling period to ameliorate the photorefractive damage in $LiNbO_3$. We will present results over a range of wavelengths and temperatures quantifying this reduction.

In conclusion, we report the fabrication of a Bragg EO modulator with a grating period of 70μm and length 30mm. We report initial results at 1.064μm showing high fractional diffraction efficiencies and an investigation into photorefractive damage in visible and blue operation.

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