High Performance Electro-Optic Polarization Conversion Type Modulator for Short-Wavelength Light Using Periodically Poled $MgO:LiNbO_3$

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Abstract: We fabricated an EO polarization conversion type modulator for short-wavelength light using periodically poled $MgO:LiNbO_3$ and evaluated the characteristics by using an external grating complex resonator laser. The maximum conversion efficiency 91% was obtained. The wavelength selectivity of the modulator was in good agreement with the calculated value.

Introduction: Ferroelectric $LiNbO_3$ (LN) crystal has large nonlinear-optic (NLO) and electro-optic (EO) coefficients. Periodically poled LN (PPLN) has been applied to NLO quasi-phase-matched wavelength conversion devices and EO devices.[1–6] One of the EO devices is a polarization conversion type modulator, and the intensity modulation of the near-infrared light has been demonstrated.[3–5] Recently, we reported the polarization conversion type modulator for short-wavelength light using periodically poled MgO:LN (PPMgLN).[6] PPMgLN has not only excellent EO properties but also higher resistance to photorefractive damage than non-doped LN. Therefore it is suitable for the modulation of high power and short-wavelength light. Since this modulator has narrow wavelength-bandwidth, wavelength selective modulation and multi-channel modulation for optical communication and signal processing can be realized by cascading a number of modulators with slightly different grating periods. In this paper, we report fabrication of a compact EO polarization conversion type modulator using PPMgLN and evaluation of the modulation characteristics by using an external grating complex resonator GaN laser.

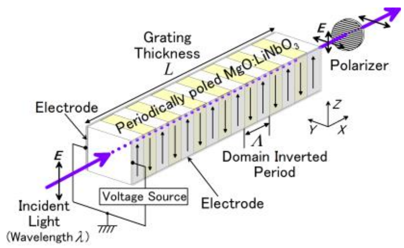

Fig. 1: EO polarization conversion type modulator using PPMgLN.

Operation Principle: A schematic illustration of EO polarization conversion type modulator using PPMgLN is shown in Fig. 1. When an electric field parallel to Y axis is applied to MgO:LN, the optical principal axes of the index ellipsoid rotate and non-diagonal components of the dielectric tensor are generated through the EO effect. When the appropriate field is applied to PPMgLN with the period to satisfy the phase matching condition between the ordinary and extraordinary polarized lights, the polarization conversion takes place. The grating period required to satisfy the phase matching condition is given by $\Lambda = \lambda/(n_o - n_e)$, where λ is the wavelength, n_o and n_e are the ordinary and extraordinary refractive indices. From the coupled-mode equations, the conversion efficiency under the phase matching condition can be written as

$$\eta = \sin^2 [2Lr_{51}(n_e^3 n_o^3)^{1/2} E/\lambda], \qquad (1)$$

where L is the grating thickness, r_{51} is the EO coefficient and E is an applied electric field parallel to Y axis. To modulate the violet light with $\lambda = 407$ nm ($n_e = 2.31$, $n_o = 2.42$),[7] we determined the grating period $\Lambda = 3.6$ μm. For the grating thickness $L = 1.0$ mm and $r_{51} = 28$ pm/V,[8] the applied field required for $\eta = 100\%$ was estimated as $E_{\eta\,\max} = 0.86$ kV/mm.

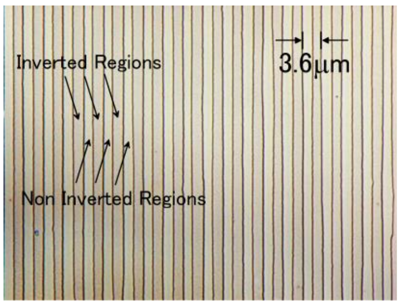

Fig. 2: Fabricated domain-inverted structures after etching.

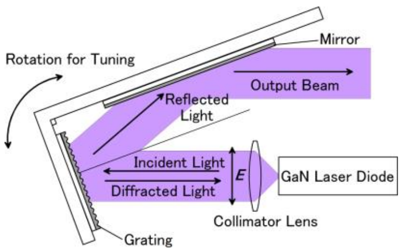

Fig. 3: Complex resonator laser using external grating.

Fabrication: We fabricated domain-inverted structures with 3.6

μm period by applying voltage in 0.2 mm^t Z-cut MgO (5 mol%) : LN.[6, 9] Figure 2 shows the micro-photograph of the fabricated structures after etching. High-quality domain-inverted gratings were obtained over 1.0 × 1.0 mm^2 area. Fabricated PPMgLN was annealed at 600°C for 15 hours in the O_2 atmosphere to reduce the relaxation phenomena during the modulation.[2] The ±X and ±Y faces were polished, and Al electrodes for the modulation were deposited on the ±Y faces. The size of the crystal was 2.3 mm (Y direction) × 5 mm (X direction). The required applied voltage for η = 100% was estimated as 2.0 kV.

Evaluation of modulation characteristics: The spectrum width of an ordinary Fabry-Perot GaN laser is broad due to multi-mode lasing. Therefore it is difficult to obtain high conversion efficiency in the modulator which has narrow wavelength bandwidth (< 1nm). We constructed a complex resonator laser using an external grating as shown in Fig. 3. The beam from the GaN laser diode was collimated by a lens and incident to the grating of 3600 lines/mm (Littrow mounting configuration). As shown in Fig. 4, the spectrum width (FWHM) of the complex resonator laser was < 0.04 nm, which was much narrower than that of the laser without the grating. Also, the wavelength tuning over a range of ~1.5 nm was obtained by changing the angle of the grating.
We evaluated the characteristics of the fabricated modulator. The beam of the complex resonator laser (λ = 407 nm) was incident as the ordinary or extraordinary polarized light in PPMgLN. The voltage was applied to the modulator, and the vertical and horizontal polarization components of the output light were measured using a polarizer and a photodiode. The measured dependence of the horizontally and vertically polarized light powers upon the applied voltage is shown in Fig. 5. In Fig. 5(a), the vertically (horizontally) polarized light power was maximum (minimum) at 2.6 kV, and the maximum conversion efficiency 89% (= max converted light power / total light power) was obtained. In Fig. 5(b), the horizontally (vertically) polarized light power was maximum (minimum) at 2.6 kV, and the maximum efficiency 91% was obtained. Next, the wavelength selectivity of the modulator was measured. Figure 6 shows the dependence of the conversion efficiency upon the incident light wavelength. The FWHM of the experimental result was 0.7 nm, which was in good agreement with the calculated value 0.6 nm. This result means that fabricated domain-inverted structures has good uniformity.

Conclusions: We fabricated the EO polarization conversion type modulator using PPMgLN and evaluated the modulation characteristics. The maximum conversion efficiency as high as 91% was obtained. The wavelength selectivity of the modulator was in good agreement with the calculated value.

References

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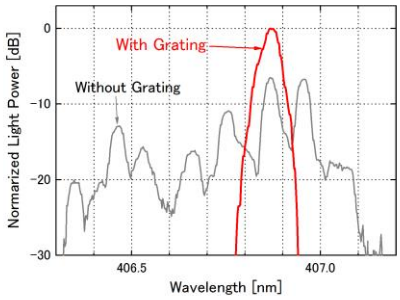
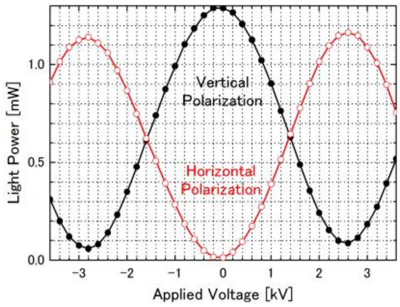
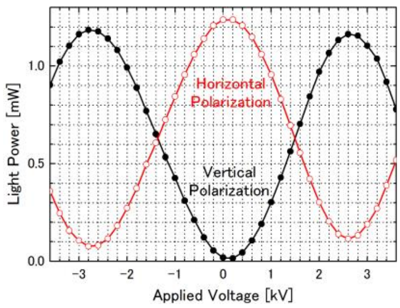


Fig. 4: Comparison of oscillation spectra. (Resolution: 0.04nm)



(a) Input: Vertical polarization



(b) Input: Horizontal polarization

Fig. 5: Dependence of powers of polarization components upon applied voltage.

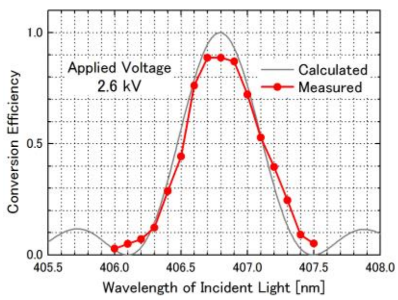


Fig. 6: Dependence of conversion efficiency upon wavelength.
(Input: Vertically polarized light)