EO Spatial UV-Light Modulator Using Periodically-Poled Deep-Proton-Exchaged s-$LiTaO_3$ Waveguide

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***Abstract*— We propose and demonstrate an electro-optic spatial light modulator using a deep-proton-exchanged waveguide in periodically poled MgO:s-$LiTaO_3$ thin crystal for UV laser light. The fine pixel profile, the good contrast and low driving voltage were accomplished at 355nm wavelength.**

Keywords-component; proton-exchage; domain inversion; lithium tantalate; spatial light modulator; ultraviolet (UV) laser

I. Introduction

A few approaches for electro-optic (EO) laser light modulation using ferroelectric domain inverted grating structures were demonstrated [1, 2]. We are developing EO Bragg deflection spatial light modulators aiming at applications to mask-less microlithography apparatuses and laser display systems [3]. For application to lithography systems, in particular, high-speed modulation of high-power UV laser light is an essential requirement. Therefore, crystals having a high optical damage threshold, e.g., MgO doped stoichiometric lithium tantalite (MgO:SLT) [4] should be adopted to avoid the optical damage problem [2]. Use of a waveguide structure allows implementation of compact and stable devices of low driving voltage and small pixel size. However, conventional shallow waveguides, such as annealed proton-exchanged waveguides [5], having a shallow mode depth of several microns are not suitable for implementation of modulations for high power laser light. Waveguides of lager mode size are required to avoid the optical damage by reducing the light power density, and reduce propagation losses caused by scattering. In this report, we propose a new device structure using a deep-proton-exchanged (DPE) waveguide. We developed a DPE waveguide in MgO:SLT of a mode size as large as 20μm. We accomplished successful spatial light modulation at 355nm UV wavelength in the modulator constructed by the DPE waveguide in a periodically poled crystal. The fine pixel profile and the good contrast were obtained.

II. Device Description and Design

The EO Bragg deflection modulator as a building block of the spatial light modulator is shown in Fig.1. Let Λ, L, λ, n_e be the grating period, the grating thickness, the optical wavelength and the extraordinary refractive index, respectively. An

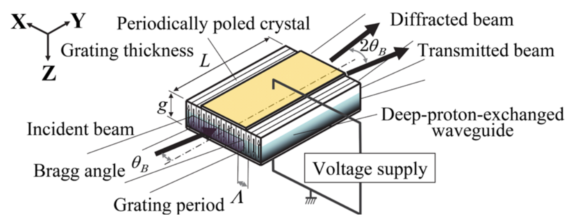

Figure 1. Configuration of the electrooptic Bragg deflection modulator.

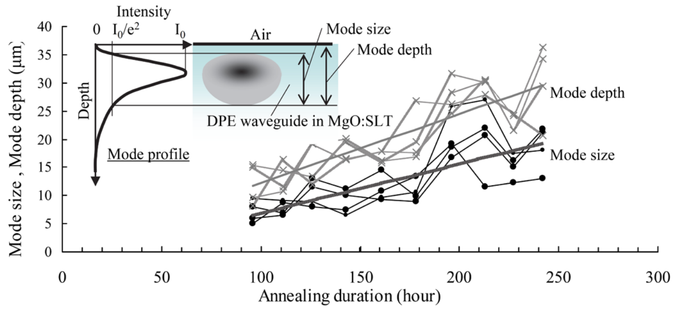

Figure 2. Measured result of the mode size and the mode depth.

incident beam with a polarization parallel to the Z axis enters the waveguide in a Z-cut MgO:SLT crystal at the Bragg angle $\theta_B = \sin^{-1}(\lambda/2\Lambda)$. When the driving voltage is applied between the electrodes, the light is diffracted. The efficiency η for the fundamental order Bragg diffraction is given by

$$\eta = \sin^2(\kappa L), \quad \kappa = \pi\Delta n_e/\lambda, \quad \Delta n_e = -2n_e^3 r_{33} V/\pi g, \quad (1)$$

where κ and Δn_e are the coupling coefficient and the Fourier amplitude of the periodic modulation in extraordinary refractive index, V is the voltage applied between electrodes, g the distance between electrodes, and r_{33} the Pockels constant [6]. We adopted the DPE waveguide to avoid the optical damage, reduce the propagation loss, and improve the pixel profile. In order to reduce the driving voltage, the distance between electrodes and the crystal thickness should be small. To obtain the high resolution (small pixel size), the electrode width, the distance between adjacent electrode segments and the domain period should be short. In addition, the crosstalk should be minimized. To satisfy these requirements, we

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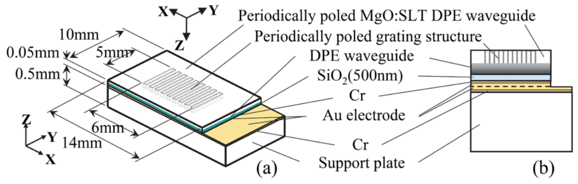

Figure 3. Fabricated modulator. (a) Perspective view. (b) Cross section.

adopted Λ=7.5μm, g=50μm and L=5mm. For λ=355nm, r_{33}=36.0pm/V and n_e=2.34 (MgO:SLT), the voltage for the maximum diffraction efficiency was calculated as 6V from (1).

III. Fabrication

As a preliminary experiment to establish the DPE waveguide fabrication technology, waveguides in 1 mol% MgO:SLT were fabricated by proton exchange in pyrophosphoric acid at 230 deg for 20 min and annealing at 400 deg with various annealing duration. A laser beam at 355nm wavelength with a diameter of 23μm was fed into the fabricated waveguides, and the guided mode profiles were measured on the output facet. The measured mode size and depth, defined in the inset of Fig.2, are plotted in Fig.2 against the annealing duration. It turned out that an annealing duration of 200 hours or longer was necessary to obtain a mode size with a diameter of 20μm.

Fig.3 shows the fabricated modulator. This modulator consists of two elements. One of the elements is a DPE waveguide in a Z-cut MgO:SLT crystal with a thickness of 50μm. A periodically poled grating structure with a period of 7.5μm and an interaction length of 5mm was formed in the central area. Another one is a SLT crystal with a thickness of 500μm as a robust support plate. Then, a planner waveguide was formed in the crystal by proton exchange in pyrophosphoric acid at 230 deg for 20 min and annealing at 400 deg for 238 hours. A SiO_2 buffer layer was deposited by RF sputtering. Cr/Au thin films were deposited over each crystal. The DPE waveguide was direct bonded to the support plate with Au layers in-between. The DPE waveguide substrate was polished to reduce the thickness to ~50μm.

IV. Experimental Result

Fig.4(a) shows the experimental setup for spatial light modulation with multiple pixels. A mode-locked neodymium 3rd harmonic laser of 355nm wavelength was used. Electrodes of 50 segments with a period of 7.5μm were formed on a separate glass substrate. These electrode segments were put in contact with the waveguide crystal with orientation parallel to the diffracted beam as shown in Fig.4(b), and were driven by parallel signals. Fig.5(a) and (b) show 2 examples of spatial light modulation patterns obtained at 10V driving voltage. In this demonstration, adjacent 5 electrodes were connected together to compose one pixel of 37.5μm width. Fig.5(a) shows a pattern where 5 pixels of odd serial numbers were diffracted, and Fig.5(b) shows a pattern where 5 pixels of even serial numbers were diffracted. The fine pixel profile and the good contrast suitable for mask-less microlithography apparatuses were accomplished.

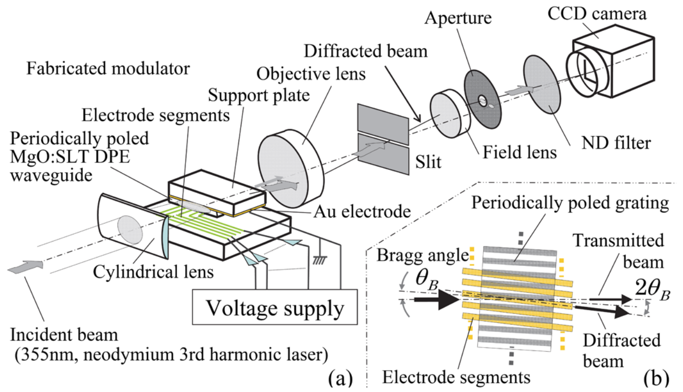

Figure 4. Experimental setup for spatial light modulation. (a)Perspective view. (b)Orientation of electrodes.

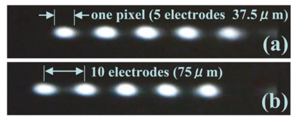

Figure 5. Photograph of the spatial light modulation output.

V. Conclusions

We have successfully demonstrated the EO spatial UV-light modulator using periodically-poled deep-proton-exchanged MgO:SLT waveguide. We are developing the spatial light modulator of higher resolution and larger number of pixels.

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