技術報告

A Method for Making High-Resolution
Pockels Readout Optical Modulator (PROM)

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The resolution of a Pockels readout optical modulator (PROM) using a $Bi_{12}SiO_{20}$ single-crystal plate has been improved. This improvement was achieved by lapping the $Bi_{12}SiO_{20}$ crystal to reduce its thickness to $50\,\mu m$ and by using thin glass plates as insulating layers. The new PROM has a resolution of 34 lp/mm and an effective area of $18\times18\,mm^2$.

1. Introduction

A spatial light modulator (SLM) is one of the key devices in optical computing and optical image processing. However, the SLMs available up to now have never reached a stage of practical use in spite of many proposals for use. In order to apply the SLM to practical uses, it is necessary to develop a SLM with a large capacity for information and a small physical volume, that is, a high-resolution SLM. A Pockels readout optical modulator (PROM) consists of an electrooptic and photoconductive crystal plate, such as a $Bi_{12}SiO_{20}$ (BSO) single crystal, and insulating layers. In previous PROM devices, the BSO plate was made by lapping a bulk crystal to reduce its thickness to hundreds of μm. Parylene films, mica plates or thin glass plates were often used as the insulating layers. The properties of a conventional PROM device with a $300\text{-}\mu m\text{-}$thick BSO plate and $20\text{-}\mu m\text{-}$thick glass plates[1] are shown in Table 1. Insufficient resolution is the most serious problem.

Deterioration of a readout image in operation of the PROM is caused by the distortion of charge distribution in the BSO crystal plate originating from the intensity distribution of a write-in image and the bend of the line of electric force in the crystal plate. The distortion of charge distribution and the bend of the line of electric force are generated in the write-in process through the following mechanism. An exposed light generates hole-electron pairs. The major carriers (electrons) in the BSO crystal move in the longitudinal direction, the direction along the thickness of BSO plate, by means of an externally applied uniform electric field, while the holes stay at the position where the pairs of electrons and holes are created. Some of the electrons are trapped in the BSO crystal plate, and encounter holes remaining in the crystal. Other electrons travel far enough to reach the rear surface of the crystal plate. The charges stored in the crystal plate increase as the exposure increases. The changes in charge distribution in the longitudinal and the transverse directions appear, and the contribution of the charge distributions to the electric field in the crystal plate increases. Then the transverse component of the electric field increases with stored charges. The final distribution of the charges distorts the electric field in the BSO crystal plate from the intensity distribution of the write-in image.

Suggestions favorable to solving this problem are that (1) the BSO crystal plate used in the PROM be as thin as possible, and (2) the

dielectric constant of insulating layers in the PROM be as large as possible. In this paper, a new trial to apply the first suggestion was made through the improvement of the polishing process of the BSO crystal plate and insulating layers.

2. New Improved Methods

A thin BSO crystal plate is necessary for providing PROM with high resolution since the transverse component of the electric field in the crystal plate decreases as its thickness decreases. However, in the conventional method for making a PROM, the BSO crystal plate is made by lapping a bulk crystal. It is very difficult to obtain stationary BSO plates thinner than hundreds of μm. Recently a new method for making PROM was proposed by Nagao and Mimura.[2] In this method, a PROM is made by epitaxially growing thin BSO crystal film on a conductive BSO substrate, and it was proven that the use of a thin BSO crystal plate is effective for increasing the resolution of PROM. Unfortunately, it is difficult to grow a uniform single-crystal film with large area, although it is easy to make a uniform-quality crystal plate using a bulk crystal. This paper describes a new method of developing a high-resolution PROM with a thin BSO crystal plate made by polishing a BSO bulk crystal. The manufacturing process of the new method is illustrated in **Fig. 1**. First, two pairs of an optical flat-glass plate and a glass plate for an insulating layer were prepared as follows: (1) one surface of the optical flat-glass plate was coated with an antireflection film, and a transparent electrode was evaporated on the other surface, and (2) one side of the other glass plate was polished to give it a flatness within $\lambda/10$. Next, the polished side of the glass plate was jointed face-to-face with epoxy resin to the transparent electrode sides of the optical flat-glass plate.

To form thin insulating glass layers, the bare glass plates were polished to 10–15 μm thickness on the optical flat-glass plate. A thick BSO crystal plate with one surface finely polished was joined to the insulating layer and polished on the insulating layer. The polishing process was similar to that for glass, but the BSO crystal plate was not heated in the process to avoid thermal stress.

The other combination of insulating layer and electrode made according to the above-mentioned process was attached to the polished thin BSO crystal plate to form a PROM. This method ensures
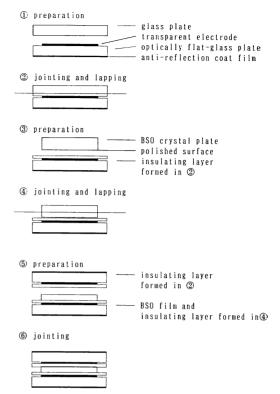
① preparation

— glass plate
— transparent electrode
— optically flat-glass plate
— anti-reflection coat film

② jointing and lapping

③ preparation

— BSO crystal plate
— polished surface
— insulating layer formed in ②

④ jointing and lapping

⑤ preparation

— insulating layer formed in ②
— BSO film and insulating layer formed in④

⑥ jointing

Fig. 1 Manufacturing process of the new PROM.

efficient manufacture of the PROM with a BSO crystal plate of thickness less than 50 μm. We repeated this process many times but failures were few in number. In addition, this method is adequate for making a PROM with a large effective area.

Table 1 Properties of PROM.

	New PROM	Conventional
Thickness of BSO	50 μm	300 μm
Material of insulator	glass BK 7	glass BK 7
Thickness of insulator	10 μm	20 μm
Size of effective area	18×18 mm^2	12×12 mm^2

Table 2 Experimental characteristics of PROMs.

	New PROM	Conventional
Half-wave voltage	56 kV*	12.6 kV
Resolution	34 lp/mm	24 lp/mm
Contrast	10^4	4.5×10^3
Sensitivity	200 μJ/cm^2	20 μJ/cm^2

* This value was estimated from the experimental curve of the electrooptic effect.
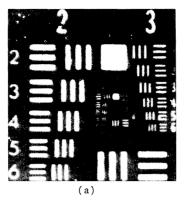
(a)   (b)

Fig. 2 Readout images from the new PROM: (a) resolution test chart, (b) a picture with gray levels.
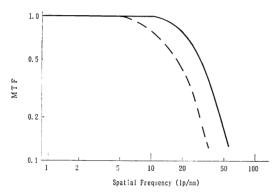

Fig. 3 Experimental MTF curves. Solid curve is the new PROM and broken curve is the conventional PROM.

Fig. 4 Characteristic curves of transmission versus exposure. Solid curve is the new PROM and broken curve is the conventional PROM.

3. Experimental Results

The properties of typical PROMs obtained in this experiment are shown in **Table 1**. To confirm the usefulness of the proposed method for making a PROM with high resolution and/or large effective area, a PROM with a thin BSO crystal plate 50 μm thick and an effective area of 18×18 mm^2 was made in this experiment.

Experimental characteristics of the new PROM are given in **Table 2** with those of the conventional PROM for comparison. The voltage applicable to the PROM was about 5 kV, which was limited by the dielectric breakdown voltage of the insulating glass layers. The recorded images of a resolution test chart and a picture on the PROM were read out by red light ($\lambda = 660$ nm) emitted from a LED (H-3000 made by Stanley Co.). The readout images are shown in **Fig. 2**. Experimental MTF curves of the new PROM and

the conventional one are shown in **Fig. 3**. From this figure, it is found that the resolution of the new PROM is higher than that of the conventional PROM. Characteristic curves of transmission versus exposure for the new PROM and the conventional one are shown in **Fig. 4**. In this figure, the transmission of the PROMs is normalized by the maximum transmission of each PROM. The sensitivity of the new PROM is lower than that of the conventional PROM because the thickness of the photosensitive layer (BSO crystal plate) of the former is thinner than that of the latter.

Unfortunately, the sensitivities of the new PROMs are lower than that of the conventional PROM and there are some other problems. In the PROM made by the new method, the readout image was very dark because the half-wave voltage of the PROM was too high, the BSO crystal plate was very thin and much of the applied voltage

dropped across the insulating layers. The half-wave voltage was estimated to be about 56 kV. Many interference fringes appeared in the readout image in the low spatial frequency region. This results are serious problems when the PROM is used in coherent optical image processing. The noise interference fringes will be reduced by coating antireflection films on the interfaces in the PROM.

The new method is useful for making PROMs with large effective areas. A PROM with an effective area of 40×40 mm² was made easily by this new method.

References

1) H. Jing, J. Chen and T. Minemoto : "A PROM device using thin glass plates for insulating layers," Jpn. J. Opt., **18** (1989) 627–631.
2) Y. Nagao and Y. Mimura : "Thin BSO film spatial light modulator," *Extended Abstracts of the 50th Autumn Meeting of the Japan Society of Applied Physics* (1990) 28 p-ZD-3.