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Magnetooptic Spatial Light Modulator with One-Step Pattern Growth on ion-milled Substrates by Liquid-Phase Epitaxy

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1. Introduction

A spatial light modulator (SLM) is a real-time reconfigurable device capable of modifying the amplitude(or intensity), phase, or polarization of an optical wavefront as a function of position across the wavefront. Various types of reusable modern SLMs with two-dimensional pixel arrays have been intensively developed over the past three decades.

A magneto-optic spatial light modulator (MOSLM) provides a visual image using the Faraday rotation effect of magneto-optical garnet film [1, 5-9]. The MOSLM has the advantages of high switching speed, robustness, nonvolatility, and radioactive resistance [2]. However, the MOSLM has significant disadvantages, as follows. A large drive current is required to produce a sufficient magnetic field to nucleate the reversed magnetization at selected pixels. Since a physically isolated pixel has a deep gap produced by the ion milling process, a planarization process of the deep gap is required to deposit the conductor lines. Also, the isolated positions in each pixel have had to be ion-implanted to reduce the external bias field for saturating pixels.

Recently, selective area growth of Ⅲ - V compound semiconductors has been investigated by many researchers. Ⅲ- V compound semiconductors are grown on nonplanar or SiO2 masked substrates. Few studies have been performed about one-step pattern growth in relation to selective area growth of other materials. Krumme et al. and Okamura et al. have studied selective area epitaxy of iron garnet films on ion-bombarded substrate by rf magnetron sputtering [3]. Yokoi et al. have investigated one-step growth of magnetic garnet waveguides on masked Ti substrate by liquid-phase epitaxy (LPE) [4].

In this study, we report on a new approach to pattern formation of iron-garnet films on ion-milled substrates by LPE and its application to magnetooptic spatial light modulator. This new method overcomes the disadvantages associated with groove etching for the confinement of magnetic regions among which are limited geometrical resolution due to underetching and nonplanar surface topology. Thus, this method offers new possibilities for the fabrication of integrated magneto-optic light switch arrays, magnetic waveguides and similar devices.

2. One-step pattern growth

The concept of one-step pattern growth is based on the combination of a single-crystal epitaxial film growth by LPE and a impeded film growth on a substrate whose surface has been locally damaged and milled by ion bombardment before film deposition. Preparing a one-step pattern growth in an iron-garnet film comprises five process steps: (i) proper treatment of the single-crystal Sm substituted gallium-garnet substrate (SGGG) to produce an unperturbed surface for epitaxy; (ii) formation of a photoresist mask on the substrate; (iii) ion-milling of the thickness of 100 nm on the unprotected substrate surface as pixel gap areas; (iv) removal of the mask; and (v) LPE of the iron-garnet film onto the bare substrate. The thickness of the grown magnetic garnet film of $(BiYGd)_3(FeGa)_5O_{12}$ was about 3.5 μm. Figures 1 and 2 show a micrograph of pixels formed by one-step growth with a pixel gap of 2 μm and several pixel sizes of 5, 10, and 15 μm, and its SEM image. These results clearly show the interface between pixel (expitaxial area or protected area) and pixel gap (perturbed epitaxial area or unprotected area) guides magnetic walls just like a groove.

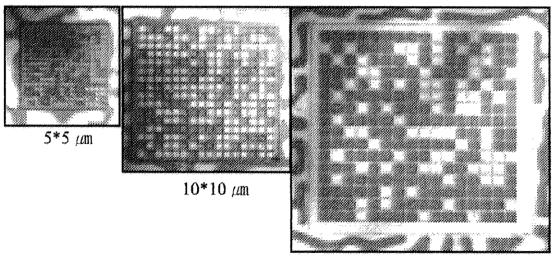


Fig.1. Micrograph of pixels formed by one-step growth with a pixel gap of 2 μm and several pixel size of 5, 10, 15 μm.

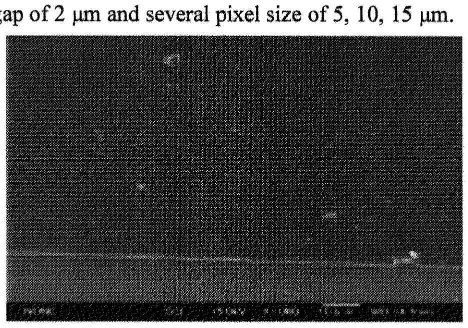


Fig.2. SEM image of pixels formed by one-step growth.

3. Fabrication of the MOSLM

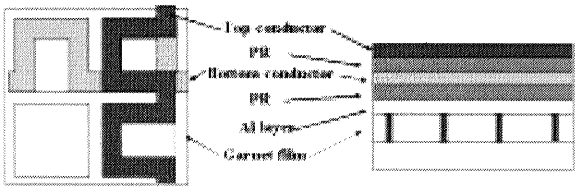
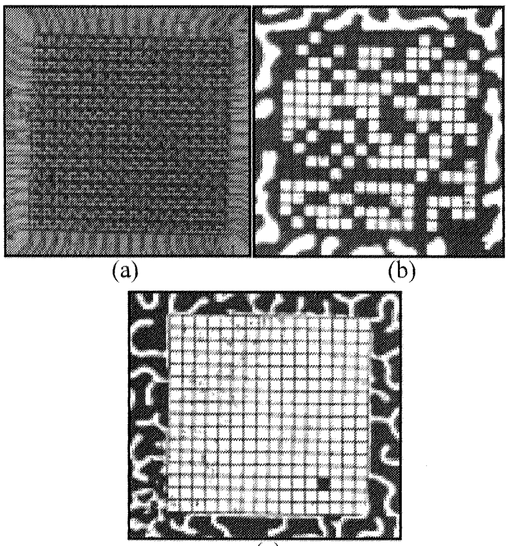


Fig.3. Schematic of a structure of MOSLM and its cross section



(a) (b)

(c)

Fig. 4. Microphotographs of (a) bottom and top conductors of a fabricated MOSLM device, (b) its pixel, and (c) switched pixel by bottom and top conductors and external bias field.

Figure 3 shows a schematic of a structure of MOSLM and its cross section. The MOSLM had the layer structure of substrate (SGGG) / iron garnet pixel formed by one-step growth / reflector layer (Al, 200 nm) / insulator layer (PR, 330 nm) / bottom conductor (Al, 500 nm) / insulator layer (PR, 430 nm) / top conductor (Al, 800 nm), in turn, as shown in Fig. 4a. Finally, as a passivation layer, a polymer layer 5 μm thick is deposited over the entire device and removed from the bonding pads. And then the dicing and wire bonding is done. The number of pixels was 16x16=256. The pixel was 16x16 μm square wide and pixel gap was 2 μm wide. The width of bottom and top conductor is 4 μm. The pixels are seen as light or dark depending upon their magnetization direction by the external bias field (Fig. 4b).

For effectively operating the MOSLM, the magnetic field generated by the current flowing in the only single conductor line is designed to be insufficient to switch the state of a single pixel. The combined magnetic fields induced by the current flowing in the bottom and top conductor lines switch the state of selected pixels only. The orthogonal conductor lines make it possible to switch individual pixels by random selection. Figure 4c shows the micrograph of switched pixel of the fabricated prototype MOSLM. When the current of 80 mA for the bottom conductor and 120 mA for the top conductor, respectively, under no external bias field was carried, the pixels were demagnetized. Moreover, the prototype MOSLM fabricated in this study is switched by applying currents of 40 mA for the bottom conductor line and 80 mA for the top conductor line under external bias field of 20 Oe. Although our MOSLM has about 3 times wider conductor width and about 2 times thicker conductor, compared to the conventional MOSLM, a driving current of our MOSLM device is over 2 times smaller than that of the conventional MOSLM which requires minimum currents of 70 mA and 150 mA for the bottom and top conductor lines, respectively.

4. Conclusions

We demonstrated one-step pattern growth of iron garnet films on ion-milled substrates by LPE and its application to magnetooptic spatial light modulator. This new method overcomes the disadvantages associated with groove etching for the confinement of magnetic regions among which are limited geometrical resolution due to underetching and nonplanar surface topology. Thus, this method offers new possibilities for the fabrication of integrated magneto-optic light switch arrays, magnetic waveguides and similar devices.

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