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Magneto-optical Spatial Light Modulator for 3D Holographic Display

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Abstract

Magneto-optical spatial light modulator (MOSLM) have been developed for realizing 3D holography. It comprises magnetic tunneling junctions with rare-earth transition metal magnetic materials such as Gd-Fe and Tb-Fe-Co, which is well known MO materials. The device is driven by current induced magnetization switching (CIMS). And magneto-optical Kerr effect was used for modulating reflected light. Switching current density of the MTJs shows about 1×10^6 A/cm^2, which was one of the smallest current density for CIMS. We fabricated a MTJs array on an active matrix backplane transistors with 100×100 pixel format and a pixel pitch of 2 μm, which pixel pitch could drastically increases the viewing zone of the reconstructed holography images. CIMS of the light modulation layer was accomplished which current was supplied from the back plane transistor with bias magnetic field. A successful demonstration of displaying a 2-dimmensional character image was achieved.

1. Introduction

Holographic movie (i.e. electro-holography) [1], [2] has long been considered as an ideal technology and the ultimate goal for 3D imaging, since it reconstructs the same wavefronts of light that are diffracted from an object. It provides for natural and realistic images with motion parallax, without the need for specialized glasses used in stereogram imaging. A lot of methods have been proposed for realizing the electro-holography with spatial light modulators (SLMs) [2]-[4]. One of the most difficult issues to realize electro-holography is narrow viewing zone which is originated from insufficiently small pixel pitch of the display device. The pixel pitch has to be less than one micron to obtain as large viewing zone angle as >30 degree, which none of the current commercial SLMs can satisfy. High resolution spatial light modulators have been developed for holography application, such as an optical addressing SLM with photo-refractive polymer [5] and magnetic materials [6]. Those methods have the advantage in extending the scale of the display, however additional writing laser scanning system could become large and might not appropriate for consumer application such as TVs. On the other hand, electrically address MOSLM driven by current induced magnetization switching has also been investigated [7]. In this article, we present recent progress of the magneto-optical (MO) SLM which is controlled by backplane transistor (spin-SLM).

2. MTJ based light modulator array driven by MOS-FET backplane

2-1. The spin-SLM

Figure 1 shows a cross-sectional schematic illustration of a pixel of the spin-SLM. A magnetic tunneling junction (MTJ), which consists of a pinned layer, MgO spacer, and light modulation layer, is sandwiched by transparent and MOS-FET drain electrode. The magnetization of the light modulation layer reversed by the spin transfer torque produced by injection current. A pixel was selected using a MOS-FET backplane transistor by applying voltage to the gate. An incident light can be modulated by magneto-optical Kerr effect which depends on the direction of the magnetization of the light modulation layer. The pixel size can be easily reduced to sub-micron dimension since the pixel can be fabricated by lithography methods, which is crucial for holography application to obtain large viewing zone of the reproduced images. Moreover, switching speed is very fast compared to the conventional SLMs, such as the liquid crystal on silicon (LCoS) or digital micro-mirror device (DMD), which is also very important for extremely large number of pixels.

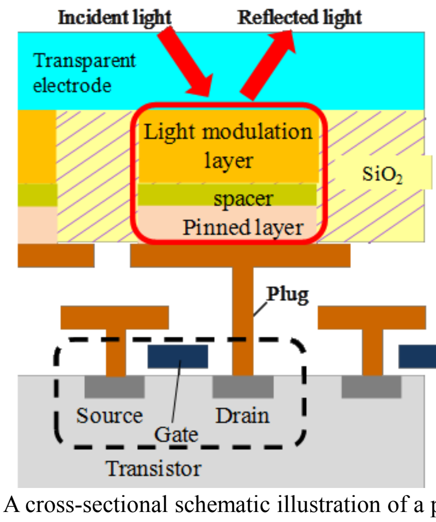

Fig. 1 A cross-sectional schematic illustration of a pixel of the spin-SLM.

2-2. Magnetic tunneling junctions for light modulator application

It is important to note that MTJ for SLM application requires high spin injection efficiency for reducing switching current with MO materials which normally does not show high spin polarization. The MTJ is composed of Tb-Fe-Co (20 nm) /Co-Fe (0.5nm) pinned layers, MgO spacer and Co-Fe/Gd/Gd-Fe light modulation layers, which is well known for MO materials. Coercivity of the pinned layer was about 2 kOe (not shown), which was much larger compared to the light modulation (free) layers. Figure 2 shows Kerr hysteresis loops (λ=780 nm) of Gd-Fe based light modulation layers with ±0.5 kOe (minor loops). The Gd-Fe shows perpendicular magnetic anisotropy (PMA). However, when the Co-Fe (0.3 nm) was inserted between MgO and Gd-Fe for obtaining higher spin polarization, the PMA of the Gd-Fe was destroyed and became in-plain. This is because the Co-Fe having large saturation magnetization (M_s) and in-plane anisotropy is exchange-coupled to the Gd-Fe, and demagnetization of the Co-Fe surpass the PMA of Gd-Fe. As the blue plot of the Fig. 2 indicated, the additional layer of Gd between the Co-Fe and the Gd-Fe layer successfully induced the PMA, which could be attributed to a reduction of M_s in Co-Fe/Gd by forming anti-ferro coupling of Co-Fe and Gd.

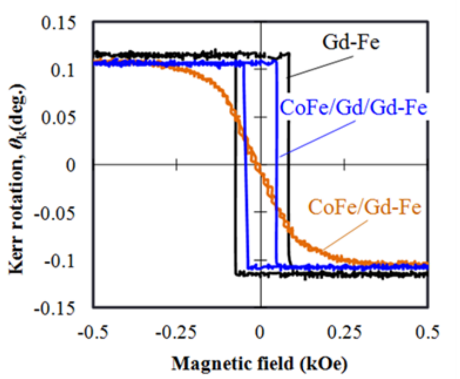

Fig. 2 Kerr loops for various light modulation layers

We fabricated MTJs of [Tb-Fe-Co (20 nm) /Co-Fe (0.5 nm) /MgO (1.0 nm)/ Co-Fe(0.3) /Gd(0.2)/Gd-Fe(9)] for investigating electrical properties without the backplane transistor. MR ratio was about 7~12% with the insertion of the Co-Fe(0.3 nm), which was a significant increase from a MR ratio of 0.5% with the Gd-Fe light modulation (free) layer. Crystallization annealing for MgO was not applied since it may crystallize amorphous Gd-Fe as well which may result in deteriorating the PMA. This is why the MR ratio was not as large as coherent tunneling [8]. Although the MR ratio was not very high, successful CIMS was observed for the MTJ with the switching current density (J_{c0}) about 1.1×10^6 A/cm^2, which was one of the smallest current density for CIMS [9]. One should note that thickness of the light modulation layer (free layer), which is proportional to the switching current, was an several time thicker than that of the typical free layer in MRAM.

2-3. Spin-SLM controlled by Si MOS-FET back-plane.

We fabricated an array of MTJs on a Si MOS-FET backplane, which has 100 × 100 array pixel layout with 2μm pixel pitch. Stack structure of the MTJ was slightly modified, which is [Tb-Fe-Co (10 nm) /Co-Fe (0.5 nm) /MgO (1.08 nm)/ Co-Fe(0.25) /Gd(0.2)/Gd-Fe(9)], and lateral size of the MTJ was about 0.5 μm square. Electrical properties of the MTJs were evaluated through the backplane transistor. A typical *MR* loop for a pixel was shown in Fig. 3 (a). The *MR* ratio was about 10-11%, H_c was 115 Oe with a loop shift of -130 Oe, which shift is attributed from a stray field of the pinned layer. We applied voltage (height; 1.2V, width; 1μs) to switch the magnetization in MTJs through the backplane transistors with a magnetic field of -200 Oe for cancelling the stray field. Designated pixels were selected and applied voltage for displaying the text characters of "NHK". Fig. 3(b) shows differential MO image of the spin-SLM after the voltage application, and clear text image for "NHK" was observed. As you carefully investigated the image, some error pixels were found, which did not switch with voltage application, or which did switch without the voltage application. Those are attributed to the variation of the switching field.

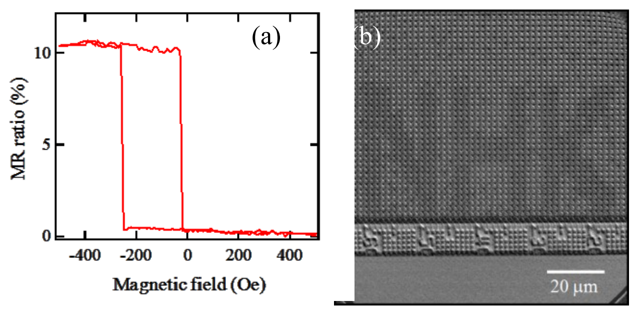

Fig. 3 (a) A MR loop for a MTJ pixel and (b) a differential MO image of the spin-SLM after spin injection.

4. Conclusions

We have developed MTJs for light modulator application with Gd-Fe/Tb-Co-Fe based materials and fabricated an array of MTJs on a MOS-FET backplane with 100 × 100 pixel layout with 2μm pixel pitch And we have shown successful demonstration of switching magnetization and its display capability of letters.

Acknowledgements

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