PS-7-23

Extended Abstracts of the 2015 International Conference on Solid State Devices and Materials, Sapporo, 2015, pp266-267

Demonstration of Spatial Demultiplexing of Polarization Modulation Signal Based on Magneto-optical Modulation of Multiplexed Lightwave in Fiber

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Abstract

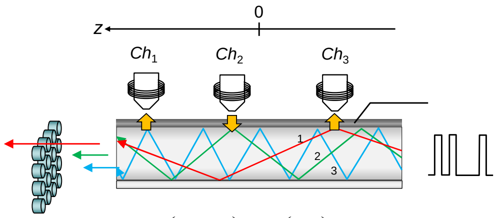
We propose a magneto-optical modulator aiming at multiplexed transmission of polarization modulation signal (PMS) based on mode multiplexing technique with a magneto-optical hybrid fiber composed of a multimode fiber and a GdFe thin layer. We experimentally show that the local modulation of magnetization in the GdFe layer generates PMS mode-selectively on a multiplexed lightwave, which is also spatially demultiplexed on the output pupil of the fiber. The result suggests that the local position of magnetization modulation on the magnetic layer and the site on the output pupil works as an input and output channel, respectively.

1. Introduction

The polarization modulation of lightwave or polarization shift keying (PolSK) is a promising approach to increase data transmission rate in optical communications [1-2], and has been extensively investigated using interferometer-type systems [3]. Here, we propose a polarization modulator of lightwave based on the magneto-optical (MO) effect [4]. An advantage of the MO modulator is that we are able to add memory functionality of the magnetization into the state of polarization (SOP) of lightwave [5]. Recent studies of ultrafast phenomena and controllability of magnetization by *all-optical* method [6-7] would incorporate high-bandwidth applications of magnetic medium in the optical system. The aim of the present work is a multiplexed transmission of polarization modulation signals (PMSs) based on mode multiplexing technique [8]. Using a MO hybrid fiber composed of a multimode optical fiber and a magnetic GdFe layer, we show the mode-selective generation of PMSs on lightwave in the fiber by local modulation of magnetization on the magnetic layer and also demonstrate their spatial demultiplexing.

2. Principle of multiplexed transmissions of PMSs

Figure 1 shows the principle of multiplexing of PMS. MO medium is adjacent to the interface of fiber core. Local modulation of magnetization at a position z changes the off-diagonal component of dielectric tensor around z by a polar Kerr effect in the present case. Because each modes of the lightwave in the fiber propagate via each passes and cause MO effect around their corresponding positions, the local positons of magnetic layer with a suitable choice work as a mode-selective input channels of PMS. After fiber transmission, the output PMSs on the each mode are detected by two dimensional detection systems. A relatively wide area of the magnetic layer makes matrix-like PMS protocol.



$$\begin{pmatrix} PMS_{Ch1} \\ PMS_{Ch2} \\ PMS_{Ch3} \\ \cdots \end{pmatrix} = (\tilde{M}) \begin{pmatrix} Ch_1 \\ Ch_2 \\ Ch_3 \\ \cdots \end{pmatrix}$$

Fig. 1 Schematic multiplexing of PMS. The center of magnetic layer is $z = 0$.

3. MO hybrid fiber and experimental

A multimode fiber having a core of 50 μm was polished from the side and removed its cover and clad layer by a rotating flap wheel for the effective optical coupling between them. Polishing length is 5 mm along fiber. The rough surface was buffed to obtain an optically flat. After then, A 20 nm-thick GdFe layer with perpendicular magnetization sandwiched between 3 nm-thick Ru layers was deposited by DC magnetron sputtering at room temperature. This MO hybrid fiber has 15 cm of length in the side of input and output of fiber, for mode-mixing of input light and transferring test of PMS, respectively. Local magnetization on the GdFe layer at the position of z (see Fig.1) is periodically switched by an AC magnetic field (2 kHz) with diameter of 1.3 mm. A s-polarized laser (λ = 783 nm) is used for an optical source, which undergo periodic MO effect at the interface of magnetic layer and the core around z by magnetization switching. Output PMS of MO fiber is detected by a two-dimensional scanning μ-MO microscopic system with a balanced detection system and a specific modulation technique [9].

4. Result and discussion

Spatial distribution of MO signal on the output pupil of fiber is depicted Fig. 2(a). The complicated pattern is due to interference by many modes in the core. Combined Figs 2 (b) show the MO signals around sites A-C in Fig. 2(a) for different z of magnetization modulation on the magnetic

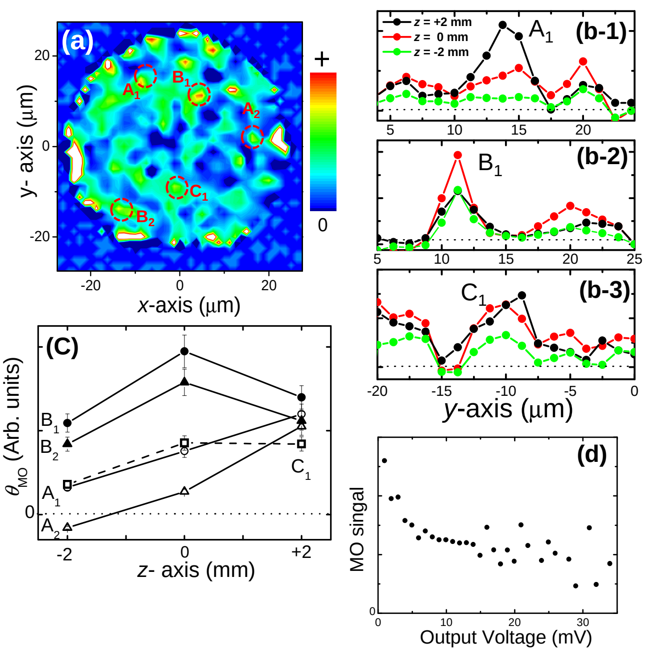


Fig. 2 (a) Spatial distribution of MO signals for s-polarization. (b) MO signals with various z around site A1, B1 and C1. (c) MO signal vs. z. (d) MO signal vs. light intensity on the output pupil.

layer. MO signals for unique z are detected around sites A_1 and B_1, in contrast to site C_1. MO signals depending on z at site A~C is shown in Fig. 2(c). Site A and B output a predominant MO signal at unique z = 2 and 0 mm compared to other positions, respectively. This means that the lightwave with PMS generated at these z positions are spatially demultiplexed on the output pupil. This result suggests that the position z_i on the magnetic layer and site X_i on the output pupil of fiber behave as an input and output terminal of PMS when a suitable threshold is set. Ambiguous peak of MO signals at site C_1 will be explained by that the lightwave, detected at C_1, causes MO effect at both z = 0 and 2 mm.

Additionally, the MO signals have a trend to become small with increasing light intensity on the output pupil. We expect that the superposition of modes of lightwave with different phase in the core compensates the amount of MO signals on each mode. Such MO signals should be extracted with each mode by mode demultiplexing technique in future.

We also roughly extracted the modes of lightwave which causes MO effect at z = 0 and 2 mm using following expression.

$$\Delta\theta_{MO}^{z=i}(x,y)=\theta_{MO}^{z=i}(x,y)-\left(\theta_{MO}^{z=j}(x,y)+\theta_{MO}^{z=k}(x,y)\right)/2 \qquad (1)$$
$$(i,j,k)=(0,\pm 2mm)$$

The site having positive value of $\Delta\theta_{MO}^{z=i}$ outputs maximum MO signal which is generated at $z = z_i$. Thus the spatial distribution of positive $\Delta\theta_{MO}^{z=i}$ mainly involves the modes undergoing MO effect at z_i. Figure 3 shows the spatial pattern for z = 0 and 2 mm, respectively. There is a clear difference between them, which suggests that magnetization modulation at the different position z generated MO signals on the different modes. That is, PMS was mode-selectively generated on the multiplexed lightwave in the fiber by local modulation of magnetization.

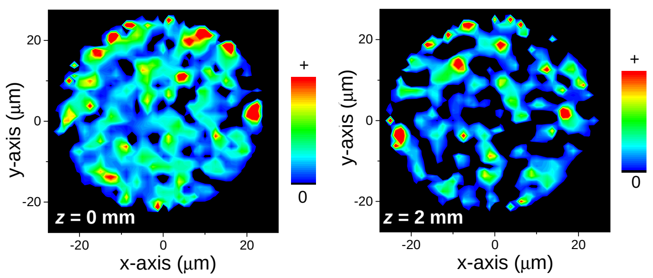


Fig. 3 Spatial distribution of differential MO signals with magnetization modulation at z = 0 (left) and 2 mm (right), respectively.

5. Conclusions

Multiplexed transmission of polarization modulation signals are discussed using a MO hybrid fiber composed of multimode fiber and GdFe thin layer. Local modulation of magnetization in the magnetic layer by an ac magnetic field generates PMS on a lightwave in the fiber mode-selectively. The PMSs are spatially demultiplexed.

Acknowledgements

We acknowledge partial supports from Advanced Photon Science Alliance Project from MEXT and Grant-in-Aid for Scientific Research (No. 22226002 and 25870217) from JSPS.

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