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Detection of magneto-optical effects in optical waveguides in close contact with thin film of GdFe alloy

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1. Introduction

There have been a few studies on dynamic control of magnetic/spin states in various magnetic materials with successive optical pumping [1-3]. If those magnetic materials could be optically coupled with an optical waveguide, polarization of light propagating in the optical waveguide may be controlled with magnetic/spin states. This would give rise to various applications such as magneto-optical memory and all-optical buffer memory [4,5]. We suppose that constituent magnetic materials should fulfill the following four points: (i) a sufficiently large magneto-optical effects, (ii) inducement of non-equilibrium magnetic states with low-power optical excitation, (iii) ease in placing it in adjacent to a waveguide, and (iv) adequate optical coupling with the optical waveguide. Concerning the criteria (i) and (ii), we have selected a thin GdFe film, the representative magneto-optical materials as exemplified by the MO storage technology [6,7], and have demonstrated coherent control of magnetization precession with low-power optical pulses with those films [5]. This material has also attracted great attention recently on the basis of the demonstration of all-optical magnetization reversal with high-power optical pulses [8,9].

In this paper, we are concerned with the criteria (iii) and (iv). Concretely stated, we study experimentally the optical coupling between a fused-silica prism and a GdFe thin film under specific configuration in which the angle of incident light on the surface of a magnetic medium is very large, as shown in Fig.1. With experimental data, we discuss the feasibility of optical coupling with very large incident angle, θ_{inc}, beyond 85°. Moreover, we show briefly the present statue of processing optical fibers aiming at the realization of an optical coupling between a fiber core a magnetic material.

2. Experimental

The sample was prepared by directly depositing a GdFe-based multilayer structure on a synthetic fused-silica prism (Edmund Optics; $n \sim 1.453$). Prior to the deposition, two vertical side-surfaces of the prism were mechanically polished to yield the optical flat surfaces. The multilayer structure, which consists of a 20-nm-thick ferrimagnetic $Gd_{0.27}Fe_{0.73}$ layer sandwiched between two 3-nm thick Ru layers, was deposited on the optically flat bottom surface of the prism by DC magnetron sputtering technique without intentionally heating the prism. As shown in Fig.1, the sample thus prepared was mounted upside down on a sample holder for optical measurements at room temperature. A *p*- or *s*-polarized laser beam (λ = 785 nm) was impinged from one of the vertical side-surface, and the angle of polarization rotation of the light beam (θ_{MO}) coming out from the opposite side surface was measured by an optical bridge detection system. Here, polarization rotation results from magneto-optical (MO) effect. Control experiments were also carried out from the air side.

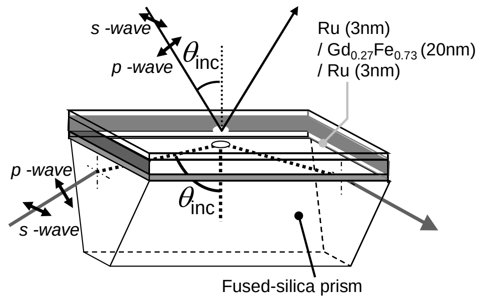

Fig. 1. Experimental configuration.

As for the fiber processing, we have been building the fiber polish system using rotating polishing disks together with in-situ optical monitoring. With this system, cover and clad layers of an optical fiber is expected to remove locally with controlled optical leakage. In the present work, we showed the results obtained from a multi-mode fiber with a core diameter of 50 μm.

3. Results and Discussions

Shown in Fig.2 (a) are dependence of MO signals θ_{MO} on the incidence angle of a light beam θ_{inc} for both *s*- and *p*-polarizations. For control experiment with *s*-polarization, the value of θ_{MO}, being θ_{MO} ~ 0.1° in the relatively small θ_{inc} region, monotonously decreases with increasing θ_{inc}. Similar trend is observed in the experiment with light propagation through a glass. For control experiment with *p*-polarization, the value of θ_{MO} stays nearly constant at θ_{MO} ~ 0.2° up to θ_{inc} ~ 65°, beyond which it increases and shows a maximum value of θ_{MO} ~ 0.35° at θ_{inc} ~ 75°, and then decreases with further increasing the incidence angle. Presence of a maximum value can be understood in terms of the Brewster angle at which the reflectivity of *p*-polarization becomes minimum, which in tern enhances MO effect. This is consistent with the θ_{inc} dependence of the reflectivity measured separately using a reference Ru/GdFe/Ru/Si(001) sample, as shown in Fig. 2 (b). As for the results obtained from the experiment with light propagation through a glass, the magnitude of θ_{MO} becomes roughly twice as large as those in the control experiment except for high θ_{inc} region. This fact can be understood in terms of the difference in the reflective index between the air and a glass. For θ_{inc} > 84°, the MO signals do not vanish but turn into negative values; e.g., θ_{MO} ~ 15 mdeg. at θ_{inc} = 88°. This fact indicates the presence of finite optical coupling between a magnetic material and an optical waveguide even at a large incident angle, which is very encouraging in view of applications of MO effects.

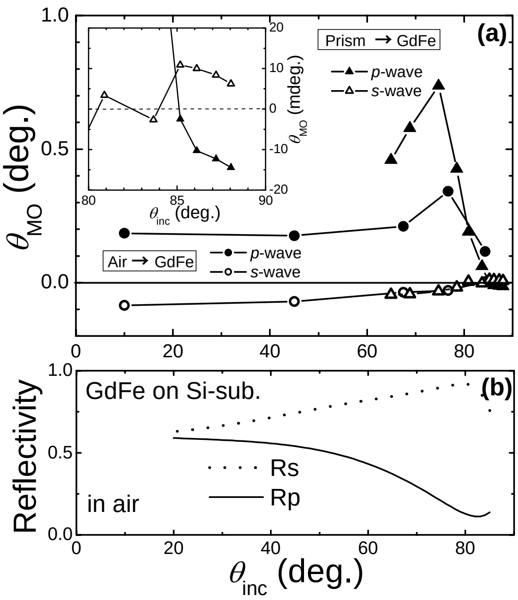

Fig. 2 (a) plots of θ_{MO} vs. θ_{inc} for four different configurations. The inset shows data at θ_{inc} > 80deg. (b) Reflectivity vs. θ_{inc} obtained from the separate sample.

The concept of controlling the depth of the scraped cove/clad layer in an optical fiber with in-situ optical monitoring (λ = 690 nm) is shown in Fig.3. The light in a core leaks out when the thickness of a clad layer is reduced by polishing away the clad layer. We stopped the process of polishing when the light intensity becomes 70 ~ 90% with

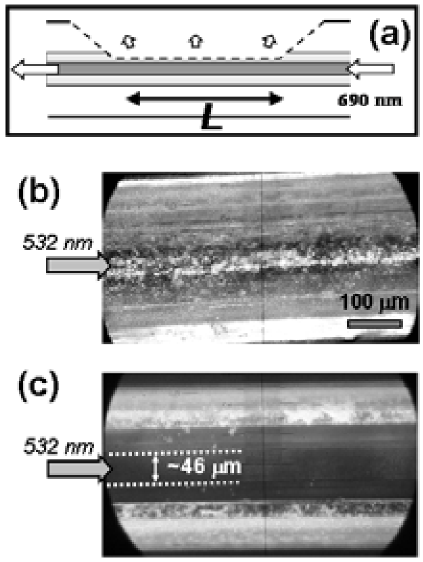

Fig. 3 (a) a schematic illustration of *in-situ* monitor during the polishing process. A plan view image of a polished surface with (b) rough and (c) fine finish. A green laser beam of λ = 532 nm was used for optical inspection.

respect to the initial intensity. A bright central region is observed when the polished surface is not sufficiently smooth (Fig.3 (b)), whereas the bright feature is hardly observed when the surface is completed with buffed, smooth surface (Fig.3(c)). These results indicate the validity of processing optical fibers with rotating polishing/buffing disks.

4. Conclusions

MO effects in optical waveguides in close contact with ferrimagnetic GdFe-based multi-layers have been studied as a function of incident angle of light. Processing an optical fiber by polishing and buffing techniques was disclosed.

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