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A study of magnetorstriction and its applications to Silicon-on-insulator waveguides

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Abstract: *The magnetostriction of thin amorphous ferromagnetic layer on top of optical waveguide was studied. Reversible magnetorstriction may be used to adjust polarization related parameters like polarization dependent loss (PDL) by applying an external applied magnetic field as low as 100Oe.*

1. Introduction

An understanding of the optical effects of stress in planar optical waveguides is important because of its influence on the optical phase and the resulting effects on polarization and frequency dependent transmission in integrated interferometers and arrayed waveguide gratings. The stress distribution in silicon can be analyzed by optical methods such as infrared photo-elastic fringe pattern [1] and micro-Raman techniques. For example, stress-induced phase change in Mach-Zehnder Interferometer on silicon can be used as pressure sensor [2]. Here we demonstrate stress induced polarization compensation through a thin amorphous ferromagnetic overlay with possible application in OEIC technology.

2. Magnetostriction

Stress on silicon waveguide can be varied by soft ferromagnetic layer which can in turn be controlled by small external magnetic field. The change in dimension due to rotation of magnetization vector on ferromagnetic materials is known as magnetostriction. For fractional changes in the length, the longitudinal magnetostriction coefficient, λ, is defined as [4]:

$$\lambda = \frac{\Delta\ell}{\ell} \qquad (1)$$

where l is the original length of the specimen. The effect of unidirectional stress on ferromagnetic materials can generally be divided into two classes. Positive magnetostrictive materials give an increased magnetization by tension and the material expands when magnetized. Negative magnetostrictive materials show a decrease in magnetization by tension and the material contracts when magnetized [3]. Magnetostriction coefficients of four materials consider here is quoted in table 1 [4],[5]. Both positive and negative magnetostrictive ferromagnetic thin films were investigated. It is worth to note that the sign of magnetostriction depends on both crystal orientation and direction of applied external field [4]. The dimensional change of ferromagnetic layer above the waveguide can therefore provide tensional stress on it and the polarization change during transmission can be varied by external magnetic field.

3. Fabrication

The single-mode silicon-on-insulator (SOI) rib waveguide was designed with the aid of a Beam Propagation Method (BPM) mode solver and the mode profile of the propagated beam is shown in figure 1. Fabrication was done by photolithography process with reactive-ion-etch (RIE) for rib height control. The whole layer was then covered by 0.5μm thermal oxide before ferromagnetic metal sputtering by ANATECH RF sputtering system. Different ferromagnetic sources including Co, Ni, CoFe and NiFe were optimized to about 0.5μm thick for comparison. To avoid crystal orientation effect on magnetostriction value, amorphous ferromagnetic thin films were used for comparison.

4. Experimental Results

With both input and output facets polished to optical quality, polarization states of different overlaid materials were investigated under small external field up to about 100Oe. This small external magnetization guarantees the reversible magnetostriction range during experiment. Cross-sectional profile of SOI rib waveguide is shown on the right of figure 1. Polarization-dependent-loss (PDL) was then recorded using AGILENT 8509B polarization analyzer and the scanning of polarization dependent optical power along waveguide can be used as stress profile monitoring.

Polarized laser beam of 1.5μm was used as transmission wavelength. Figure 2 shows the polarization dependent loss measured under different transverse magnetic field directions and strengths. Under small magnetic field to about 120Oe, all amorphous ferromagnetic thin films show similar behavior with maximum PDL recorded under particular magnetic field strength. Directional dependent of magnetic field may be due to asymmetrical variation of waveguide during fabrication and sputtering processes. The reversibility of PDL shows the dimensional change to be within elastic limit.

To see the magnetostrictive effect on waveguide structure, stress acted on waveguide can be measured by photoelastic measurement [1] under the effect external magnetic field. Laser beam with 1.15μm wavelength was sent along the propagation direction to the waveguide under test and the results were plotted with waveguide position along magnetization direction in figure 3. The fractional decrease in the length of nickel is about 30×10^{-6} in a field of 25 oersteds and is practically at its final value when a few hundred oersteds have been applied [3]. It can be shown that the power profile of waveguide changes when external magnetic field was applied in transverse direction. This change can be significant for the modification of mode profile in OEIC.

Table I Related magnetic properties of different ferromagnetic materials [4],[5].

Materials	**Saturation magnetization (emu/g)**	***Saturation Magnetostriction, λs**
Iron (Fe)	221.71± 0.08	-7×10^{-6}
Cobalt (Co)	162.55	-40×10^{-6}
Nickel (Ni)	58.57± 0.03	-33×10^{-6}
Cobalt Iron (CoFe)	/	3×10^{-4} (λ_{111})

*Values quoted under field strength 4×10^3 Oersteds [3] p.632

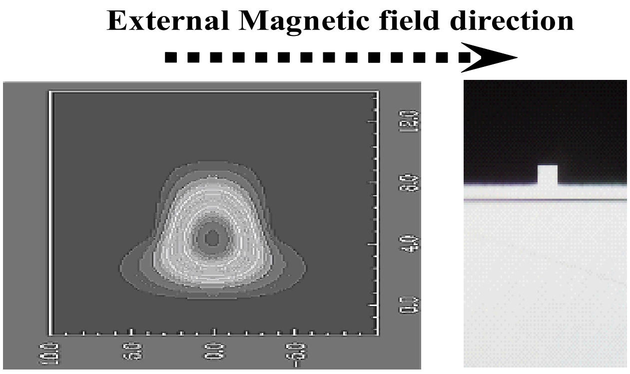

Fig. 1 Rib waveguide BPM mode cross sectional profile on the left and fabricated waveguide image on the right. The arrow indicates positive applied external magnetic field direction.

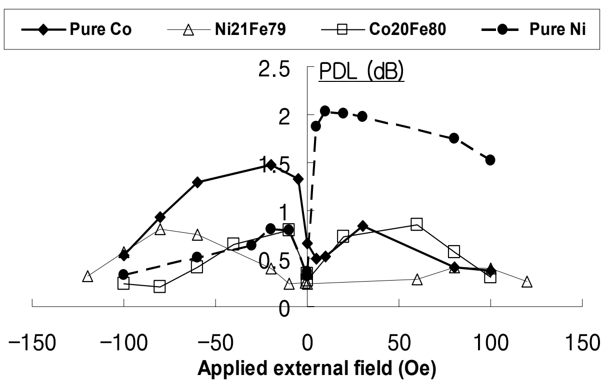

Fig. 2 In-situ polarization dependent loss measured under applied external field with different ferromagnetic overlays. Solid points represent pure metal and hollow points showing metal alloys. Dash line represents negative magnetostrictive behavior.

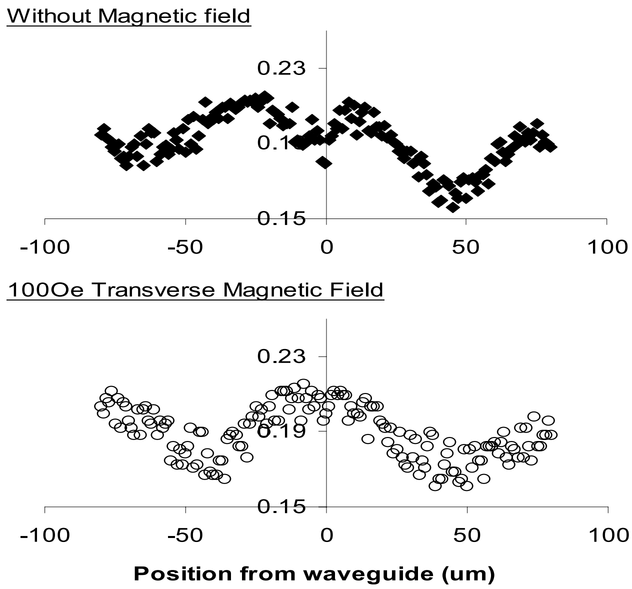

Fig. 3 Polarization dependent optical power measured by transverse scanning of waveguide without (above) and with (below) the application of external field.

5. Conclusion

We observed the elastic positive and negative magnetostriction effects on a SOI rib waveguide. With proper optimization of ferromagnetic thin film thickness and composition, the TE and TM mode propagation constants can be modified by external magnetic field and is a key to further manipulate polarization dependent parameter on OEIC.

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