論文 / 著書情報
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Title(English)	Study of cobalt ferrite thin films on silicon photonic platforms for monolithically integrated optical isolators
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種別(和文)	論文要旨
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（博士課程）
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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Optical isolators allow unidirectional propagation of light in optical communication systems, preventing backward light reflections to interfere in the stable operation of optical active elements such as lasers. For years, the integrated optics community has been looking for a viable optical isolator on chip. The lack of an integrated optical isolator is a bottleneck for laser module downscaling and cost cutting. The design of a magneto-optical waveguide isolators was proposed decades ago, and the fundamental device theory and principles are well studied. However, these devices never practical due to fabrication complexity and use of common magneto-optical (MO) materials such as garnet ferrites (i.e. Bi:YIG, Ce:YIG), which are structurally incompatible with the most common silicon and III-V photonic platforms.

With the rapid growth of silicon photonics, wafer bonding techniques were developed to integrate new materials on silicon. This gave a turnaround to the isolator problem as integration of epitaxial MO garnet ferrites on Si waveguides was now available, leading to the development of wafer-bonded silicon waveguide isolators. However, there remain unsolved innate problems of this technology such as the top cladding configuration limitation or the remaining thick garnet wafer. In parallel to wafer bonding technology, progress came to polycrystalline MO garnet ferrite film deposition techniques on silicon to realize monolithic isolators. Deposition methods are appealing for a higher fabrication throughput in overall and a lower production cost, but the required rapid thermal annealing processes at high temperatures (over 800 ° C) for film material recrystallization are dangerous for laser cavities and other optical active components. Additionally, the figure of merit of polycrystal MO material films is lower compared to their epitaxial counterparts.

In this study, the deposition of cobalt ferrite (CFO) films on silicon using a sputtering method is proposed as a solution to the above-mentioned integration issues of MO garnet ferrites. Cobalt ferrite can be deposited on silicon and has a large MO activity at the 1550 nm communication wavelength, but its high optical loss has stopped its application in practical nonreciprocal devices. Using an MgO thin film as a buffer layer, CFO films were successfully deposited on silicon by domain epitaxy, achieving (100)-oriented CFO films with almost bulk-like magnetic properties. In addition, given the strong magnetoelastic effect of cobalt ferrite, tunability of the magnetic easy axis of CFO films with their thermal residual stress was observed, which is promising for the development of devices with polarization diverse operation. Finally, large Faraday rotation at 1550 nm wavelength of the CFO films was confirmed, achieving a value of 25,600 ° /cm, which is to the best knowledge of the author, the largest Faraday rotation for any MO material on silicon reported to the conclusion of this research work.

Thereafter, the CFO films were integrated on Si waveguide micro ring structures aiming to demonstrate actual isolation. Due to the strong remanence in the CFO films, self-biased operation is possible eliminating the cumbersome magnet integration demand of MO garnets. An isolation ratio of 9.6 dB near 1550 nm wavelength was achieved with a compact ring device footprint of less than 100 microns. However, since a fabrication process using a silica spacer has not been optimized, the device performance could have been compromised. This initial demonstration is encouraging to develop compact size isolators of easy integration for specific applications such as semiconductor optical amplifiers protection and stabilization. But the figure of merit of the present CFO films should be improved before that.

On the other hand, integrated TE mode isolation has been long pursued, but the top cladding geometry of MO garnet bonded devices is limited to TM mode operation, while the growth of garnet side clads in Si waveguides is still primitive. For this reason, a compact ring isolator using a CFO film as inner cladding is proposed and numerically studied. The effect of bending modes becomes a challenge in micro ring structures of radius values below 10 microns. Then, a conformal transformation theory is discussed to analyze the effect of small bend radius in curved MO waveguides to optimize the MO effect. It was found that the effect of a curvature in a MO waveguide can be compensated adopting a narrower core. CFO ring isolators with ultra-reduced size were numerically demonstrated, but the large CFO material loss induces a high device insertion loss. Nevertheless, reducing the optical absorption of CFO material is promising to make these devices more practical.

Finally, two promising approaches to reduce the inherit optical absorption of cobalt ferrite material are reviewed and discussed: Substitution of iron content with nonmagnetic cations, and cobalt ferrite nanocrystal-based composite materials. A CFO/MgO multilayer waveguide structure is also proposed to improve the device figure of merit. It is expected that improving the material figure of merit of cobalt ferrite films would lead to the realization of practical integrated silicon isolators for specific applications.