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Direct Bonding of Magneto-optical Materials for Optical Nonreciprocal Devices

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Optical nonreciprocal devices such as optical isolators and circulators play important roles in photonic circuits. Optical isolators allow light waves to propagate only in one direction. By virtue of this, they prevent undesired back reflections from launching into optical active devices, which contributes to stabilizing the operation of optical active devices. Optical circulators have a unique function that enables to process counter-propagating light waves.

There are several ways to realize these functions which need breaking the time-reversal symmetry. Non-magneto-optical approaches such as a traveling wave modulation scheme and use of an optical nonlinearity are attractive, since they can be realized only with commonly used optical waveguide materials like silicon and III-V compound semiconductors. However, they have the disadvantages that extra RF sources are needed or, in some configurations, devices can provide the direction-dependent transmission under limited conditions of optical input.

A magneto-optical material plays an essential role to realize the optical nonreciprocal functions. Among several magneto-optical materials, rare earth iron garnet is the best candidate for optical fiber communications applications because of its large first order magneto-optical effect and practically low optical absorption. A key issue for realizing the optical nonreciprocal devices in commonly used optical waveguide platforms like silicon is how to integrate the magneto-optical garnet. We developed a surface activated direct bonding technique to achieve this. This technique enables to make use of a high-quality single-crystalline magneto-optical garnet having a large magneto-optical constant which is epitaxially grown in a separate process. Also, the direct bonding on a silicon waveguide enables to obtain sufficient interaction of light wave with a magneto-optical material. In bonding a magneto-optical garnet on silicon and III-V, lowering the process temperature is a key issue, since there is a large difference in thermal expansion between garnet and semiconductors. We succeeded in bonding a 1.5 x 1.5 mm^2 single-crystalline magneto-optical garnet $(CeY)_3Fe_5O_{12}$ (Ce:YIG) on silicon by applying a pressure of ~5 MPa to a contacted sample at 200 ^oC after a surface activation process of nitrogen plasma exposure (Fig. 1) [1].

Using this technique, an optical isolator was fabricated in a silicon waveguide. Magneto-optical phase shifters are incorporated in Mach-Zehnder interferometer (MZI) waveguide arms to achieve constructive and destructive interferences for forward and backward propagation, respectively. The fabricated isolator exhibited an optical isolation >30 dB in a 1550 nm wavelength band [2]. Also, a 4-port optical circulator function was demonstrated with an isolation >30 dB. In these devices, the length of magneto-optical phase shifter was reduced to 430 μm for a 450-nm-wide and 220-nm-thick silicon waveguide, because a sufficient interaction of light wave with Ce:YIG was obtained in spite of a high refractive index of silicon.

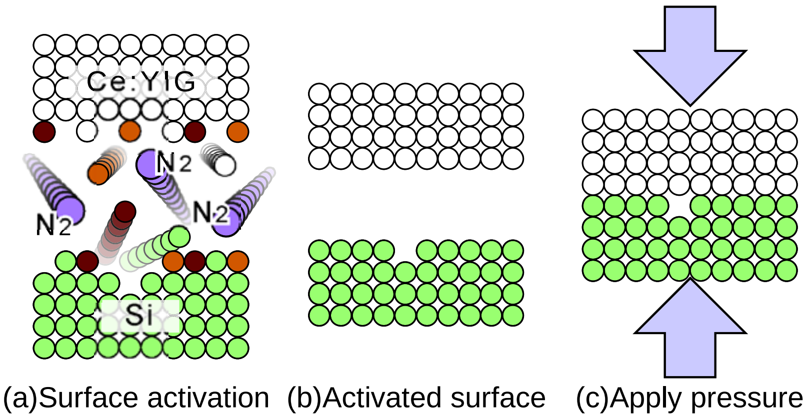

Fig1. Surface activated direct bonding process.

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