Silicon Ion Implantation Enables Mode Conversion Control in Silicon Nitride Asymmetric Directional Couplers

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The rapid development of artificial intelligence has brought great convenience to people's lives. However, it has also created an unprecedented demand for computing power. Because light has high propagation speed and inherent parallelism, researchers have begun to explore photonic accelerators based on photonic integrated circuits (PICs). Photonic crossbar arrays based on wavelength division multiplexing can achieve multiply-accumulate operations of up to 10^{12} per second [1]. Mode division multiplexing (MDM) can be used to further improve the parallelism of photonic accelerators [2]. Asymmetric directional couplers (DCs) are one of the key devices for implementing MDM in PICs. However, fabrication errors can have a significant impact on the mode conversion of asymmetric DCs. We proposed that silicon ion implantation, a low-loss trimming method, can effectively control mode conversion in asymmetric DCs [3], ultimately helping to improve the performance of photonic accelerators based on MDM technology.

Figure 1(a) shows a schematic of the silicon nitride (Si_3N_4) asymmetric DC trimmed by silicon ion implantation. Because the refractive index of silicon (~ 3.48) is higher than that of Si_3N_4 (~ 2.01), silicon ion implantation can increase the effective refractive index n_{eff} of the guided mode in the implanted waveguide. As shown in Figures 1(b) and 1(c), the n_{eff} of the TE_0 mode in the narrow waveguide is larger than the n_{eff} of the TE_1 mode in the untrimmed wide waveguide, resulting in a low transmission of less than −10 dB. After silicon ion implantation, the n_{eff} of the TE_1 mode in the wide waveguide increases, resulting in the fulfillment of the phase-matching conditions and therefore a high transmission of close to 0 dB, as shown in Figure 1(c).

In conclusion, we show that silicon ion implantation can effectively control the n_{eff} of the guided mode in the waveguide, facilitating the mode conversion of the asymmetric DC. The insertion loss of the trimmed asymmetric DC in the simulation is less than 0.1 dB. In our experiment, we demonstrated an 18 dB improvement in the transmission of the fabricated asymmetric DC by a single silicon ion implantation.

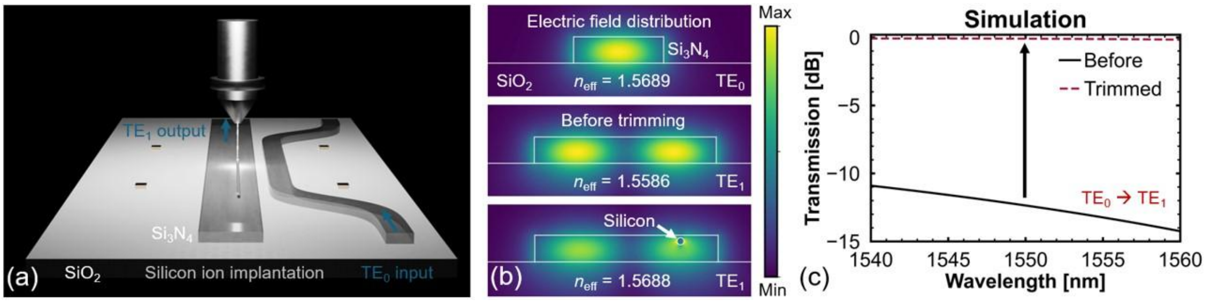

Figure 1. (a) Schematic of silicon ion implantation for a Si_3N_4 asymmetric DC. (b) Electric field distribution and n_{eff} of the TE_0 mode in an 1175 nm-width waveguide and the TE_1 mode in a 2375 nm-width waveguide. The height of the waveguides is 340 nm. (c) Transmission spectrum of the asymmetric DC before and after silicon ion implantation.

References:

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