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Monolithic integration of polarization and mode division (de)multiplexing in silicon carbide integrated platforms

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Abstract: We monolithically integrate polarization and mode division (de)multiplexers in SiC integrated platforms, which can manipulate six TE and TM multimodes, simultaneously. We numerically and experimentally demonstrate the device with good performances.

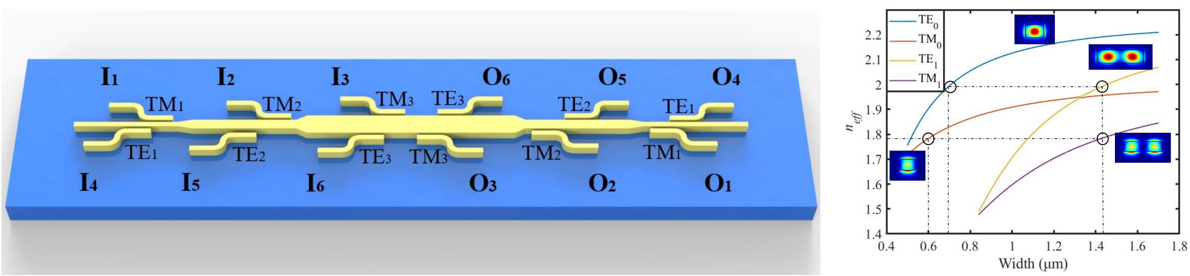
1. Introduction

Photonic chips with large data transmission capacity are of great interest for both quantum and classical optical communications. To enlarge the capacity, different multiplexing technologies have been applied, such as wavelength-, polarization-, time-, space- and mode- division multiplexing. Among them, polarization division multiplexing (PDM) and mode division multiplexing (MDM) are widely explored and show large potential to expand the capacity by introducing additional degrees of freedom in polarizations and the spatial modes. Some relevant devices, such as polarization beam splitters and mode converters, have been widely explored for PDM and MDM [1]. Monolithic integration of these devices with multiple functionalities is always highly desired in photonic integrated circuits (PICs).

Silicon carbide is emerging as a popular integrated photonic platform during the past decade. The possession of wide bandgap, strong second- and third-order nonlinearities, and high-brightness optically addressable color centers, makes SiC a promising candidate in nonlinear and quantum photonics from near UV to mid-infrared wavelength range [2]. Many devices with different functionalities have been demonstrated in the SiC integrated platform, including microresonators, photonic crystals, gratings, polarization beam splitters, power splitters, et al, and SiC is regarded as a growing alternative to silicon based PICs [3]. However, there is still a lack of design on the manipulation of polarization and spatial modes in SiC integrated platforms.

In this work, we demonstrate monolithic integration of PDM and MDM in the SiC integrated platform.

2. Design and simulation



(a) (b)

Fig. 1. (a) Schematic of the device for PDM and MDM. (b) Effective refractive index of TE_0, TE_1, TM_0, TM_1 modes of 400 nm thick 4H-SiC waveguides as a function of the waveguide width.

Fig. 1 shows the schematic of the device for PDM and MDM. Fundamental modes in single-mode waveguides at the inputs (I) are converted into multimodes (first-, second-, and third-order modes) in the trunk multi-mode waveguide, through asymmetric directional couplers (ADCs), for both TE and TM polarizations. Thus, six multimodes can co-propagate in the trunk waveguide simultaneously. And they can be coupled out individually through the ADCs to the corresponding outputs (O). In the coupling region, the same-order modes with different polarizations share the trunk waveguide with the same width, while different-order modes are coupled into the trunk waveguides with different widths. Short tapers are used to connect the trunk waveguides with different widths.

Here, we show the way to design the ADC for both polarizations with the same order. Using the first-order modes as an example, the effective refractive index (n_{eff}) of TE_0, TE_1, TM_0, TM_1 modes as a function of the waveguide width are simulated in Fig. 1(b). For the purpose of efficient coupling, n_{eff} of the two converting modes are supposed to be equivalent, based on the phase-matching condition. Once the width of the trunk multi-mode waveguide is selected, n_{eff} of the TE_1 and TM_1 modes can be obtained. Then, the widths of the single-mode waveguides for coupling the TE_0 and TM_0 modes can be determined, according to the equivalent n_{eff} of the TE_1 and TM_1 modes, respectively. The design strategy can also be applied to the second- and the third-order modes.

3. Fabrication and characterization

We fabricate the device in a 4H-SiC-on-insulator chip, with a SiC layer thickness of 400 nm. A microscope and a scanning electron microscope (SEM) images of the device are shown in Fig.2(a) and 2(b), respectively.

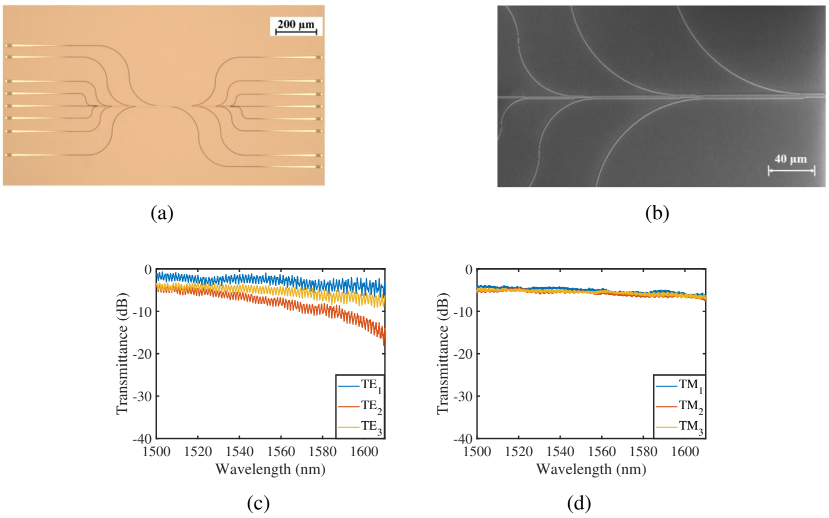


Fig. 2. (a) Microscope image of the whole testing device. (b) Zoom-in SEM image of the coupling region. Transmission spectrum of (c) TE and (d) TM multimodes.

Fig. 2(c) and 2(d) shows the transmission spectrum of the TE and TM multimodes, respectively. The maximum efficiency is $\leq$5 dB for the six multimodes with generally low crosstalks >10 dB, and the operational bandwidth is generally wide and flat. However, the transmittance is decreasing with the wavelength, indicating the phase matching condition is satisfied at shorter wavelength, due to the linewidth variation and fabrication imperfections.

4. Conclusion

In summary, we numerically and experimentally demonstrate PDM and MDM in the SiC integrated platforms, which paves the way for SiC as a competitive candidate in PICs for quantum and classical optical communications.

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