Investigation of Optical Phase shift by Free-carrier effect in Germanium Waveguides for Mid-infrared Photonics

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Introduction: Mid-infrared (MIR) integrated photonics is showing great potential on optical communications and molecular sensing, therefore it is becoming more and more attractive to the scientists [1]. Germanium (Ge) is expected to be an ideal material for its superior electrical and optical properties in MIR spectra [2]. In this work, we investigated the feasibility of optical phase shift by free-carrier plasm dispersion on a Ge-on-insulator (GeOI) MIR photonic platform operating at 2 μm band.

Fabrication Process: Carrier-injection Ge phase shifters were fabricated using Ge PIN waveguides described in [3]. To form a lateral PIN junction along the Ge waveguide, we used phosphorous spin-on-glass solid source diffusion which enabled n-type doping with the electron density of 1.9×10^{19} cm^{-3}. We used boron ion implantation for p-type doping, resulting in the hole density of 1.3×10^{19} cm^{-3}. Contact Ni/Al electrodes were formed by sputtering and lift-off process. Both ring and asymmetric Mach-Zehnder interferometer (MZI) were implemented to measure the amount of phase shift in the Ge waveguide at a 2 μm wavelength.

Results & Conclusions: We evaluated the operation of the Ge MZI modulator with injection currents from 0 to 20 mA for one of the arms, as shown in Fig. 1. We observed a peak shift associated with the plasma dispersion in Ge. A π phase shift was obtained by 20 mA, showing much higher modulation efficiency than that of Ge-on-Si modulators [4]. Note that the extinction ratio (ER) of the Ge MZI modulator rapidly degraded from 22 dB to 2 dB when the injection current increased to 20 mA due to the large free-carrier absorption effect in Ge. The phase shift of a Ge ring modulator was also studied as shown in Fig. 2. Owing to the ring cavity, a large static modulation depth of 18 dB at 1972.07 nm was obtained with only 2 mA injection. The Q factor of the ring slightly degraded from 3,819 to 3,464 in this case. In summary, this work proved the feasibility of phase modulation in a Ge waveguide on the GeOI platform, which will be very important in the future MIR photonic application.

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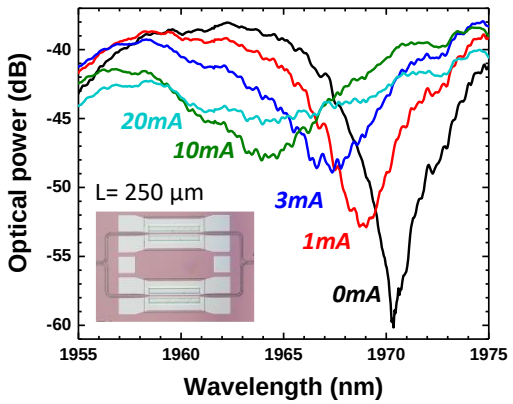

Fig. 1 Optical spectra of a Ge MZI modulator with 250-μm-long phase shifter with various injection currents.

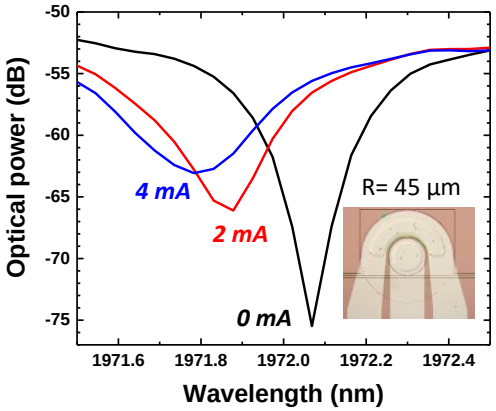

Fig. 2 Optical spectra of Ge ring modulator with radius of 45 μm with various injection currents.