Carrier-injection Ge MIR Variable Optical Attenuator Formed by Spin-on-Glass Doping

°Z. Zhao[1], C.-P. Ho[1], S. Takagi[1] and M. Takenaka[1] ([1]The University of Tokyo)
E-mail: zhaozq@mosfet.t.u-tokyo.ac.jp

Introduction: Mid-infrared (MIR) photonics is now attracting more attention for optical communication and sensing with a wide operation wavelength from 2 μm to 15 μm [1]. Germanium (Ge) is now emerging as a potential to broaden the application in MIR thanks to its large transparency window and superior optical properties. We have investigated a Ge-on-insulator (GeOI) platform for MIR photonic integrated circuits [2, 3]. In the previous study [3], the efficiency of a carrier-injection Ge variable optical attenuator (VOA) was limited by the poor PIN junction property due to the insufficient doping density of phosphorus in Ge. This work demonstrated an efficient Ge VOA by using spin-on-glass doping (SOG).

Fabrication: The process flow of a Ge VOA was shown in Fig. 1 (a). A Ge-on-insulator wafer with a 250-nm-thick Ge layer was prepared by wafer bonding and Smart-Cut™. A Ge rib waveguide was formed by EB lithography and ICP dry etching. Then, a 10-nm-thick SiO_2 hard mask was deposited in PECVD for boron (B) implantation. An additional 100-nm-thick hard mask was deposited for SOG doping of phosphorus (P) afterward. The SOG solution was spin on the Ge waveguides with diffusion windows opened by BHF for P doping. After spinning, SOG solution was baked for 2 h at 200°C on a hotplate and then P atoms were diffused into the Ge layer for 1 min. at 650°C in N_2 ambient. 40-nm-thick nickel contacts were formed by metal sputtering and lift-off. Fig. 1 (b) exhibited the plane-view of a fabricated 250-μm-long Ge VOA.

Results & Conclusions: The doping density of the n^+-region was improved from 3.0×10^{17} cm^{-3} to 1.9×10^{19} cm^{-3} by applying SOG technique. As a result, an efficient Ge VOA with an improved modulation efficiency of 320 dB/A was experimentally demonstrated, which is 2.7 times larger than previous result as shown in Fig. 2. Furthermore, effective carrier lifetime (τ_{eff}) of Ge VOAs was also extracted by fitting results to numerical simulation. Even with a small τ_{eff} of 0.25 ns, our Ge VOA still exhibited comparable efficiency with a conventional Si VOA which usually has τ_{eff} of more than 7 ns [4]. This result explicated that the trade-off between efficiency and lifetime can be improved using a Ge VOA, paving a way of efficient and high-speed VOA for MIR photonics.

References: [1] Soref, R., Nature Photon., 2010, 4, (8), pp. 495-497 [2] Kang et al., Mater. Sci. Semicond. Process. 42, 259–263 (2015). [3] Kang, J., Takenaka, M., Takagi, S., Opt. Express, 2016, 24, (11), pp. 11855-11864. [4] Park, S., Yamada, K., Tsuchizawa, T., et al., Opt. Express, 2010, 18, (11), pp. 11282-11291.

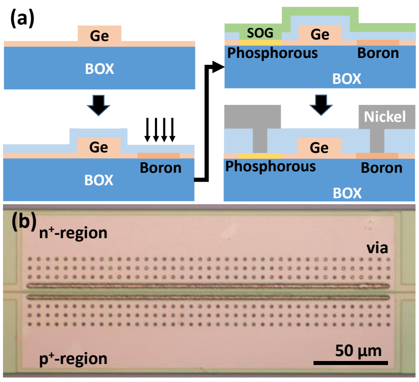

Fig. 1 (a) Process flow of a Ge VOA fabricated by SOG; (b) Plane-view microscope image of a 250-μm-long Ge VOA.

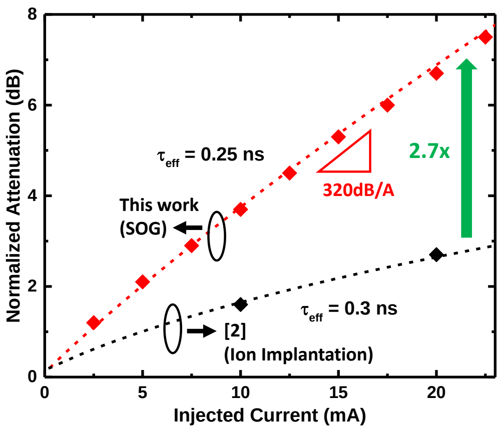

Fig. 2 Attenuation in Ge VOAs as a function of injected current.