Germanium-on-Silicon Photonic Devices

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Ge epitaxial layers on Si have been studied for near-infrared (NIR) photodiodes (PDs) in Si photonics as well as for optical modulators and lasers. In this presentation, our recent progresses [1-5] are presented on waveguide-integrated vertical pin PDs using Ge epitaxial layers grown on Si-on-insulator (SOI) layers as well as Ge/SiGe heterostructure technologies for higher-performance photonic devices.

For practical telecommunication applications, there exist severe requirements in the device performance for Ge PDs, (1) high photodetection efficiency at 1.3 - 1.6 μm, (2) high operation frequency more than 10 GHz, (3) low dark leakage current as small as 1 μA or below, etc. These requirements should be satisfied even at temperatures as high as 80˚C. High-quality Ge layers on Si are necessary, and the device structures and processes should be optimized. A typical optical microscope image for a fabricated Ge pin PD and the schematic cross-section are shown in Fig. 1. Waveguide-integrated Ge PDs were successfully fabricated using Ge epitaxial layers selectively grown on SOI layers by chemical vapor deposition (CVD).

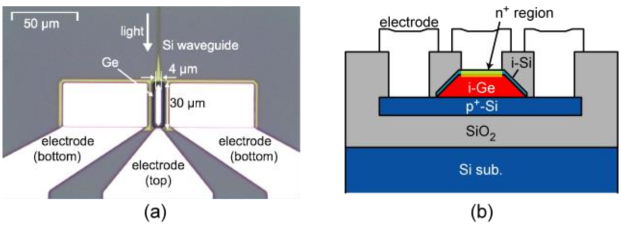

Fig. 1. (a) Typical optical microscope image and (b) schematic cross-section for Ge PD integrated with Si optical waveguide.

Figure 2(a) shows typical current-voltage (I-V) characteristics under dark and under the illumination of 1.55-μm light through the Si waveguide. The dark leakage current showed a small value of 0.02 μA at the 1-V reverse bias. The current was increased with the illumination, revealing a successful PD operation. A high responsivity was obtained to be 1.0 A/W.

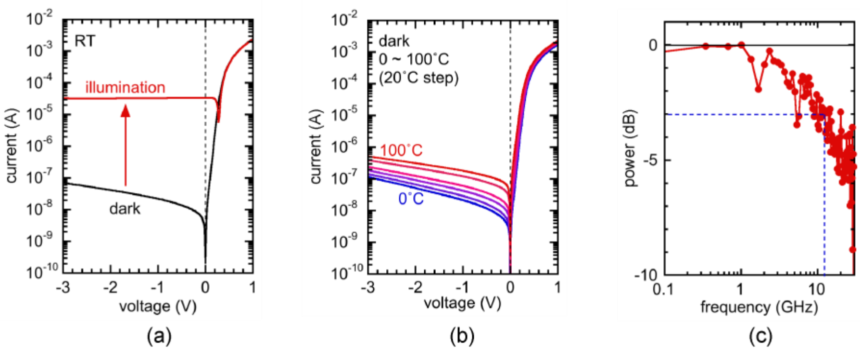

Fig. 2. (a) I-V characteristics with and without illumination of 1.55-μm light, (b) I-V characteristics under dark at different temperatures, and (c) frequency response.

Temperature dependence of I-V characteristics was measured under dark, as in Fig. 2(b). The dark current was less than 1 μA even at the increased temperature of 100°C, which is typically required for the practical applications. Figure 2(c) shows a typical frequency response. The 3-dB cutoff frequency was as large as 12 GHz, which was limited by the RC delay due to the high series resistance. The reduction of series resistance should lead to the 3-dB cutoff frequency more than 30 GHz.

SiGe/Ge heterostructures have potential applications to higher-performance devices. An example is low-noise and low-voltage avalanche photodiode (APD), where a SiGe layer is inserted at the interface between the optical absorption layer of Ge and the carrier-multiplication layer of Si or Ge, as in Figs. 3(a) and 3(b). The band discontinuity at the interface can realize low-noise and low-voltage APDs, resulting from an enhanced impact ionization for photo-generated carriers injected from the Ge optical absorption layer via SiGe. As in Fig. 3(c), the measured multiplication gain for hole-injection Ge/SiGe/Ge APDs was reduced in comparison with APDs without SiGe. This indicates that the SiGe/Ge heterojunction is effective for the low-voltage APD operation, although the excess noise characteristics are under investigations. Band engineering is also discussed using strained SiGe, which serves as a stressor to externally apply a stress to Ge mesa stripes selectively grown on Si.

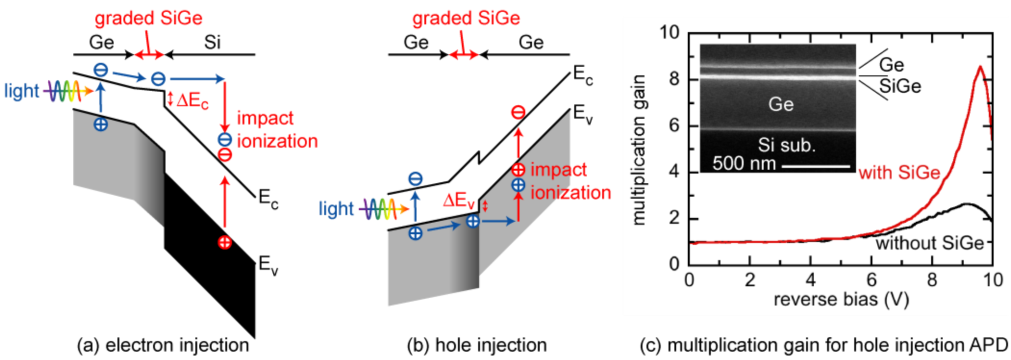

Fig. 3. Schematic band diagrams for Ge/SiGe heterostructure APDs.

Acknowledgements

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References

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