Electroluminescence of n-Ge/i-Ge/p-Si Hetero Junction PIN LEDs

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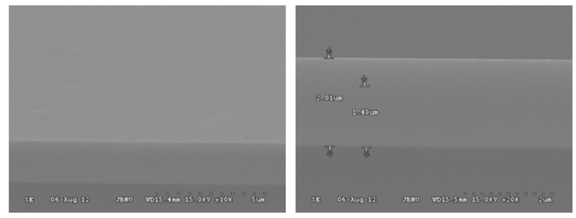
We have investigated the electroluminescence of phosphorus doped n-Ge/i-Ge/p-Si hetero junction structure grown on boron doped P-type Si (100) wafers (8 inch in diameter, resistivity=5~15Ω·cm) by using rapid thermal chemical vapor deposition (RTCVD).

The surface morphology and cross-section of the n-Ge/i-Ge layer were inspected by SEM. Fig. 1 (a) shows that the surface roughness of the n-Ge/i-Ge layer is smooth and Fig. 1(b) shows cross-sectional SEM image of the n-Ge/i-Ge layer with thickness of ~2.01 μm.

In order to investigate the crystalline homogeneity and the microscopic strain state of the Ge epilayer, high-resolution X-ray diffraction analysis was performed. The (400) peak of the Ge layer was observed at 5522 arcsec separated with respect to Si peak, as shown in the Fig. 2. This value is smaller than the expected one between the fully relaxed Ge and Si. According to Bragg's law, the peak distance is 5649 arc sec with the relaxed lattice constants 5.431 and 5.658 Å for Si and Ge, respectively. The smaller peak distance between epitaxial n-Ge/i-Ge layer and Si substrate indicates that the epitaxial n-Ge/i-Ge layer is under tensile strain. From the peak positions, the in-plane lattice constant is evaluated to be 0.5664 nm for n-Ge/i-Ge layer, corresponding to the in-plane tensile strain of ~0.47%. This result can be explained by the difference in thermal expansion coefficient between Si (2.6×10^{-6} °C^{-1}) and Ge (5.6×10^{-6} °C^{-1}). In a cooling process, the rapid heat dissipation along the growth direction increases the shrinkage of the Ge lattice parameter along the same direction rather than other in-plane directions. The HR-XRD rocking curve shape demonstrates the superior quality n-Ge/i-Ge layer and absence of tensile strain components.

The p-i-n structures include a ~0.61μm thick heavily phosphorus doped p-Ge layer, a ~1.4μm thick intrinsic Ge layer, and p-Si substrate. The photograph of the p-i-n photo-diode fabricated from n-Ge/i-Ge/p-Si hetero junction structure is shown in the Fig. 3.

The electroluminescence spectra of pin LED fabricated from n-Ge/i-Ge/p-Si hetero junction structure was measured at room temperature. The electroluminescence spectrum was analyzed by using a 500-mm grating monochrometer. It was detected with an InGaAs photodetector. The measurement range goes from 1300 nm to 1800 nm or 0.954 eV to 0.689 eV, respectively. The electroluminescence spectrum is obtained for different currents. The pin LEDs fabricated from n-Ge/i-Ge/p-Si hetero junction structure are operated at high forward currents up to 1.5 A. So the electroluminescence spectra of a LED with an intrinsic thickness of 1400 nm and a radius of 800 μm are illustrated in Fig. 4 for currents up to 3.0A. Therefore smaller structures (active mesa radius) lead to desired higher current densities while decreasing the current densities in the contact layers as well as the applied voltage. It is necessary to keep the currents in the contact layers as low as possible preventing a strong heating of the devices and its possible destruction. The heating also complicates the analysis of the electroluminescence spectra due the changing series resistance (decreasing with higher temperatures) and temperature dependency of the direct band gap.



(a) (b)

Fig 1. (a)Surface morphology and (b) cross-sectional SEM image of the n-Ge/i-Ge/p-Si hetero junction structure.

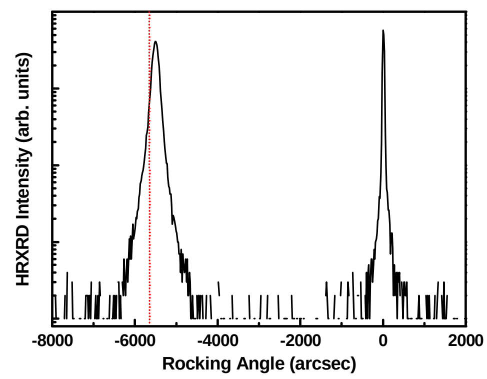


Fig 2. HRXRD (004) rocking curve of the n-Ge/i-Ge/p-Si hetero junction structure.

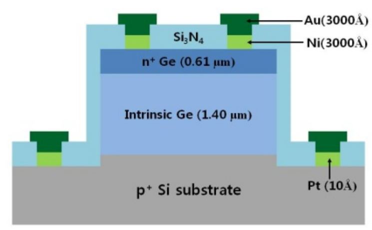


Fig 3. Schematic diagram of the p-i-n LED fabricated from n-Ge/i-Ge/p-Si hetero junction structure.

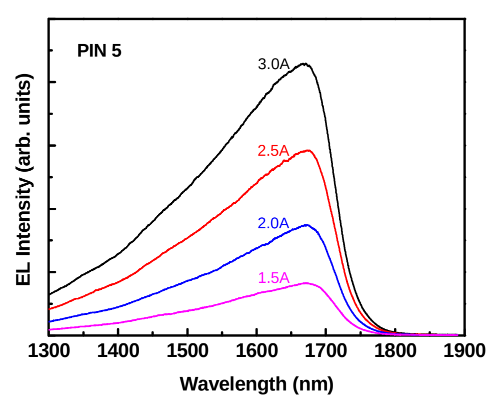


Fig. 4. Room temperature electroluminescence (EL) spectra of p-i-n LED fabricated from n-Ge/i-Ge/p-Si hetero junction structure for different injection currents.