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Influences of Metal/Ge Contact and Surface Passivation on Light Emission and Detection for Asymmetric Metal/Ge/Metal Diodes

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Abstract

We demonstrate direct band gap electroluminescence (EL) and 1.55 µm light detection at room temperature for n-type bulk germanium (Ge) by using a fin type asymmetric lateral metal/Ge/metal structure. HfGe/Ge and PtGe/Ge contacts were used for injecting holes. Electron cyclotron resonance plasma oxidation and bilayer passivation (BLP) were employed for surface passivation. Higher EL intensity and lower dark current intensity were observed by using PtGe/Ge contact and BLP, due to the lower/higher barrier height of holes/electrons for PtGe/Ge and smaller density of interface states for BLP, respectively.

1. Introduction

To fabricate next-generation high-performance ultra large scale integration, intra- and inter-chip optical interconnections are key technologies, for which the essential issue is the integration of photonic devices with electronic circuit using complementary metal-oxide-semiconductor (CMOS) compatible process. To realize this, germanium (Ge) is a promising optoelectronic material due to its quasi direct band gap (DBG) nature and CMOS friendly property. It is also well known that a low temperature process is necessary for the next generation CMOS technology. Unfortunately, processes for pn type Ge photonic devices are hardly to be employed due to the high thermal budget.

Recently we succeeded in fabricating fin type asymmetric metal/Ge/metal (MGeM) diodes with a low temperature process, of which clear DBG electroluminescence (EL) signals were observed at room temperature (RT) [1], due to the small barrier heights of electrons (Φ_{BN}) and holes (Φ_{BP}) for respective TiN/Ge and HfGe/Ge contacts [2, 3]. Since this asymmetric MGeM diode is also suitable for light detection, both photo emitters and detectors can be possibly fabricated using CMOS friendly processes. To improve performance of this asymmetric MGeM diode, it is essential to fabricate metal/Ge contacts with higher efficiency of carrier injection and to passivate active region surface with higher quality.

In this paper, we investigate influences of metal/Ge contact and surface passivation on DBG light emission and detection for this asymmetric MGeM structure, by employing two metals of HfGe and PtGe, as well as two passivation methods of electron cyclotron resonance (ECR) plasma oxidation and bi-layer passivation (BLP) [4].

2. Experimental

Figure 1 shows fabrication process flow of the asymmetric MGeM diodes. Sb-doped n-type (100) Ge substrates were used with donor concentration of 6.5 - 8.2 × 10^{15} cm^{-3}. After cleaning, SiO_2 was deposited by rf sputtering followed by a postdeposition annealing (PDA) and a mesa etching. To fabricate metal/Ge contacts for hole injection (left side metal shown in the inset of Fig. 1), Pt and Hf were deposited and protected by Ti and TiN using radio frequency (rf) sputtering, respectively, and patterned by a lift-off process, followed by a postmetallization annealing (PMA). During above processes, PtGe/Ge and HfGe/Ge contacts were formed [3, 5]. Then, TiN (right side metal) was also deposited by rf sputtering and patterned by lift-off process, followed by a PMA. The surface of active region was passivated using two methods. One is an ultrathin SiO_2/GeO_2 BLP fabricated by a physical vapor deposition (PVD) of SiO_2 on Ge surface with addition of O_2 [4]. Another is a GeO_2 layer fabricated by ECR plasma oxidation. Then a 250 nm-thick SiO_2 layer was deposited for each sample by PVD and ECR sputtering, respectively, without breaking the vacuum, followed by a PDA. At last, Al electrodes were formed followed by a contact annealing. Detailed fabrication parameters are also shown in Fig. 1. Finally, four diodes were fabricated, which are referred to as Pt-BLP, Pt-ECR, Hf-BLP, and Hf-ECR, respectively.

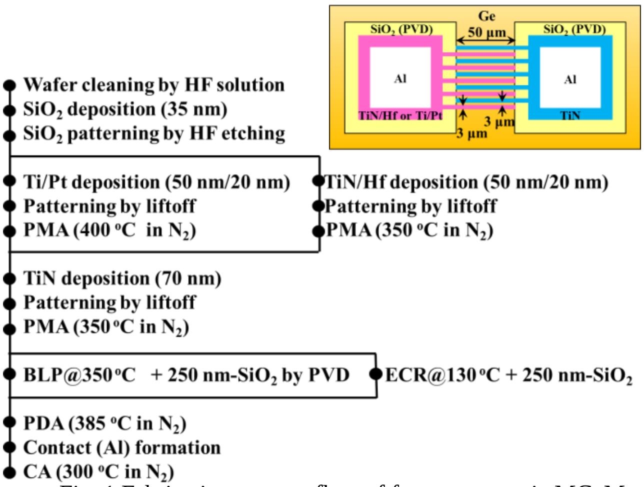

Fig. 1 Fabrication process flow of four asymmetric MGeM diodes.

3. Result and discussion

Figure 2 shows current intensity-bias voltage (*I-V*) characteristics at RT for all diodes. Pt-BLP and Pt-ECR showed lower dark current intensity (I_{dark}) than Hf-BLP and Hf-ECR, due to the difference of Φ_{BN} between PtGe/Ge (0.60 eV) and HfGe/Ge (0.57 eV), which were confirmed by *I-V* measurement for PtGe/Ge and HfGe/Ge contacts. It is also can be seen that I_{dark} of diodes with BLP are lower than those of diodes with ECR passivation. This should be associated with the lower density of interface states (D_{it}) of Ge surface with BLP, as shown in Fig. 3, which was measured by deep level transient spectroscopy for metal oxide semiconductor capacitors fabricated using the same process as those of the MGeM diodes.

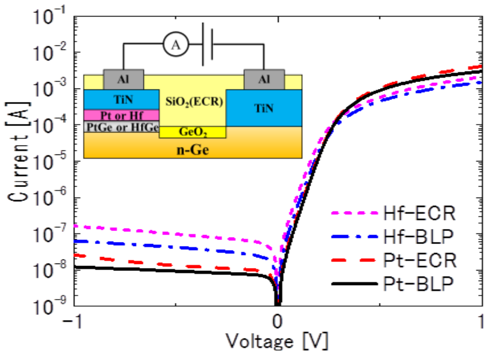

Fig. 2 *I-V* characteristics for MGeM diodes. Inset shows cross-sectional structure of MGeM diodes and how the *I-V* characteristics were measured.

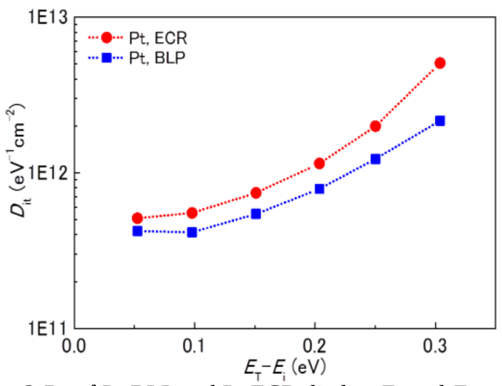

Fig. 3 D_{it} of Pt-BLP and Pt-ECR diodes. E_T and E_i are energy positions of interface states and mid-gap, respectively.

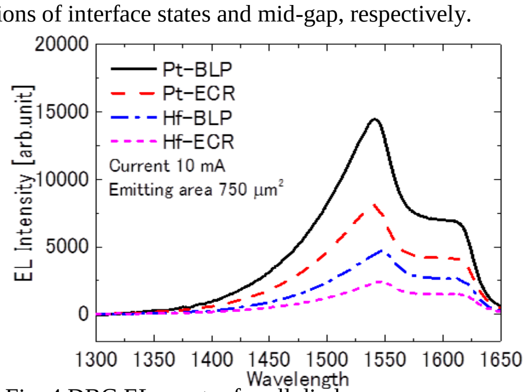

Fig. 4 DBG EL spectra for all diodes.

Figure 4 shows DBG EL spectra for all diodes. EL intensities I_{EL} were enhanced by replacing Hf with Pt, due to the higher efficiency of hole injection from PtGe/Ge contact (Φ_{BP} are 0.06 and 0.09 eV for PtGe/Ge and HfGe/Ge, respectively). By using the same metal/Ge contact, diodes with BLP show higher I_{EL} than those with ECR passivation, due to decreased rate of non-radiative recombination at Ge surface (lower D_{it} for diodes with BLP).

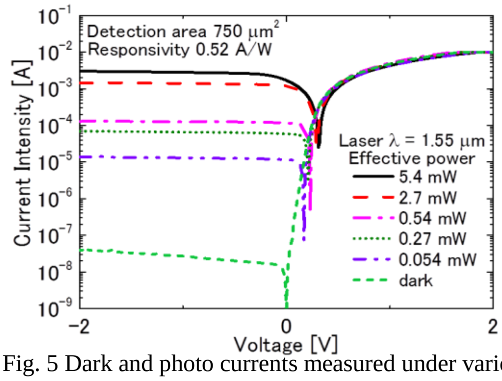

Fig. 5 Dark and photo currents measured under various laser powers using a typical PtGe/Ge/TiN diode with BLP.

Figure 5 shows dark and photo currents at 1.55 μm under various laser powers. A low I_{dark} of 2.7 × 10^{-8} A was measured at a reverse bias of -1 V. The on/off ratio is about four orders of magnitude at a laser power of 0.54 mW, which is comparable with a p-i-n Ge photo detector [6]. A reasonable responsivity of 0.52 A/W was measured at -1 V, corresponding to an external quantum efficiency of 41.6 %.

4. Conclusions

Fin type lateral asymmetric MGeM diodes were fabricated for DBG light emission and detection. HfGe/Ge and PtGe/Ge contacts were used for injecting holes. ECR plasma oxidation and BLP were used for surface passivation. Higher I_{EL} and lower I_{dark} were observed by using PtGe/Ge contact and BLP, due to the lower/higher barrier height of holes/electrons for PtGe/Ge and smaller density of interface states for BLP, respectively. For the PtGe/Ge/TiN diode with BLP, small I_{dark} of 2.7 × 10^{-8} A was measured under a reverse bias voltage of -1 V. A linear dependence of photo current intensity on laser power was observed with a responsivity of 0.52 A/W at -1 V, corresponding to an external quantum efficiency of 41.6%.

References

[1] D. Wang, T. Maekura, S. Kamezawa, K. Yamamoto, H. Nakashima, Appl. Phys. Lett. 106, 071102 (2015).

[2] M. Iyota, K. Yamamoto, D. Wang, H. Yang, H. Nakashima, Appl. Phys. Lett. 98, 192108 (2011).

[3] K. Yamamoto, T. Yamanaka, K. Harada, T. Sada, K. Sakamoto, S. Kojima, H. Yang, D. Wang, H. Nakashima, Appl. Phys. Express 5, 051301 (2012).

[4] K. Hirayama, K. Yoshino, R. Ueno, Y. Iwamura, H. Yang, D. Wang, H. Nakashima, Solid-State Electron. 60, 122 (2011).

[5] Y. Nagatomi, S. Tanaka, Y. Nagaoka, K. Yamamoto, D. Wang, H. Nakashima, Jpn. J. Appl. Phys. in press.

[6] M. Takenaka, K. Morii, M. Sugiyama, Y. Nakano, S. Takagi, Opt. Express 20, 8718 (2012).