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Influence of High Concentration Impurity Doping on Light Emission for Asymmetric Metal/Ge/Metal Diodes

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Abstract

We investigated relationship between carrier concentration and light intensity in electro luminescence (EL). The carrier concentration of substrate can be controlled annealing temperature, carrier density decreased with increasing of annealing temperature. By using doped substrate, we demonstrate direct band gap electroluminescence (EL) of 1.55 μm at room temperature for a fin type asymmetric lateral metal/Ge/metal structure. The light intensity increased with injection current. However, the light intensity is not enough level for light source of optical interconnection due to low hole injection. It implies that balance is important for carrier recombination, difference between number of electrons and holes has to be almost same.

1. Introduction

The processing speed of Ultra Large Scale Integration (ULSI) has rapidly increaed for long time by folowing Moore's law[1]. By using scaling law, size of Metal-Oxide-Semiconductor Field Effect Transistor (MOSFET) has been reduced. It means that performance and power consumption of ULSI has been improved. However, processing speed of ULSI is saturated recently due to physical limitation of down sizing for MOSFET. To solve this problem, optical interconnection has been proposed as one of solutions. It consist of light source and photo detector. Thus, we focus on fabrication of these components with Ge because Ge has high affinity for Si-CMOS process and direct band gap (DBG) of 0.8 eV corresponding to a wavelength of 1.55 μm which is suitable for optical communication. We already demonstrated electroluminescence (EL) at a wavelength of 1.55 μm with asymmetric metal/Ge/metal structure diodes[2],[3]. In addition, this component can also be used for photodetection, whose responsivity of 0.70 A/W[3],[4]. The photoresponsivity is higer than world standard of 0.40 A/W proposed by International Technology Roadmap for Semiconductors (ITRS). On the other hand, light intensity of light source is not enough level for optical interconnection. This is because, Ge is indirect transition semiconductor. It means that number of electron on direct transition conduction band is few to compare with number of electron on indirect transition conduction band. To solve this problem, we try high concentration impurity doping to Ge. In this study, we investigated relationship between carrier concentration and condition of diffusion, demonstrated EL spectra with high concentration impurity doped Ge substrate.

2. Experimental procedure

In-doped p-type (100) Ge substrates were used with holes concentration of 2.33×10^{16} cm^{-3}. After chemical cleaning with HF solution, substrates were dried at 200 °C for 10 min. Then OCD (Sb) spin coating was conducted followed by OCD baking at 200 °C for 20 min. After that, In-diffusion process was conducted (condition is shown in Fig. 1(a)). Next, OCD was peeled by HF solution followed by SiO_2 deposition to prevent out diffusion. Finally, Push-diffusion process was conducted (condition is shown in Fig. 1(b)).

(a)Condition for in-diffusion

(b)Condition for push-diffusion

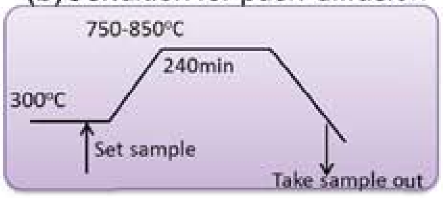

Figure 1. Condition for diffusion (a) in (b) push.

By using this doped Ge, we measured carrier density with Hall effects measurement system and fabricated asymmetric metal/doped-Ge/metal diode based on fabrication process flow as shown in Fig.2 and investigated EL spectra.

- Wafer cleaning by HF solution
- SiO_2 island formation (35 nm)
- Ti/Pt deposition (50 nm/20 nm)
  PMA (400 °C in N_2)
- TiN deposition (70 nm)
- PMA (350 °C in N_2)
- Passivation process
  BLP@350 °C + 250 nm-SiO_2 by PVD
- PDA (385 °C in N_2)
- Contact (Al) formation

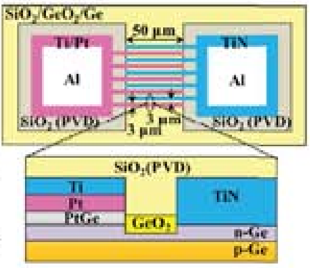

Figure 2. Fabrication flow for Ge diode.

3. Result and Discussion

Figure 3 shows relationship between carrier concentration of doped Ge substrate and annealing temperature. After in-diffusion, the sample shows carrier concentration of approximately 1 x 10^{20} cm^{-3}. Carrier concentration is decreased with increasing annealing temperature. On the other hand, sheet carrier concentration is stable in each annealing temperature. It means out diffusion is prevented by SiO_2 capping layer, impurity can diffuse into deep position.

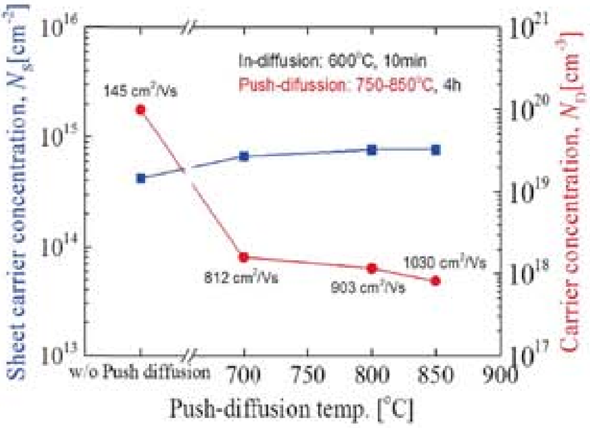

Figure 3. Relationship between carrier concentration and annealing temperature.

Figure 4 shows EL spectra for asymmetric metal/doped-Ge/metal diode (carrier concentration is 3.8 x 10^{18} cm^{-3}). We observed the wavelength of 1.55 µm corresponding to optical wavelength. The light intensity is increased with increasing of injection current. However, the intensity is lower than intensity of lower carrier concentration substrate. In EL, light intensity corresponds to carrier recombination between electrons and holes. The substrate has high electron density, it means low hole density. Thus, we think small number of holes affects this decreasing in light intensity.

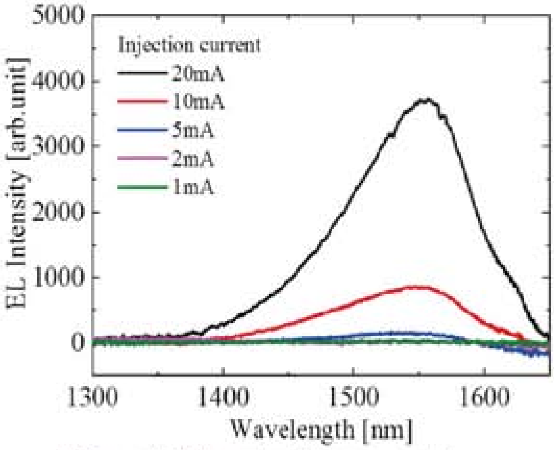

Figure 4. EL spectra for asymmetric metal/doped-Ge/metal diode.

4. Conclusion

In this study, we try to enhance performance of asymmetric metal/Ge/metal diode with high concentration impurity doping. The light intensity of our device with doped-Ge shows lower performance to compare with previous one due to small number of holes. However, we succeeded to control carrier concentration of 1 x 10^{20} to 8 x 10^{17} cm^{-3}. As a next step, we investigate optimized condition of doping to get higher light intensity with lower carrier concentration substrate.

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