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Interface Tuning of metal/β-Ga_2O_3 Schottky barrier diode by Post Thermal Annealing

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Abstract

Impacts of post thermal annealing (PTA) at various temperatures on interface characteristics of Pt/β-Ga_2O_3 Schottky barrier diode have been investigated. By capacitance method and Richardson's plot, we demonstrate that Schottky barrier height (SBH) increases for 300 °C PTA and then decreases with increasing annealing temperature. However, the breakdown voltage is severely degraded after the post annealing, which should be due to the interdiffusion between metal and semiconductor. Current density J, specific on-resistance R_{on}, and net donor concentration are also affected by PTA.

1. Introduction

Gallium oxide (Ga_2O_3) has attracted substantial interest for the power electronic applications due to its large bandgap and extremely high breakdown electric field [1]-[3]. Lots of research efforts have been devoted to exploring Ga_2O_3 MOSFETs [2], [3] and Schottky barrier diodes (SBDs) [1],[4] that demonstrated the reasonably good breakdown characteristics commensurate. Influences of metal anode and surface treatment on Ga_2O_3 device performance have been investigated [5]-[7].

In this paper, we characterize the Pt/β-$Ga_2O_3(\bar{2}01)$ SBDs with different post thermal annealing (PTA) temperatures. Current density J, specific on-resistance R_{on}, Schottky barrier height (SBH), net donor concentration (N_d - N_a) and breakdown characteristics of the devices annealed at various temperatures are discussed.

2. Device Fabrication

The starting wafer was β-$Ga_2O_3(\bar{2}01)$ sample. Back Ohmic contact of Ti/Au was deposited by E-beam evaporation followed by thermal annealing. SiO_2 field plate with device patterns was formed by BOE etching, and top Pt(15 nm) /Ti(5 nm)/Au(50 nm) anode was deposited by lift-off process. Finally, PTA at 300 and 400 °C for 30 seconds was carried out. Fig. 1(a) shows the schematic of the fabricated β-Ga_2O_3 SBD.

2. Results and Discussion

Fig. 1(b) shows the typical forward J versus voltage V curves of devices with and without PTA. The devices have a diameter of 200 μm. At V = 2 V, as-fabricated Ga_2O_3 SBD has a J of 6.2 A/cm^2, which is higher than that of 300 °C annealed device, 3.5 A/cm^2, but significantly lower compared to the device annealed at 400 °C, 162 A/cm^2. By a linear fitting, R_{on} of as-fabricated SBD is extracted to be

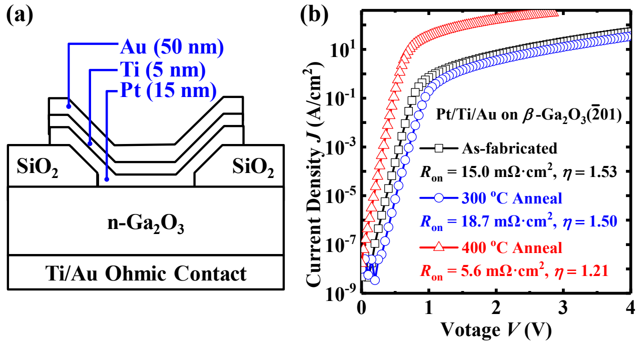

Fig. 1 (a) Schematic of the fabricated metal/β-$Ga_2O_3(\bar{2}01)$ SBD. (b) Forward J - V curves of devices with and without PTA.

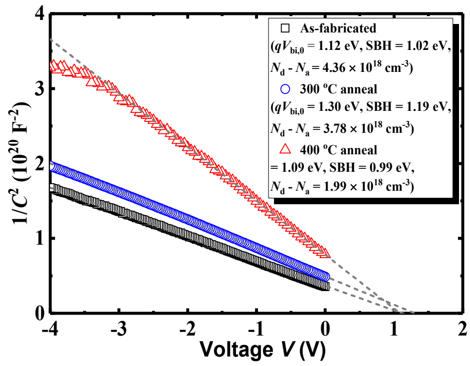

Fig. 2. $1/C^2 - V$ plots and linear fitting lines of β-$Ga_2O_3(\bar{2}01)$ SBDs with and without PTA showing the PTA temperature dependent $qV_{bi,0}$ and N_d - N_a values.

15 mΩ·cm^2, and after PTA at 300 and 400 °C, devices exhibit R_{on} of 18.7 and 5.6 mΩ·cm^2, respectively. Obviously, after 400 °C PTA, Ga_2O_3 SBD achieves the significantly improved forward characteristics.

Fig. 2 presents the $1/C^2$ versus V curves of SBDs with and without annealing measured at room temperature. Relation of C and zero-bias built in potential ($qV_{bi,0}$) is given by[4]

$$\frac{1}{C^2} = \frac{2(V_{bi,0} - kT/q - V)}{q\varepsilon S^2 (N_d - N_a)}, \tag{1}$$

where, k is the Boltzmann constant, T is the absolute temperature, q is the electron charge, ε is the dielectric constant of Ga_2O_3, S is the area of anode. $qV_{bi,0}$ of devices and the N_d - N_a in β-$Ga_2O_3(\bar{2}01)$ can be extracted from the horizontal axis intercepts and slope of the linear fitting $1/C^2 - V$ plots, respectively. Relation between $qV_{bi,0}$ and SBH $q\phi$ is $q\phi = qV_{bi,0} + (E_c - E_f) - e\Delta\phi$, where E_c and E_f are the conduction band minimum and Fermi level of β-Ga_2O_3, respectively. $e\Delta\phi$ is induced by the image force produced in

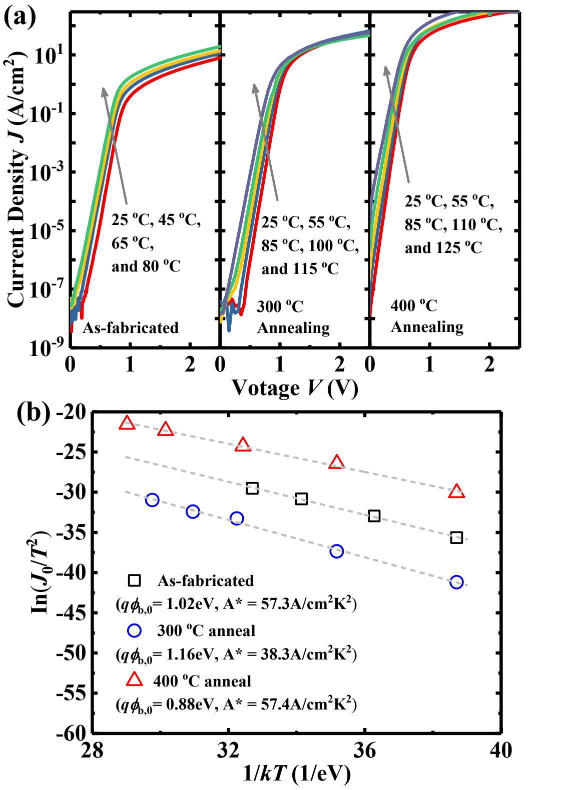

Fig. 3. (a) Temperature dependence of forward J - V curves of the SBDs with and without PTA. (b) Richardson's plots showing the different $q\phi_{b,0}$ and A* values.

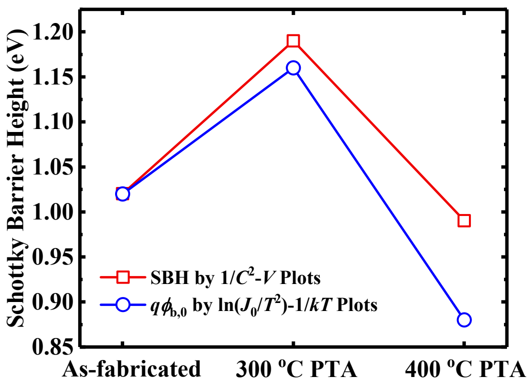

Fig. 4. Comparison of SBH values of as-fabricated SBDs and devices underwent PTA using $1/C^2$–V plots and Richardson's plots.

the Pt under zero bias [4], [8]. It is demonstrated that $q\phi$ value increases for 300 °C PTA and then decreases with increasing annealing temperature. It is observed that N_d - N_a decreases with the increasing of PTA temperature. It is speculated that the diffusion of Pt atoms into Ga_2O_3 leads to the deactivation of n-type dopants in the region near metal/semiconductor interface.

Based on the thermionic emission theory, J is expressed as [1],[8]

$$J = J_0 \exp(\frac{qV}{nkT})[1-\exp(-\frac{qV}{kT})], \quad (2)$$

where, $J_0 = A^*T^2\exp(-q\phi_{b,0}/kT)$, $q\phi_{b,0}$ is effective SBH, and A* is the Richardson constant. Fig. 3(a) shows the measured temperature dependence of forward J - V curves of

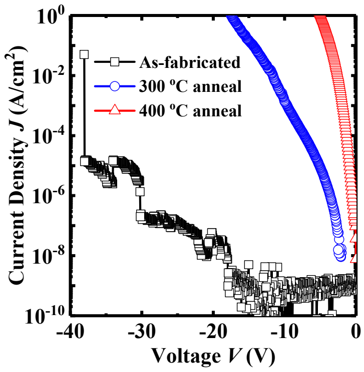

Fig. 5. Reverse J – V curves of β-Ga_2O_3 SBDs measured at room temperature, showing the significant degradation of breakdown characteristics of the devices after PTA.

the SBDs with and without PTA. The Richardson's plots $\ln(J_0/T^2) = \ln(A^*) - q\phi_{b,0}/kT$ together with the linear fitting lines shown in Fig. 3(b) demonstrate that the change of $q\phi_{b,0}$ induced by PTA is consistent with that obtained by $1/C^2$ – V plots.

Fig. 4 compares the measured SBH values using $1/C^2$ – V and Richardson's plots for the as-fabricated devices and those with PTA. Both methods demonstrate that SBH increases for 300 °C PTA and then decreases at 400 °C anneal.

We further investigate the breakdown characteristics of Ga_2O_3 SBDs. Fig. 5 shows the reverse J – V curves of β-Ga_2O_3 SBDs measured at room temperature, which indicate the significant degradation of breakdown characteristics in the devices after PTA. It is noted that, after 400 °C PTA, the reverse and forward J characteristics are getting similar. It is supposed that during the PTA, the interdiffusion between Pt and Ga_2O_3 transforms the abrupt barrier at metal side into graded junction, and Pt atoms diffusing into semiconductor might lead to the decomposition of Ga_2O_3 into sub-oxides, which have the smaller bandgap.

3. Conclusions

Comparison study on electrical performance Pt/β-Ga_2O_3 SBDs with and without PTA is carried out. By $1/C^2$ – V and Richardson's plots, we demonstrated that SBH increases for 300 °C PTA and then decreases at 400 °C. However, the breakdown voltage is severely degraded after the post annealing, which should be due to the interdiffusion between metal and semiconductor.

References

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