D-5-05
Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp283-284

Application of TiO_2 Layer for Reducing Pd/GaSb Schottky Junction Leakage Current

Yun-Pin Chang[1], Ming-Li Tsai [1] and Chao-Hsin Chien[1]

[1] Development of Electronics Engineering and Institute of Electronics, National Chiao-Tung University
1001 University Road, Hsinchu 30010, Taiwan
Phone: +886-3-5712121-54252 E-mail: chchien@faculty.nctu.edu.tw

Abstract

In order to improve thermal stability of GaSb Schottky barrier diode (SBD), a TiO_2 layer was introduced into metal/n-GaSb interface to form a junction with improved rectifying contact. A current on/off ratio of 3×10^4 was achieved for a Pd/TiO_2/GaSb SBD with relatively high thermal stability up to 450 °C. Since the TiO_2/GaSb interface possesses low conduction band offset, only a negligible series resistance was detected even when a 9-nm thick TiO_2 layer was used. However, increasing TiO_2 thickness led to Schottky barrier height lowering, which in turn resulted in higher reverse leakage current level. This was speculated to be related to more fixed oxide charges presented in the TiO_2 layer, in which conduction mechanism was verified by fitting to be the Poole- Frenkel emission.

1. Introduction

GaSb with high carrier mobilities has great potential to apply to high speed and RF circuits. The main issue to achieve high performance GaSb-channel MOSFETs is tackling poor low dopant solubility, which will lead to very high source/drain resistance. Fortunately, the Fermi level of metal/GaSb junction is pinned near the valence band edge. This feature leads to natural rectifying behavior of metal/n-GaSb junction for the p-channel MOSFETs. Several studies have revealed that the alloy S/D could be introduced into GaSb MOSFETs. However, GaSb having high chemical reactivity is thermally unstable. During the S/D metallization, the defect centers will be generated which will induce increment in reverse leakage current. In recent years, literature reported that an insertion of TiO_2 layer between metal and semiconductor could achieve Fermi level depinning or shifting, resulting in an Ohmic contact. [1] In an aim to enhance the thermal stability of metal/n-GaSb junction, we proposed using TiO_2 layer for improving the rectifying characteristics of the Schottky junction instead of forming the Ohmic contact.

In this study, we demonstrated the Pd/TiO_2/GaSb SBD had a better rectifying behavior and thermal stability with respect to the Pd/GaSb SBD. In addition, various SBH modulation mechanisms were discussed in order to deeply understand the SBH lowering phenomenon. We also calculated the emission coefficient based on the Schottky and Poole-Frenkel (P-F) emission models. Our result showed that the P-F emission might explain the increase in leakage current of SBD with increasing the thickness of the TiO_2 layer.

2. Experiments

Fig. 1(a) shows the process flow of GaSb SBDs. First, (100)-oriented n-type GaSb:Te substrate with a doping concentration of 2×10^{17} cm^{-3} was cleaned by HCl to remove native oxides. Then, we deposited the SiO_x as field oxide by using PECVD. After defining the active area, the samples were immersed into HCl solution again, then transferred into the ALD chamber immediately. The hydrogen plasma treatment was employed in ALD chamber to remove native oxide, followed by an *in-stu* TiO_2 layer deposition. Finally, we sputtered a Pd(10 nm)/TiN(50 nm) stack on TiO_2 surface as front contact. Post-metallization annealing (PMA) in nitrogen for 1 min was employed. The back side ohmic contact was formed by sputtering a Ti(10 nm)/Al(300 nm) layer. The schematic diagram of SBDs was displayed in **Fig. 1(c)**. For comparison, Pd/GaSb SBDs were also fabricated based on the same process excluding the ALD step. Notably, although we used HCl solution to remove the native oxides prior to the Pd layer deposition, a native oxide layer was formed immediately after the GaSb surface exposed to the air. The schematic diagram of Pd/GaSb was shown in **Fig. 1(b)**.

3. Results and Discussion

Figs. 2 (a) and **(b)** show TEM image and EDS mapping of the Pd/GaSb SBD after PMA at 350℃. As the Pd layer is deposited directly on the GaSb surface, Pd has high reaction to GaSb. We did observe that Pd diffused into substrate without any post deposition thermal treatment (not shown). In addition, Pd/GaSb treated with PMA at 350 ℃ could form PdGa alloy. However, severe agglomeration was observed via TEM image and EDS mapping. **Figs. 3 (a)** and **(b)** shows the TEM image and EDS depth profile of the Pd/TiO_2/GaSb. We observed the TiO_2 layer resisted the Pd diffusion efficiently, which could suppress the alloy formation. **Fig. 4 (a)** shows the *I-V* characteristics of the Pd/GaSb and Pd/TiO_2/GaSb SBDs. The agglomeration resulted in higher junction leakage current with increasing PMA temperature. Introducing the TiO_2 layer suppressed the leakage current significantly. The Pd/TiO_2/GaSb SBD could endure PMA temperature up to 450°C. This indicates the Pd/TiO_2/GaSb SBD has better thermal stability than the Pd/GaSb SBD. The electrical properties are summarized in **Table. I,** the on/off ratio in our case is the highest as compared to previous literatures. **Figs. 4 (b)** display the *I-V* characteristics and the extracted series resistance of the Pd/TiO_2/GaSb SBD. The forward current did not degrade with the increase of TiO_2 thickness because of the low conduction band offset between TiO_2 and GaSb and correspondingly no visible increase in series resistance appeared. **Fig. 4 (c)** shows the ideality factor and SBH of the Pd/TiO_2/GaSb SBD treated with PMA at 350 ℃. Thicker TiO_2 layer reduced the tunneling probability leading the improved ideality factor, but the SBH was also reduced. Z. Yuan *et. al*. found that the TiO_2 can suppress the metal-induced gap states (MIGS) and reduce SBH between low work function metal and GaSb. [1] However, Pd is a high work function metal, the SBH should be the same and even higher. Thus, we think other mechanisms might be responsible for the SBH lowering. The interface dipole seems not possible because the interfaces were the same for various TiO_2 thicknesses. Therefore, we speculate that the presence of fixed oxide charges in TiO_2 layer induced a potential drop which increased with increasing thickness is the cause of the SBH lowering.

In order to realize the conduction mechanism for reverse current, we investigated both the P-F and Schottky emission models. [2] **Figs. 4 (a)** and **(b)** show the curve fitting of Poole-Frenkel emission and Schottky emission, respectively. The emission coefficient (S_{exp}) was extracted by using the slope of the fitting curve in the voltage range from −0.25 to −1V. We also calculated the ideal emission coefficient (S_{ideal}) to distinguish which mechanism was dominant. **Fig. 4 (c)** shows the $\Delta S \equiv |S_{ideal} - S_{exp}|$ versus temperature. The S_{exp} largely deviated from S_{ideal} in the case of Schottky emission. Thus, the reverse current was dominated by P-F emission regardless of the temperature.

4. Conclusions

In this study, we improved the rectifying characteristic of the Pd/GaSb SBD by inserting the TiO_2 layer. The Pd/TiO_2/GaSb SBD could endure thermal process up to 450 ℃ without causing significant junction degradation and series resistance. Using TiO_2 with an appropriate thickness might be suitable for S/D structure in GaSb MOSFETs.

Acknowledgement

The authors are thankful for Grant MOST 104-2221-E-009-060-MY3 from the Ministry of Science and Technology, Taiwan.

References

[1] K. Nishi *et al.*, J Appls Phys. 115, 034515 (2014).

[2] C. B. Zota *et al*, Appl. Phys. Express 5, 071201 (2012).

[3] M. Yokoyama *et al.*, Appl. Phys. Lett. 104, 093509 (2014).

[4] Z. Yuan *et al*, Appl. Phys. Lett. 98, 172106 (2011).

[5] D. Tomer *et al*, Appl. Phys. Lett. 106, 173510 (2015).

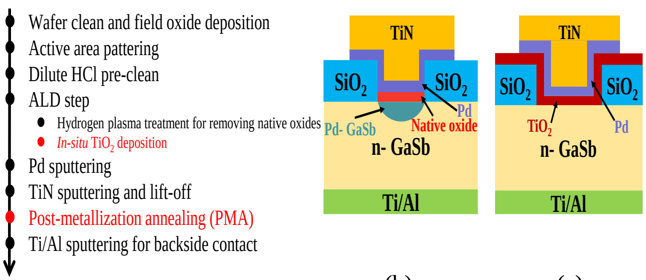


Fig. 1 (a) Process flow and schematic diagram of (b) Pd/GaSb SBD and (c)Pd/TiO_2/GaSb SBD.

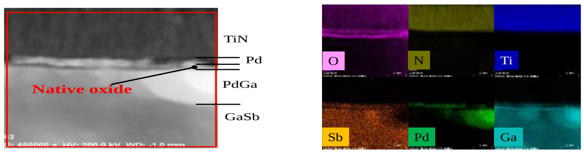


Fig. 2 (a) Dark field TEM image and (b) EDS mapping of Pd/GaSb SBD after PMA at 350℃.

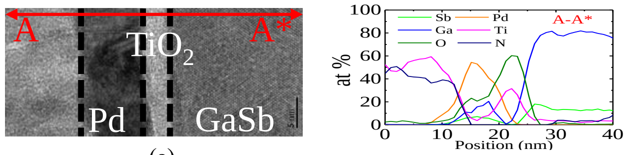
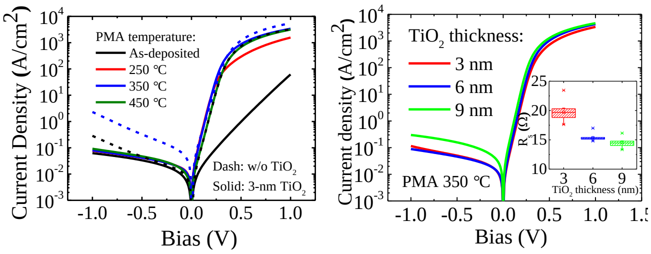


Fig. 3 (a) HRTEM image and (b) EDS depth profile of Pd/TiO_2/GaSb SBD after PMA at 350℃.



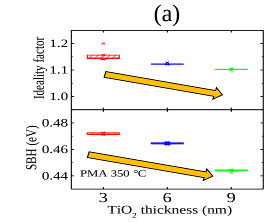
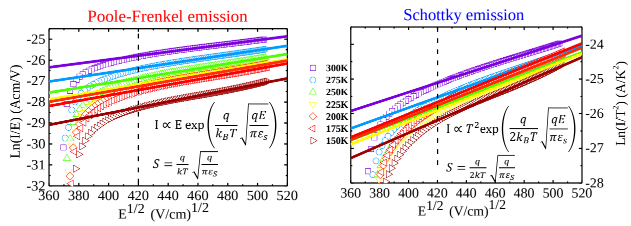


Fig. 4 (a) *I-V* characteristics of Pd/GaSb and Pd/TiO_2/GaSb SBDs. (b) *I-V* characteristics, Inset: series resistance, and (c) SBH and ideality factor of Pd/TiO_2/GaSb SBDs after PMA at 350 ℃.



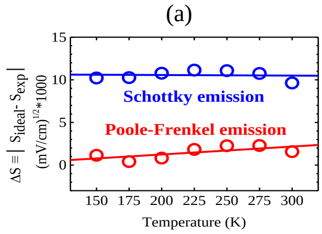


Fig. 5 (a) Temperature-dependent P-F emission and (b) Schottky emission plot of Pd/TiO_2(9 nm)/GaSb. (c) The deviation plot for carrier transport.

Table. I Comparison of electrical properties of GaSb SBDs.(ϕ_{metal} is metal work function)

Reference	Structure	ϕ_{metal} (eV)	RTA temperature	I_{on}/I_{off} at ±1V	n
This work	TiO_2/Pd	5.6	450 ℃	3×10^4	1.2
[3]	Ni-GaSb	5.3	250 ℃	1×10^4	1.1
[3]	Pd-GaSb	5.6	250 ℃	8×10^3	1.1
[3]	Co-GaSb	5	350 ℃	2×10^3	1.3
[4]	Ni-GaSb	5.3	350 ℃	7×10^2	n.a
[5]	Ni-GaSb	5.3	250 ℃	3×10^3	1.1