D-6-4

Extended Abstracts of the 2012 International Conference on Solid State Devices and Materials, Kyoto, 2012, pp755-756

Nickel Stanogermanide Ohmic Contact on N-type Germanium-Tin ($Ge_{1-x}Sn_x$) using Se and S Implant and Segregation

Yi Tong,[1] Shaojian Su,[2] Bin Liu,[1] Lanxiang Wang,[1] Phyllis Shi Ya Lim,[1] Yue Yang,[1] Wei Wang,[1] Kain Lu Low,[1] Guangze Zhang,[2] Chunlai Xue,[2] Buwen Cheng,[2] Genquan Han,[1,] ** and Yee-Chia Yeo.[1,] *

[1] Department of Electrical and Computer Engineering, National University of Singapore (NUS), Singapore 117576.
[2] State Key Laboratory on Integrated Optoelectronics, Institute of Semiconductors, Chinese Academy of Sciences, Beijing, People's Republic of China 100083.
**Phone and Fax: +65 6516-1589, E-mail: hangenquan@ieee.org *Phone: +65 6516-2298, Fax: +65 6779-1103, E-mail: yeo@ieee.org

1. INTRODUCTION

Germanium-tin ($Ge_{1-x}Sn_x$) is an attractive channel material for high performance n-MOSFETs due to its high electron mobility [1]. $Ge_{1-x}Sn_x$ channel n-MOSFETs was recently reported [2], and non-self-aligned metallic Ni contacts n^+ $Ge_{1-x}Sn_x$ source and drain (S/D) were used. Good self-aligned ohmic contacts with low Schottky barrier height on n^+ $Ge_{1-x}Sn_x$ S/D are needed. However, there are no reports of self-aligned ohmic contact formation on n-type $Ge_{1-x}Sn_x$ (n-$Ge_{1-x}Sn_x$).

In this work, we report the first demonstration of self-aligned nickel stanogermanide Ni($Ge_{1-x}Sn_x$) contacts on n-$Ge_{1-x}Sn_x$, featuring ion implantation and segregation of selenium (Se) or sulfur (S) at the Ni($Ge_{1-x}Sn_x$)/n-$Ge_{1-x}Sn_x$ interface. Self-aligned ohmic contacts on n-$Ge_{1-x}Sn_x$ were achieved for the first time.

2. DEVICE FABRICATION

Fig. 1 shows the process flow used for fabrication of contacts or Schottky diodes on n-GeSn. Schematic of a Ni(GeSn)/n-GeSn contact with pre-stanogermanide Se or S implant and segregation is shown in Fig. 2.

A 150 nm thick GeSn film was epitaxially grown on n-type Ge (100) substrate using solid source MBE system at 180 ºC [11], as shown in Fig. 3. The substitutional Sn composition is 4.2%, as determined by high resolution X-ray diffraction (HRXRD). The as-grown GeSn film was p type, and the unintentional doping concentration is 4.98×10^{16} cm^{-3}, as measured by Hall measurement. The GeSn films were counter-doped using phosphorus (P) with a dose of 1×10^{13} cm^{-2} at energies of 50, 130, 250 keV. A 400 ºC 5-minute rapid thermal anneal (RTA) step was used for P activation.

200 nm PECVD SiO_2 was deposited and patterned to define active regions. Se and S implants were performed at energies of 8 and 5 keV, respectively, at the same dose of 1×10^{15} cm^{-2}. A 10-nm-thick Ni was deposited after native oxide removal in the active region. This was followed by a RTA at 350 ºC for 30 s in N_2 ambient for the stanogermanidation. Unreacted Ni was then removed using sulfuric acid (H_2SO_4). This completed the formation of self-aligned Ni($Ge_{1-x}Sn_x$) contacts.

Finally, 200 nm thick Al was deposited on the backside of the samples. *I-V* characteristics of the contact devices with an area of 100×100 μm^2 were measured. Blanket samples were also prepared using the same implant and stanogermanidation conditions for physical analyses.

3. RESULTS AND DISCUSSION

Se and S are used for the first time to lower effective electron Schottky barrier height ($\Phi_B{}^n$) of Ni($Ge_{1-x}Sn_x$)/n-$Ge_{1-x}Sn_x$ contacts. Ohmic *I-V* behaviour is clearly observed for the samples with Se or S implant (Fig. 4). $\Phi_B{}^n$ was extracted using the current-voltage method. The increased reverse currents indicate the reduction of the effective Schottky barrier height for electrons in Fig. 5. The extracted $\Phi_B{}^n$ of the samples with Se and S implant are 0.16 and 0.17 eV, respectively. Fig. 6 shows the cumulative probability plot of the reverse current measured at -1 V for Ni($Ge_{1-x}Sn_x$)/n-$Ge_{1-x}Sn_x$ contacts with Se and S implant. Atomic force microscopy (AFM) measurement was used to check the surface roughness of Ni($Ge_{1-x}Sn_x$) samples with S and Se implant, as shown in Fig. 7. The surface root mean square (RMS) values of the Ni($Ge_{1-x}Sn_x$) samples with Se and S implant are 0.73 and 0.53 nm, respectively.

X-ray diffraction (XRD) characterization was performed to check the phase of nickel stanogermanide. It is found that neither Se nor S implant affects nickel monostanogermanide formation, as shown in Fig. 8. Fig. 9 and 10 show the depth profiles of the implanted species in Ni($Ge_{1-x}Sn_x$)/n-$Ge_{1-x}Sn_x$ as obtained by secondary ion mass spectroscopy (SIMS) measurement. Implanted Se and S atoms are pushed to Ni($Ge_{1-x}Sn_x$)/n-$Ge_{1-x}Sn_x$ interface during stanogermanidation, and clear segregation peaks of Se and S are observed. It is found that Se segregation peak is located inside the Ni($Ge_{1-x}Sn_x$) film while S segregation peak is at the interface of Ni($Ge_{1-x}Sn_x$) and n-$Ge_{1-x}Sn_x$. The substantial $\Phi_B{}^n$ reduction of Ni($Ge_{1-x}Sn_x$)/n-$Ge_{1-x}Sn_x$ contacts is attributed to Se or S segregation. In addition, we compare the effective electron Schottky barrier height of Ni($Ge_{1-x}Sn_x$)/n-$Ge_{1-x}Sn_x$ and NiGe/n-Ge contacts with various species segregation reported in literature and this work (Fig. 11). Both Se and S show a strong effect on $\Phi_B{}^n$ reduction of the Ni($Ge_{1-x}Sn_x$)/n-$Ge_{1-x}Sn_x$ contacts, which may be caused by the enhancement of the traps assisted tunnelling [14].

4. CONCLUSION

We demonstrated self-aligned Ni($Ge_{1-x}Sn_x$) ohmic contact on n-$Ge_{1-x}Sn_x$ using Se or S implant and segregation. Nickel monostanogermanide was formed for both Se and S samples, and clear segregation peak of Se or S was observed.

ACKNOWLEDGEMENT. B. Cheng and C. Xue acknowledge support from Grant no. 61036003, 61176013, and 61177038, respectively, from the National Natural Science Foundation of China. Y.-C. Yeo acknowledges support from the National Research Foundation under Grant NRF-RF2008-09.

REFERENCES

[1] J. D. Sau *et al.*, *Phys. Rev. B* 75, 045208, 2007.
[2] G. Han *et al.*, *VLSI Symposium, 2012*.
[3] M. Koike *et al.*, *Appl. Phys. Express* 4, 021301, 2011.
[4] K. Ikeda *et al.*, *Appl. Phys. Lett.* 88, 152115, 2006.
[5] A. Dimoulas *et al.*, *MRS Bulletin*, 34, pp.522, 2009.
[6] K.-W. Ang *et al.*, *IEEE Electron Device Lett.* 29, pp.708, 2008.
[7] T. Nishimura *et al.*, *Solid State Electron.* 60, pp.46, 2011.
[8] L. Wang *et al.,VLSI TSA Symposium*, pp. 10, 2012.
[9] L. Wang *et al.*, *Electrochem. Solid-State Lett.* 15, pp.H179, 2012.
[10] G. Han *et al.*, *IEEE Electron Device Lett.* 33, pp.634, 2012.
[11] S. Su *et al.*, *J. Cryst. Growth*, 317, pp.43, 2011.
[12] M. Mueller *et al.*, *Mater. Sci. Eng. B* 154/155, pp. 168.
[13] D. K. Schroder, "Semiconductor material and device characterization".
[14] Y. Tong *et al.*, *VLSI TSA Symposium*, pp. 23, 2012.

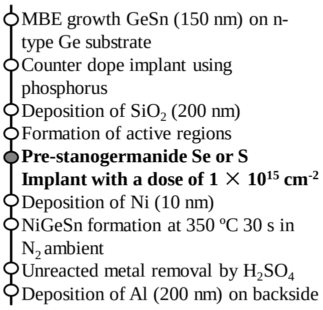

Fig. 1. Process flow for fabricating Ni(GeSn) / n-GeSn Schottky diodes with pre-stanogermanide Se or S implant and segregation.

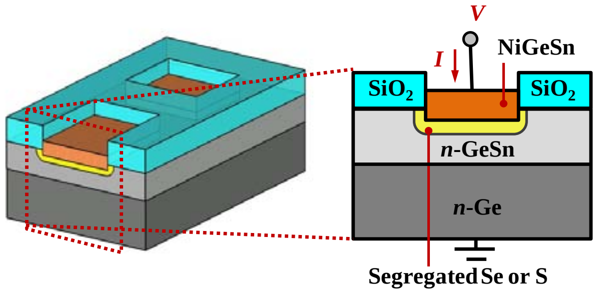

Fig. 2. Schematic of a Ni(GeSn)/n-GeSn Schottky diode with pre-stanogermanide Se or S implant and segregation. Se and S are pushed to the Ni(GeSn)/n-GeSn interface after stanogermanidation due to the snowplow effect.

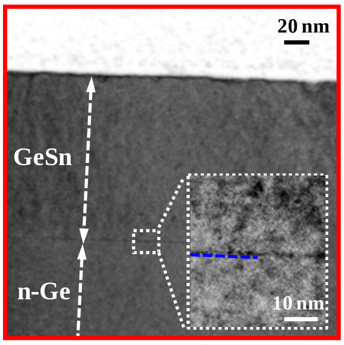

Fig. 3. TEM image of epitaxial GeSn film grown on Ge(100) substrate. GeSn film quality is good. The GeSn/n-Ge interface is clearly identified.

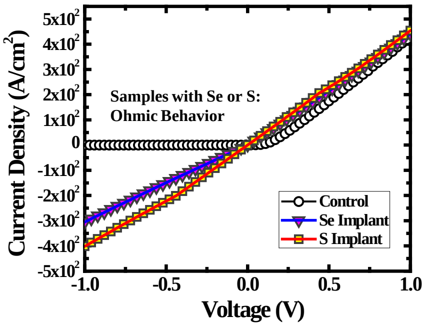

Fig. 4. Linear scale *I-V* characteristics of Ni(GeSn) contacts with Se or S implant and segregation. Ohmic behavior is clearly observed.

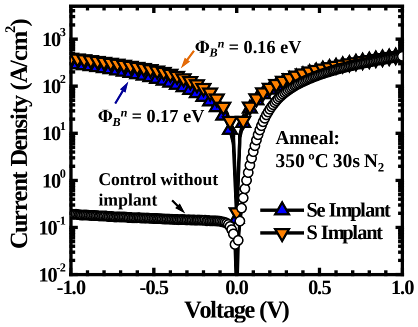

Fig. 5. $\Phi_B{}^n$ of Ni(GeSn) contacts with Se or S implant and segregation is extracted using current-voltage method.

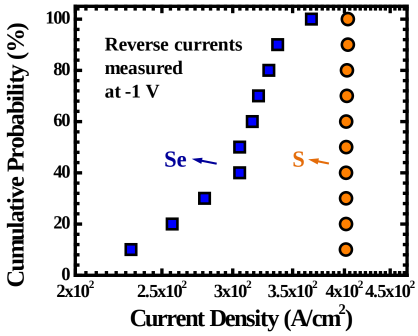

Fig. 6. The cumulative probability plot of the reverse current measured at -1 V for Ni(GeSn)/n-GeSn contacts.

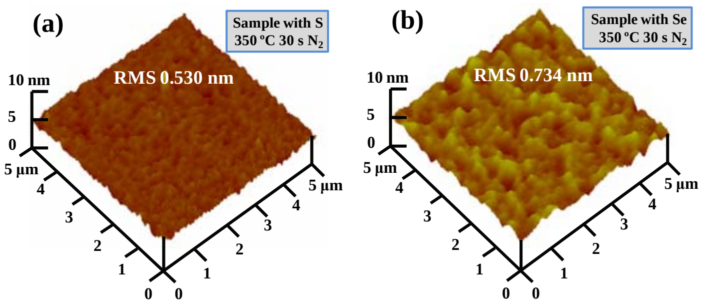

Fig. 7. Surface RMS roughness graph of Ni(GeSn)/n-GeSn blanket samples with (a) S or (b) Se implant and segregation.

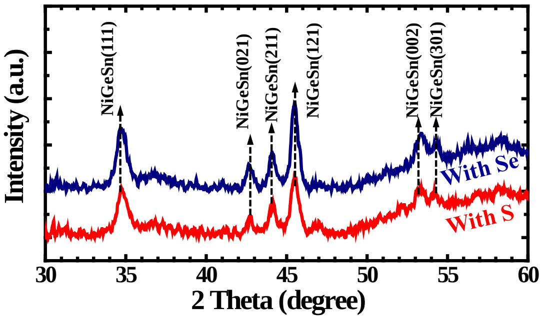

Fig. 8. XRD spectra show Ni(GeSn) formation for samples with S and Se implant and segregation.

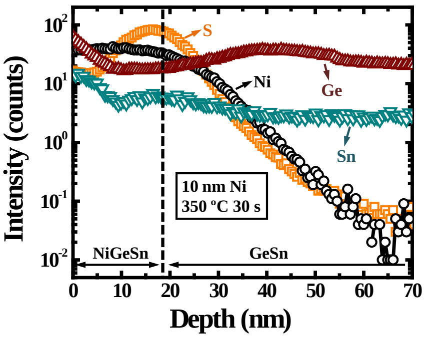

Fig. 9. SIMS depth profiles of the implanted species in Ni(GeSn)/n-GeSn contact with S implant. S segregation occurs at the Ni(GeSn)/n-GeSn interface.

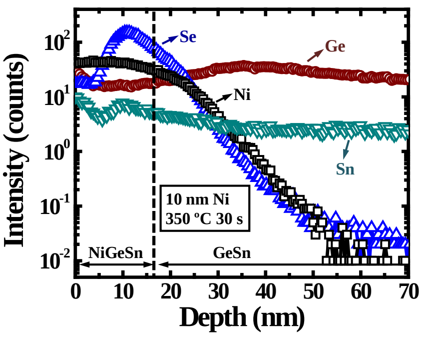

Fig. 10. SIMS depth profiles of the implanted species in Ni(GeSn)/n-GeSn contact with Se implant. Se segregation peak is found inside Ni(GeSn) layer.

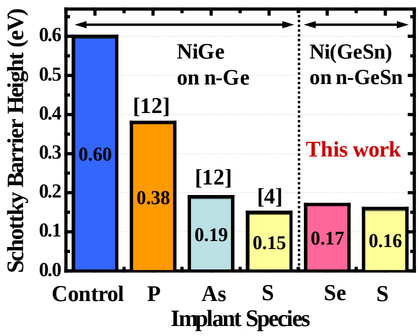

Fig. 11. Comparison of Schottky barrier height of NiGe/n-Ge and Ni(GeSn)/n-GeSn contacts with various species segregation in literature and this work.