Extended Abstracts of the 2013 International Conference on Solid State Devices and Materials, Fukuoka, 2013, pp602-603

Epitaxial Nickel Distanogermanide [$Ni(Ge_{1-x}Sn_x)_2$] Contact Formation using Pulsed Laser Annealing

Xin Xu, Wei Wang, Yuan Dong, Eugene Yu Jin Kong, Xiao Gong, Qian Zhou, Genquan Han, Pengfei Guo, Lanxiang Wang, and Yee-Chia Yeo.*

Department of Electrical and Computer Engineering, National University of Singapore (NUS), Singapore 117576.
*Phone: +65 6516-2298, Fax: +65 6779-1103, E-mail: yeo@ieee.org

I. Introduction

Germanium tin ($Ge_{1-x}Sn_x$) alloy has attracted great attention as a channel material of MOSFETs for future low power and high performance logic applications, owing to its high carrier mobility [1-3]. $Ge_{1-x}Sn_x$ channel n-MOSFETs were recently demonstrated [4], and metallic Ni contacts n^+ $Ge_{1-x}Sn_x$ S/D were used. To achieve high drive current, metal contacts with low Schottky barrier height (SBH) are needed to realize small contact resistance. Recently, laser annealing (LA) technique was used to form $NiGe_2$/n-Ge contact [5], and reduced effective electron SBH was demonstrated [6]. However, there have been no reports on $Ni(Ge_{1-x}Sn_x)_y$ formation using LA. $Ni(Ge_{1-x}Sn_x)_y$/n-GeSn contacts are not well investigated.

In this paper, laser annealing technique, for the first time, was applied to form a continuous, uniform and epitaxial nickel distanogermanide [$Ni(Ge_{1-x}Sn_x)_2$] film. In addition, Schottky diodes were fabricated to investigate the electrical property of the $Ni(Ge_{1-x}Sn_x)_2$ contacts on n-GeSn. Reduced effective electron SBH was achieved for laser-annealed sample as compared with the rapid-thermal-annealed one.

II. $Ni(Ge_{1-x}Sn_x)_2$ Formation and Characterization

A. As-grown $Ge_{1-x}Sn_x$

$Ge_{1-x}Sn_x$ films were epitaxially grown on p-type Ge (100) substrate using solid source molecular beam epitaxy (MBE) system at 170°C. Cross-sectional TEM image of a 38 nm-thick $Ge_{1-x}Sn_x$ layer is shown in Fig. 1(a). High resolution TEM (HRTEM) image in Fig. 1(b) shows defect-free $Ge_{1-x}Sn_x$/Ge interface and high crystallinity of $Ge_{1-x}Sn_x$ film. The substitutional Sn composition is 3.5% and the $Ge_{0.965}Sn_{0.035}$ layer is fully strained, as determined by high resolution XRD (HRXRD) image in Fig. 1(c).

B. Epitaxial $Ni(Ge_{1-x}Sn_x)_2$

After cyclic cleaning of the as-grown $Ge_{1-x}Sn_x$/Ge samples in DHF (HF : H_2O=1:50) and DI water, 15 nm-thick Ni was deposited by sputtering. 10-pulse laser annealing (λ = 248 nm, FWHM = 23 ns) with the fluence of 300 mJ/cm^2 per pulse was performed in N_2 ambient to form $Ni(Ge_{1-x}Sn_x)_y$. The control sample was rapid-thermal-annealed at 350 °C for 30 s.

Fig. 2 (a) and (b) show the XRD general area detector diffraction system (GADDS) scan of $Ni(Ge_{1-x}Sn_x)_y$ film formed by LA and rapid thermal annealing (RTA), respectively. Spots with strong intensity in Fig. 2(a) indicate that a single-crystalline film was formed by LA. The inset of Fig. 2(a) shows the integrated diffraction intensity as a function of 2θ. Two distinct $Ni(Ge_{1-x}Sn_x)_2$ peaks were identified. In contrast, diffraction rings in Fig. 2(b) indicate that a poly-crystalline $Ni(Ge_{1-x}Sn_x)$ film was formed by RTA. Fig. 3 shows the TEM image of a 62 nm-thick $Ni(Ge_{1-x}Sn_x)_2$ layer formed using LA. The entire $Ge_{1-x}Sn_x$ film was consumed during the LA step. The inset HRTEM image of interface region shows that the formed $Ni(Ge_{1-x}Sn_x)_2$ film is epitaxial. Clear epitaxial alignments between the $Ni(Ge_{1-x}Sn_x)_2$ film and the underlying substrate were observed. SIMS depth profile of Ni, Ge, and Sn for the laser-annealed Ni/$Ge_{1-x}Sn_x$/Ge(100) sample is shown in Fig. 4. Microscopic four-point probe was used for sheet resistance (R_{sh}) measurement. Fig. 5 shows the contour plot of R_{sh} measured in a 1 mm × 1 mm area of the 62 nm-thick $Ni(Ge_{1-x}Sn_x)_2$ film. R_{sh} values range from 8.7 to 9.3 Ω, indicating good uniformity of the $Ni(Ge_{1-x}Sn_x)_2$ film resistivity.

III. $Ni(Ge_{1-x}Sn_x)_y$/n-GeSn Schottky Diode

A. Device Fabrication

The key process steps for fabricating the $Ni(Ge_{1-x}Sn_x)_y$/n-GeSn diode are shown in Fig. 6. After epitaxial growth of 120 nm-thick $Ge_{0.977}Sn_{0.023}$ film, a phosphorus implant was carried out with a dose of 1×10^{13} cm^{-2} at energies of 50, 130 and 250 keV. Dopant activation was performed using RTA at 400 °C for 5 minutes. After that, a 50 nm-thick SiO_2 isolation layer was deposited and patterned to open the active region. This was followed by the sputtering of 15 nm-thick Ni. Here, two splits were introduced in the $Ni(Ge_{1-x}Sn_x)_y$ formation step: RTA at 350 °C for 30 s and 10-pulse LA at the fluence of 300 mJ/cm^2 per pulse. Unreacted Ni was then removed by concentrated sulfuric acid. Finally, a 200 nm-thick Al layer was deposited on the backside of the samples.

B. Electrical Characteristics

$Ni(Ge_{1-x}Sn_x)_y$/n-GeSn Schottky diodes with an active area of 75 × 75 μm^2 were characterized. Fig. 7 shows the *I-V* characteristics of $Ni(Ge_{1-x}Sn_x)_y$/n-GeSn diodes formed by LA and RTA, with the inset illustrating the $Ni(Ge_{1-x}Sn_x)_y$/n-GeSn Schottky diode structure. The reverse current of laser-annealed sample is 30 times higher than that of the rapid-thermal-annealed one at a bias of -1 V. The increased reverse current indicates that a lower effective electron SBH was achieved using LA. Fig. 8 shows the cumulative probability plot of the reverse current at a biased voltage of -1 V for laser-annealed samples and rapid-thermal-annealed ones, respectively. The tight distribution of reverse current density indicates good device-to-device uniformity for both splits.

IV. Conclusion

We report the first formation of an uniform and epitaxial $Ni(Ge_{1-x}Sn_x)_2$ film using pulsed laser annealing. Compared to the rapid-thermal-annealed $Ni(Ge_{1-x}Sn_x)$/n-GeSn contact, a higher reverse current was achieved in the laser-annealed $Ni(Ge_{1-x}Sn_x)_2$/n-GeSn contact, indicating a reduction in effective electron Schottky barrier height at $Ni(Ge_{1-x}Sn_x)_2$/GeSn interface.

Acknowledgement

We acknowledge support from the National Research Foundation under Grant NRF-RF2008-09.

Reference

[1] J. D. Sau *et al.*, *PRB* 75, 045208, 2007.
[2] G. Han *et al.*, *IEDM 2011*, p. 402
[3] S. Gupta *et al.*, *IEDM 2011*, p.398.
[4] G. Han *et al.*, *VLSI Symp. 2012*, p. 97.
[5] P. S. Y. Lim *et al.*, *APL* 97, 182104, 2010.
[6] P. S. Y. Lim *et al.*, *APL* 101, 172103, 2012.

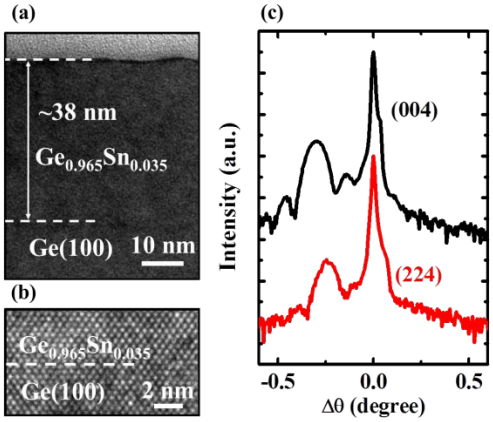

Fig. 1. (a) Cross-sectional TEM image of an epitaxial $Ge_{0.965}Sn_{0.035}$ film grown on the Ge(100) substrate. (b) HRTEM image shows defect-free interface. (c) HRXRD (004) and (224) curves show well-defined $Ge_{0.965}Sn_{0.035}$ peaks and a fully strained epitaxial $Ge_{0.965}Sn_{0.035}$ layer.

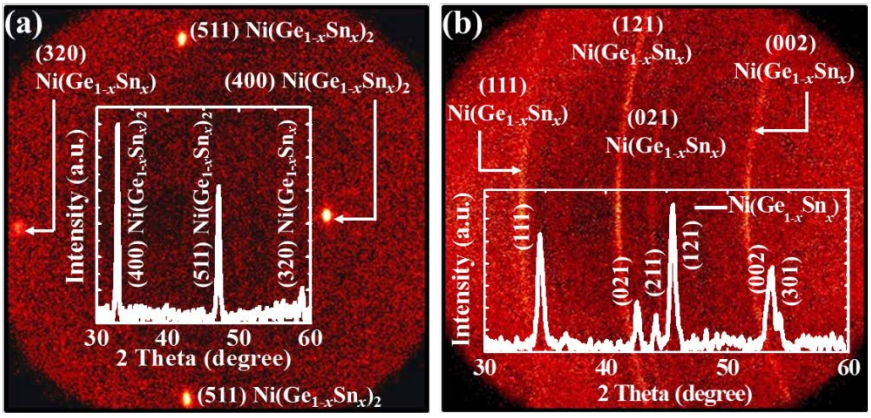

Fig. 2. XRD GADDS scan of $Ni(Ge_{1-x}Sn_x)_y$ film formed by (a) 10-pulse laser annealing (LA) at the fluence of 300 mJ/cm^2 per pulse and (b) rapid thermal annealing (RTA) at 350 °C for 30 s. Spots with strong intensity in (a) indicate a single-crystalline $Ni(Ge_{1-x}Sn_x)_2$ film was formed by LA. The inset of Fig. 2(a) shows the integrated diffraction intensity as a function of 2θ. Two distinct $Ni(Ge_{1-x}Sn_x)_2$ peaks were identified. Diffraction rings in (b) indicate that a poly-crystalline $Ni(Ge_{1-x}Sn_x)$ film was formed by RTA.

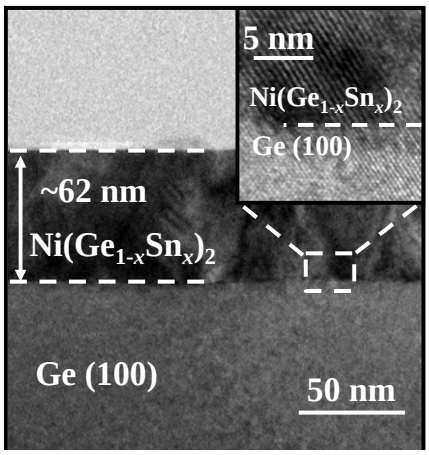

Fig. 3. TEM image of a 62 nm-thick $Ni(Ge_{1-x}Sn_x)_2$ formed using LA. The inset shows HRTEM image of a single-crystalline epitaxial $Ni(Ge_{1-x}Sn_x)_2$ layer formed on Ge.

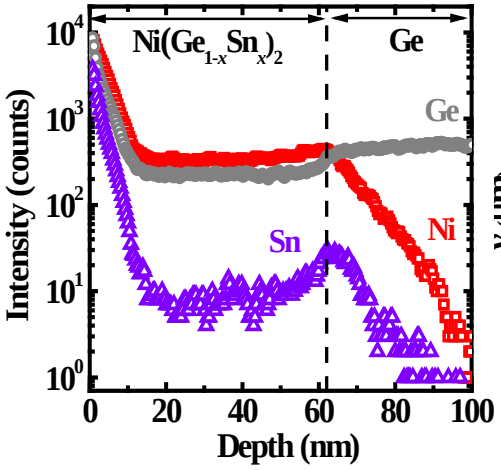

Fig. 4. SIMS depth profile of Ni, Ge, and Sn for the laser-annealed $Ni/Ge_{1-x}Sn_x/Ge(100)$ sample. The $Ni(Ge_{1-x}Sn_x)_2$/Ge interface is observed 62 nm under the surface.

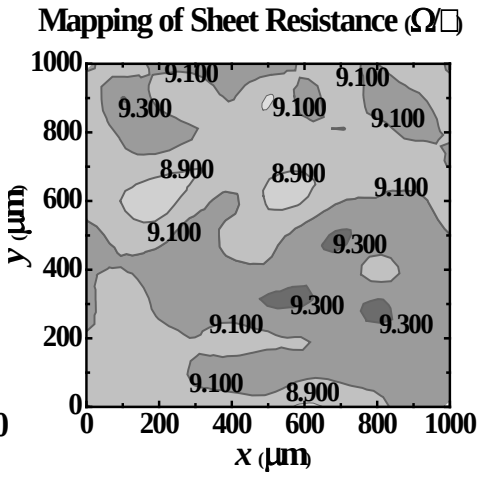

Fig. 5. Contour plot of R_{sh} measured in a 1 mm × 1 mm area of the $Ni(Ge_{1-x}Sn_x)_2$ film formed using LA. R_{sh} values range from 8.7 to 9.3 Ω, indicating good uniformity of the $Ni(Ge_{1-x}Sn_x)_2$ film.

Key Process Steps:

- **MBE growth GeSn (~120 nm) on n-type Ge (100) substrate**
- **Phosphorous Implant and Activation**
- **SiO_2 Deposition (~50 nm)**
- **Active Region Opening**
- **Ni Deposition (~15 nm)**
- **$Ni(Ge_{1-x}Sn_x)_y$ Formation**
  - **Splits: ❶ Rapid Thermal Annealing 350 ℃, 30 s**
  - **❷ Pulsed Laser Annealing 300 mJ/cm^2, 10-pulse**
- **Unreacted Metal Removal by H_2SO_4**
- **Al Deposition on backside (~200 nm)**

Fig. 6. Key process steps for fabricating the $Ni(Ge_{1-x}Sn_x)_y$/n-GeSn(100) Schottky diode. Two splits were introduced in the $Ni(Ge_{1-x}Sn_x)_y$ formation step: RTA at 350 °C for 30 s and 10-pulse LA at the fluence of 300 mJ/cm^2 per pulse.

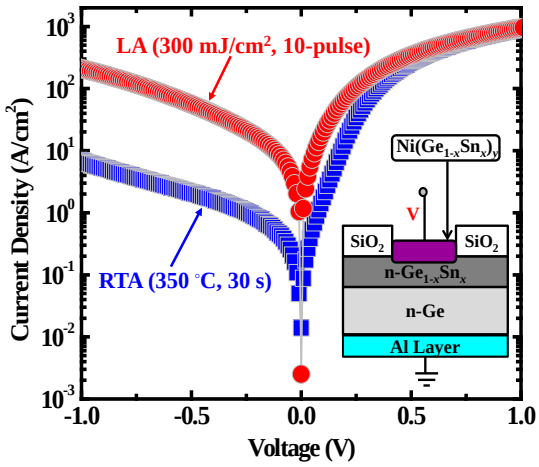

Fig. 7. *I-V* characteristics of $Ni(Ge_{1-x}Sn_x)_y$/n-GeSn(100) diode with an active area of 75 × 75 μm^2 formed by LA and RTA. The reverse current of laser-annealed sample is 30 times higher than that of the rapid-thermal-annealed one at a bias of -1 V. The inset shows the schematic of a $Ni(Ge_{1-x}Sn_x)_y$/n-GeSn Schottky diode.

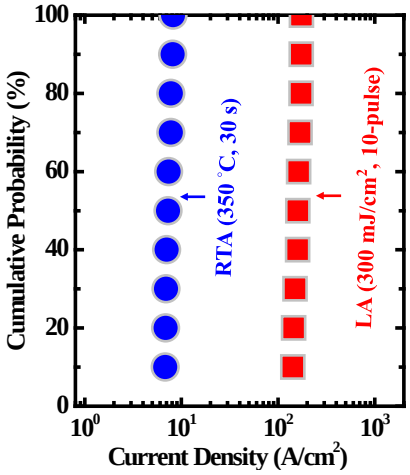

Fig. 8. Cumulative probability plot of the reverse current at a biased voltage of -1 V for $Ni(Ge_{1-x}Sn_x)_y$/n-GeSn diodes formed by LA (red square) and RTA (blue circle), respectively.