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Growth of a low dark current p-n junction

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DESCRIPTION OF DELIVERABLE

Description of work:
Surface passivation, contact formation and electrical characterization.
IBM will develop improved contact processes for n and p regions.

1. INTRODUCTION

This report is a summarizes all activities towards ohmic contact formation and electrical characterization on hexagonal $Si_{20}Ge_{80}$ nanowires. In the last report, we investigated the contact formation of a NW batch with a non-intentional n-type doping concentration in the mid 10^{18} cm^{-3}. Contacting these NWs with different metals leads to the formation of a Schottky barrier independent of the metal work function. The annealing of Ni- and Al-contacts to improve the contacts formation was difficult to control. We showed that implantation doping is a valid doping method, since recrystallization is possible into the metastable hexagonal crystal structure. NW, doped with Ga and B (p-type), showed ohmic behavior independent of the metal used and without the need to anneal.
We now report results on contact formation for the most recent batch of $Si_{20}Ge_{80}$ nanowires, which are expected to have a lower non-intentional doping level, due to improved synthesis conditions. Electrical contact formation using Ti, Al and Ni are studied, and transmission line measurements (TLM), are reported.

2. METAL CONTACTS

After receiving a new batch of NW from TU/e, we wanted to confirm the measurements results from the previous batch. For this, metal-semiconductor junctions were fabricated using evaporated Ti, Al, and Ni and following the identical fabrication protocol as previously reported. The lithographically defined contact openings on the nanowires were exposed to a short BHF etch, rinsed, dried, and immediately loaded into the evaporator to promote a clean, oxide-free interface.

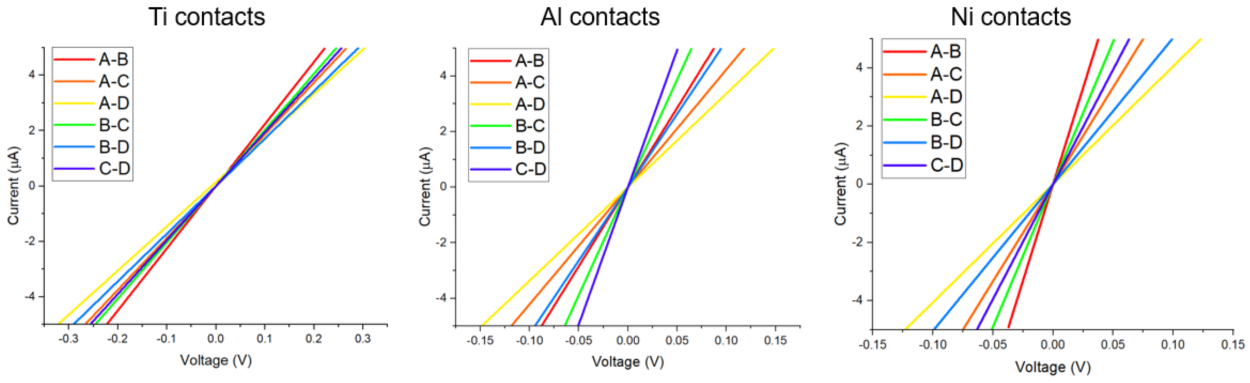

Figure 1 Properties of various metal contacts on the new batch of Hex-SiGe NWs. Independent of contact metal (Ti, Al, Ni) all devices show ohmic contacts.

The current-voltage measurements (Figure 1) show ohmic contacts independent of the metal work function, which is in contradiction with the previous results. The improvement of the contact formation may be due to the improved growth of the SiGe NW-shell resulting in a lower background doping level. The non-intentional n-type doping concentration is assumed to be in the mid 10^{18} cm^{-3} for the previous batch and in the low 10^{18} cm^{-3} for this samples. This result confirms previous findings that fermi level pinning in n-type Hex-SiGe plays an important role in contact formation. The improved HexSiGe material thus allows to fabricate electrical devices without the need for cumbersome post-annealing processes which is an important result.

3. ELECTRICAL CHARACTERISATION

3.2 Transmission Line Measurements

The high yield of ohmic contacts allowed to conduct the transmission line measurement (TLM). The wires are contacts in such a way that the distance between the contacts varies (Figure 2). Plotting the measured resistance (2-point measurements) against the distance between the contacts allows us to calculate important properties of the system, such as the resistivity of hex SiGe (ρ_{SiGe}) and the contact resistivity (ρ_C) for the different metals used.

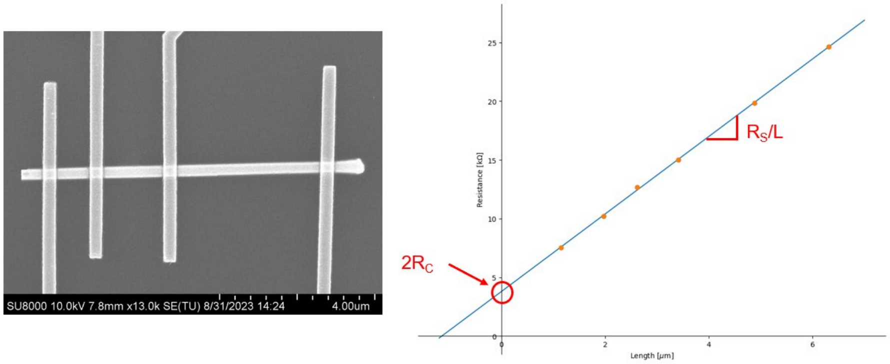

Figure 2 Position of contacts for TLM and illustration for TLM

Calculating the resistivity of SiGe and the contacts resistivity for the three different metals we obtained the results shown in table 1.

Table 1 *Resistivity and contact resistivity of Hex-SiGe NW with Ti, Al and Ni contacts*

	ρ_C [Ωcm^2]	ρ_{SiGe} [Ωcm]
Ti Contacts	7.4 ± 1.9 * 10^{-4}	4.1 ± 1.0 * 10^{-2}
Al Contacts	2.3 ± 1.2 * 10^{-5}	4.1 ± 0.3 * 10^{-2}
Ni Contacts	1.2 ± 0.9 * 10^{-5}	3.8 ± 0.3 * 10^{-2}

As expected, the similar resistivities of $Si_{20}Ge_{80}$ NWs are obtained using different metals. The resistivities were additionally confirmed by 4-point probe measurements. The contact resistivities for Al and Ni are lower than for Ti, which makes these metal preferable choice for later use. Finally, temperature dependent measurements were performed and showed ohmic behavior of the contacts down to 1.5 K.

4. CONCLUSION ON CONTACTS

Ohmic contacts independent of the metal and without annealing were realized due to the reduction of the non-intentional n-type doping concentration during the growth. The high yield of ohmic contacts allowed to electrically characterize hexagonal $Si_{20}Ge_{80}$. Using transmission line measurements we were able to calculate the resistivity of SiGe to be approximately 4 ± 0.5 * 10^{-2} Ωcm. Additionally, the calculations of the contacts resistivity showed that aluminum and nickel have a lower resistivities compared to Titanium. Overall our measurements show that the Hex-SiGe NW are highly conductive indicating a significant defect density in the material (or surface) or a significant impurity level. The rather low contact resistivity obtained is a promising result for efficient current injection in devices.

5. IMPLANTATION DOPING

In-situ or ex-situ doping of Hex-SiGe is an important requisite for the fabrication of a p-n junction, a key building block for opto-electronic devices. As showed in previous reports, implantation doping can be applied to hexagonal SiGe as recrystallization is possible. We showed that implantation doping of entire NWs with Ga or B causes the Schottky barrier to disappear and leads to linear I-Vs and ohmic contacts. Surprisingly, in nominally n-doped NWs with single sided p-implanted contacts it was not possible to observe any signs of a diode characteristics. To shed ling on this issue, a better understanding of the pristine Hex-SiGe NW material and its electronic properties is critical. We made use of the reproducible contact formation on NWs now available to extract the carrier concentration using a two-point measurement at low temperatures.

6. SHUBNIKOV-DE-HAAS OSCILLATIONS

By applying a varying magnetic field and measuring the change in the electric resistance (4-point probe measurement), it is possible to obtain quantum oscillations (Figure 3)

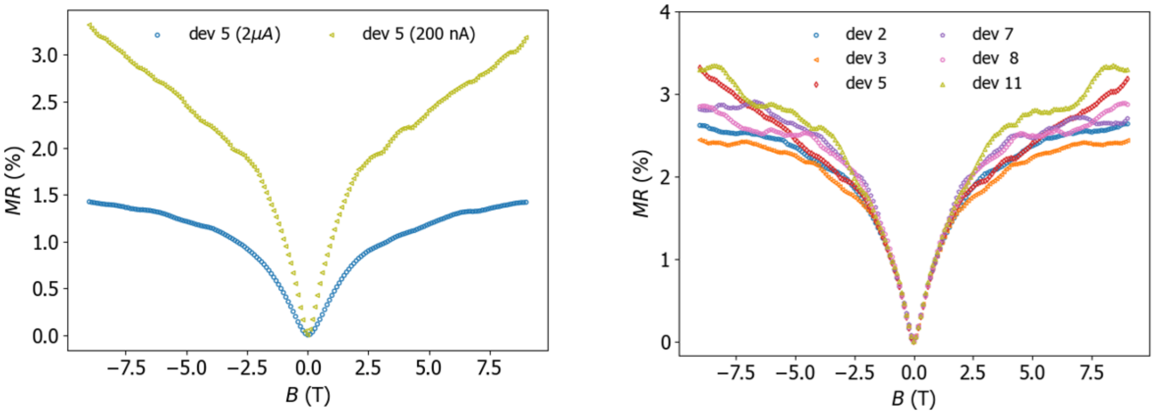

Figure 3 Magnetoresistance measurements on Hex-SiGe NWs. (left side) MR at two current levels. (right side) MR measurements at lower current for six different devices.

The signal strength obtained was very faint. Increasing the current should increase the signal of the oscillations, but as see in Figure 3 (left) this is not the case. The drop in signal amplitude indicates that the higher current induces strong self-heating, which decreases the signal. Due to the low signal, the extraction of the peaks is challenging but measurement on six devices increased confidence in the background subtraction and frequency extraction. The oscillations were used to calculate the carrier density and the mobility. Preliminary analyses results in a mobile carrier density in the order of 2x10^{17} cm^{-3} and a mobility of approximately 1100 cm^2/Vs.

7. CONCLUSION

We applied magnetoresistance measurements to Hex-SiGe NWs at low temperatures to extract SdH oscillation amplitude and frequencies and to extracted carrier density and mobility. These initial results suggest a surprisingly low (electron) carrier density in the order of 2x10^{17} cm^{-3} in the bulk of the non-intentional n-doped wires. Such a relatively low level should facilitate the fabrication of a p-n junction using ion implantation of an acceptor such as Ga or B, which is however not observed yet. Further investigations are needed to shed light on this unexpected issue.