Exploring the Relationship Between Doping and Ti-Silicidation for Advanced FDSOI Applications

M. Merlin*, T. Cabaret, H. Grampeix, J. Kanyandekwe, A. Thouvard, P. Gergaud, Ph. Rodriguez

Univ. Grenoble Alpes, CEA, LETI, 38000 Grenoble, France

In advanced node transistors, contact resistance becomes more important due to the shrinking of dimensions [1]. This has led to a switch from Ni to Ti silicides to achieve resistance reduction [2]. This change requires optimization to achieve low contact resistivity. The doping process is known to affect the silicidation process [3]. However, the effect of the high dopant concentration - required for today's transistor - on phase sequence remains unclear. In this work, we study the effect of phosphorus concentration on titanium silicidation on n-doped Si layers with low-doped (few 10^{20} atoms/cm^3) and high-doped (few 10^{21} atoms/cm^3) epitaxial layers of about 30 nm on which 10 nm thick Ti films have been deposited. The samples were then annealed to form Ti-silicide compounds.

The evolution of the phase sequence of the Ti/Si:P system for low and high-doped Si:P epitaxial layers is described in Figure 1. For both systems, the reaction starts with the consumption of the titanium layer. Around 450 °C, the metal layer is completely consumed and the C49-$TiSi_2$ phase is identified. Then, the evolution of the C49 and C54-$TiSi_2$ phases is highly dependent on the P doping concentration: in the low-doped Ti/Si:P system, the C49-$TiSi_2$ phase is completely consumed around 730 °C and then no significant diffraction line appears up to 850°C. In the high-doped Ti/Si:P system, the complete consumption of the C49-$TiSi_2$ phase is shifted from 730 °C to 580 °C. Then a diffraction line corresponding to the C54-$TiSi_2$ phase appears around 700 °C.

In addition to the in-situ X-ray measurements, the sheet resistance (Rs) was measured as a function of annealing temperature for 30 s duration in an N_2 atmosphere. As shown in figure 2, the curves show three distinct regimes : Below 600°C, the R_s decreases slightly and then remains stable at about 40 Ω/sq up to 950 °C in the low-doped Ti/Si:P system and up to 800 °C in the high-doped Ti/Si:P system. The last regime is only observed at high doping concentration, where R_s drops to 30 Ω/sq. To better understand these phase transition curves, grazing incidence X-ray diffraction measurements were performed for different thermal annealing temperatures (Figure 3). The first regime appears to be associated with the formation of the Ti_5Si_4 phase (identified as diamond symbols in Figure 3) as also observed in [4]. However, the formation of Ti_5Si_4 is not correlated with an R_s plateau that generally characterizes phase formation. The phase observed in the plateau is the C49-$TiSi_2$ (triangle symbols) which remains stable up to 950°C in the low-doped system, in contrast to the high-doped system where the drop in R_s observed around 800 °C concerns the nucleation of the C54-$TiSi_2$ phase (circle symbols) in coexistence with the C49-$TiSi_2$ phase.

The effect of P doping concentration on Ti-based silicidation described in this work is discussed compared to the results shown by S. Park *et al.* in the Ti/Si:P system for similar dopant concentrations [5]. Indeed, they observed that increasing the phosphorus concentration inhibited the formation of the C54-$TiSi_2$ phase. In contrast, by combining different characterization methods, we observed that the phase transition from the C49 to the C54-$TiSi_2$ phases is shifted to a lower temperature for the high-doped sample.

This work was supported by a grant from the French government, managed by the "Agence Nationale de la Recherche" under the France 2030 program: ANR-22-NEXG-0001 (NextGen project). Part of this work, carried out on the Platform for Nanocharacterisation (PFNC), was supported by the "Recherche Technologique de Base" program of the French National Research Agency (ANR).

References

1. A. V.-Y. Thean et al., in *2015 Symp. VLSI Technol. VLSI Technol.* (2015), pp. T26–T27.
2. C. Lavoie et al., ECS Trans. **77**, 59 (2017).
3. E. Rosseel et al., ECS Trans. **98**, 37 (2020).
4. H. Yu et al., IEEE Trans. Electron Devices **63**, 4632 (2016).
5. S. Park et al., Phys. Status Solidi A **216**, 1800620 (2019).

* *corresponding author e-mail: marie.merlin@cea.fr*

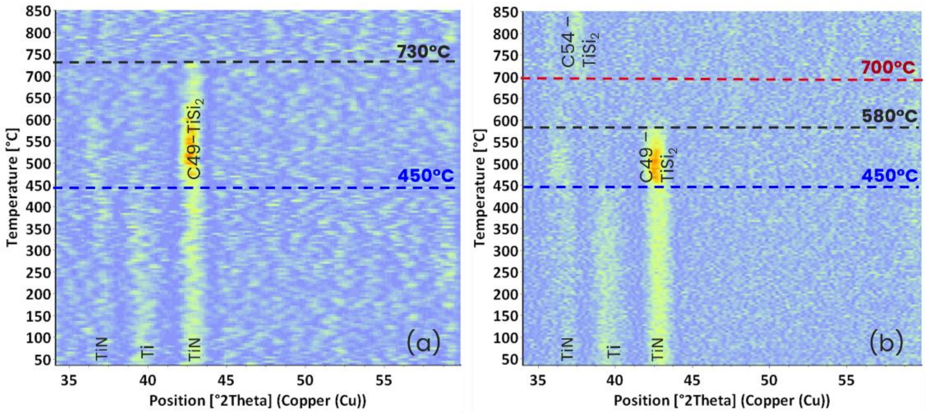

Figure 1. *In-situ* X-ray diffraction mappings corresponding to the reaction between a 10 nm Ti metal layer deposited on (a) low-doped and (b) high-doped Si:P (100) epitaxial layers. The blue dashed lines correspond to the temperature of full metal consumption and the C49 $TiSi_2$ identification. The black lines correspond to the C49 phase disappearance and the red lines to the growth of the C54 phase.

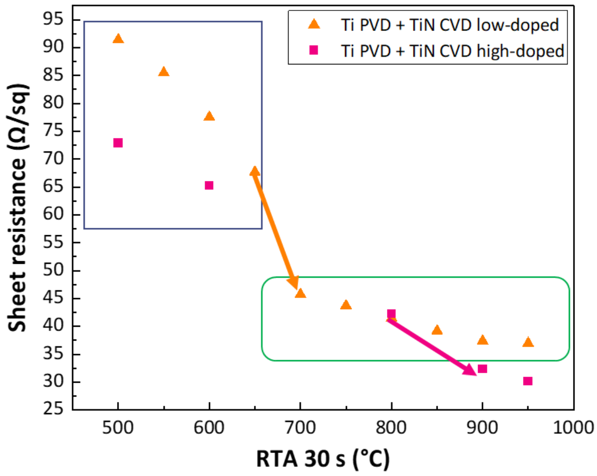

Figure 2. Evolution of the sheet resistance R_S for different rapid thermal annealing temperatures in the Ti/Si:P system with high-doped (pink squares) and low-doped (orange triangles) Si:P epitaxial layers. Samples were annealed for 30 s in an N_2 atmosphere.

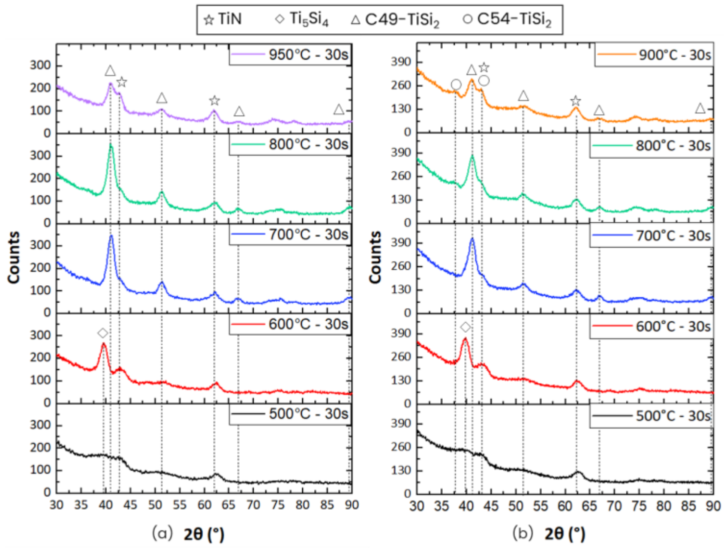

Figure 3. Grazing incidence X-Ray patterns corresponding to the evolution of the Ti/Si:P system as a function of different rapid thermal annealing temperatures, 30 s annealed in an N_2 atmosphere for (a) low-doped and (b) high-doped Si:P epitaxial layers.