Study of Doping Methods and Ge-PAI Conditions on Ti Silicidation for Advanced FD-SOI Nodes

M. Merlin[1], T. Cabaret[1], J. Kanyandekwe[1], Ph. Rodriguez[1], P. Gergaud[1]

[1]*Univ. Grenoble Alpes, CEA, Leti, 38000, GRENOBLE, France*

In advanced technology nodes, the shrinking of the source/drain contact area leads to increasing concerns about the growing prominence of metal/semiconductor contact resistance [1]. To address this issue, pre-amorphization by implantation (PAI) performed prior to Ti metallization has been proposed as an effective technique in achieving low contact resistance [2]. However, the effect of the doping process together with the PAI on Ti-silicidation with high dopant concentration remains unclear, notably the extent to which the doping process affects the material structure and, in turn, the solid-state reactions.

In this work, we study the impact of doping process as well as different Ge pre-amorphization conditions on Ti-silicidation phase sequence. (100)Si substrates were P-doped using two different methods : A double P ion implantation (I/I) was carried out on a first half of the substrates ((i) 9 keV, $3x10^{15}$ at/cm² and (ii) 0.75 keV, $6x10^{14}$ at/cm²), while the other half was doped using a 30 nm in-situ n-doped (ISD) Si:P epitaxial layer with few 10^{21} atoms/cm³. Dopants were then activated using spike annealing. In ISD layers, active P chemical concentration (N_a) of $7x10^{20}$ atoms/cm³ was achieved. P-doped silicon substrates were pre-amorphized by Ge implantation at different conditions prior to Ti metallization. The evolution of the sheet resistance (R_s) as a function of (i) the rapid thermal annealing temperature and (ii) the thickness of the amorphous silicon (a-Si) is described in Figure 1.(a) in the I/I system and in Figure 1.(b) in the ISD system. Regarding the doping method combined with PAI conditions, results display different trend evolutions, notably within the 500 – 900 °C temperature range. For high-energy PAI samples, sheet resistance was dominated by the presence of a-Si at low annealing temperatures. Then, after an annealing at 600 °C, in the I/I doped system, all samples exhibited similar R_s values, while in the ISD doped system, PAI-17 (as-deposited a-Si thickness was about 17 nm) and PAI-29 (as-deposited a-Si thickness was about 29 nm) samples exhibited lower R_s, compared to the reference (without PAI) and PAI-5 (as-deposited a-Si thickness was about 5 nm) samples. On the other hand, both systems were found to exhibit minimum R_s values after an annealing at 800 °C, regarding the PAI-29 sample in the I/I doped system and the PAI-17 and PAI-29 samples in the ISD doped system. In order to correlate these electrical behaviors with solid state reaction, complementary in plane X-ray diffraction measurements (IP-XRD) were performed. Results are presented in Figure 2. The XRD pattern recorded after annealing at 600 °C, in the region where R_s values were similar in the I/I-doped system, revealed diffraction peaks corresponding to the Ti_5Si_4 intermediate phase (identified with triangle symbols) whatever the initial a-Si thickness. In contrast, in the ISD doped system, diffraction peaks of C49-$TiSi_2$ (identified with square symbols) were observed in coexistence with the Ti_5Si_4 regarding the PAI-17 and PAI-29 samples, and this correlates with the decrease in R_s. In the two systems, the lowest R_s value was assigned to the formation of the C54-$TiSi_2$ (identified with crescent moon symbols).

The a-Si created by Ge implantation is known to be partly consumed by Ti silicidation and partly recrystallized with solid phase epitaxial regrowth (SPER) [2]. According to the SPER kinetic, all the a-Si should be recrystallized after an annealing at 600 °C. Thus, regarding the discrepancies we highlighted, doping method may impact Ti silicidation phase sequence, in addition to the Ge PAI process. As widely studied in the 1990s [3], PAI was found to enhance silicidation at lower temperatures. However, phase sequence in samples doped using in-situ epitaxial method may not undergo the same phase formation kinetic as in the ion-implantation doped sample.

The impact of doping method together with PAI conditions was studied. PAI enhanced Ti-silicidation at lower temperatures in both systems. Interestingly, the doping method was found to impact Ti silicidation too. Results suggest that the phase formation kinetics in ISD samples may be faster than those in I/I doped samples with promoting phase coexistence.

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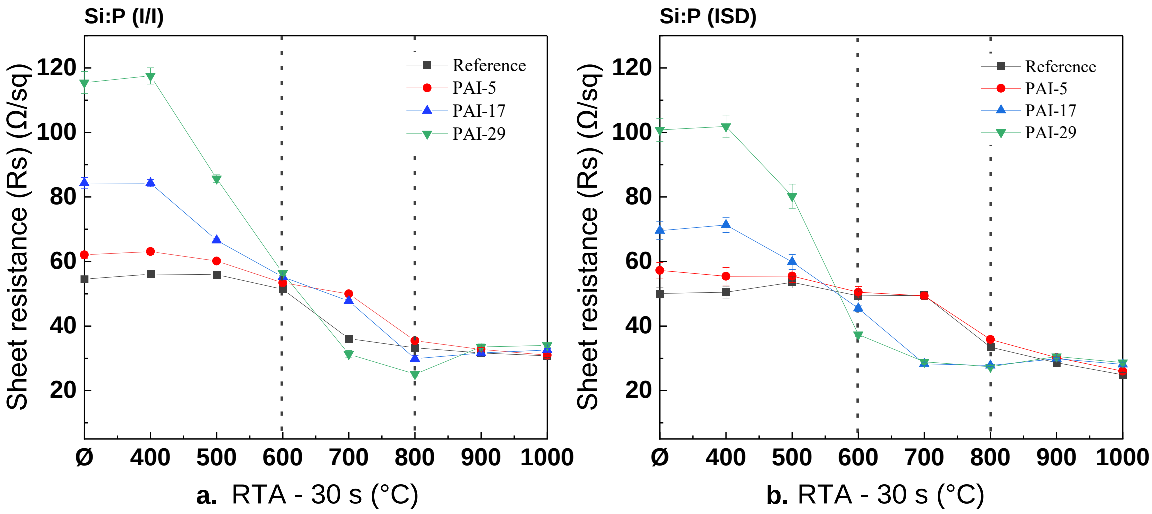

Figure 1. Evolution of the sheet resistance R_s as a function of the annealing temperature for all investigated (a) ion-implantation doped samples and (b) in-situ doped samples. Samples were annealed for 30 s in N_2 atmosphere.

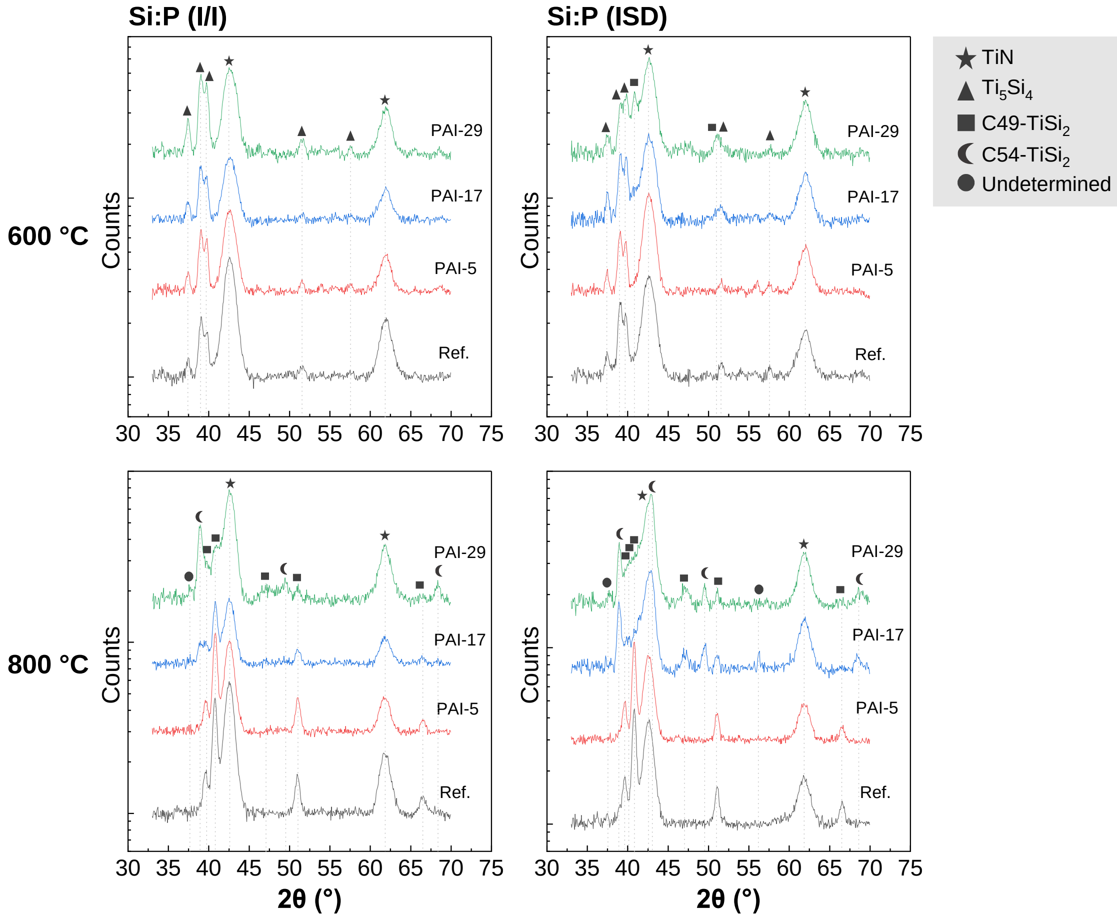

Figure 2. In-plane X-ray diffraction patterns for different Ge PAI conditions, after an annealing at 600 °C (top) and 800 °C (bottom) for the ion-implantation doped system (to the left) and the in-situ doped system (to the right). Samples were annealed for 30 s under N_2 atmosphere.