Source/drain and silicides for nanosheet device applications

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1. Introduction

The advent of nanosheet (NS) devices generates many challenges. Source/drain (SD) epitaxy e.g. no longer proceeds from Si(001) substrates, which requires optimizing the properties of layers grown on non-{001} oriented surfaces surrounded by dielectrics (Fig. 1). Process complexities and loading effects linked to unprecedentedly high aspect ratios and device densities [1] must also be accounted for [2]. Silicide reactions and resulting phases can also be affected by varied starting surfaces and pattern dimensions [3]. These questions require systematic assessments to maintain acceptably low access resistances in scaled devices. In this regard, this contribution aims at investigating the dependency of SiGe:B SD epilayers and Ti, Mo and Sc silicide properties on substrate orientation. Sc and Mo are considered due to their excellent contact properties for N- and PMOS applications, respectively [4]. Ti is used as reference.

2. Methods

The blanket $Si_{1-x}Ge_x$:B layers discussed in this work are grown using *conventional* conditions (SiH_2Cl_2, GeH_4, and B_2H_6 at 500°C) on n-type 300 mm Si wafers. The B_2H_6 flow and deposition time are adjusted to obtain 20 nm thick $Si_{1-x}Ge_x$:B layers with nominally 60% Ge and covering the 0.1-5x10^{21} cm^{-3} chemical B concentration range. Other growth parameters remain unchanged. Silicides are formed on p-type Si wafers with relatively high resistivities (> 1 Ω.cm). After Si native oxide removal, 30 nm thick Ti, Sc and Mo films are deposited using physical vapour deposition. The layers are left uncapped to enable electrical measurements, which leads to overestimated resistivities and enlarged error bars. Some samples are annealed in different conditions including (i) forming gas (10% H_2 in N_2) sintering for 20 min at 420°C and (ii) rapid thermal annealing (RTA) for 1 min at 525 or 650°C in N_2. All layers are deposited on Si(001), Si(110) and Si(111) substrates.

3. $Si_{1-x}Ge_x$:B epitaxy on Si(001), Si(110) and Si(111) substrates

Transferring the initial $Si_{1-x}Ge_x$ process from Si(001) to alternative substrates highlights differences in surface reactions and resulting layer properties. Growth rates (not shown here) and Ge contents (x) extracted by secondary ion mass spectrometry (SIMS) (Fig. 2(a)) are indeed lower on Si(110) and Si(111) compared to Si(001), which matches trends observed in [5]. Introducing and increasing the B_2H_6 flow during growth leads to a significant increase in x on Si(110). In addition, X-ray diffraction (XRD) data shown in Fig. 2(b) indicates larger reductions in apparent Ge concentration, $[Ge]_{app}$. These reductions exceed 10% on Si(001) and Si(111) due to the incorporation of high B levels. On Si(110), the observed decrease is more limited, partly compensated by the increase in x. Fig. 3(a) eventually compares $Si_{1-x}Ge_x$:B resistivities as a function of the B_2H_6 flow used during growth. Resistivity minima are obtained for different B_2H_6 flows. Notably, resistivities are the lowest for $Si_{1-x}Ge_x$:B / Si(111), down to 1.2x10^{-4} ohm.cm. This minimum corresponds to the largest active B concentration recorded in this study. Doping activation therefore seems to be enhanced in $Si_{1-x}Ge_x$:B grown on {111} surfaces, which suggests opting for contact formation prior to SD merging.

4. Ti, Sc and Mo silicide formation on Si(001), Si(110) and Si(111) surfaces

The impact of substrate orientation on silicidation and resulting physical properties as a function of post metal deposition thermal budget is also investigated. Ti and Sc silicides are found to thicken with increasing the thermal budget on all surfaces, while Mo does not show any reaction up to 525°C (not shown here). Fig. 3(b) compares Ti, Sc and Mo silicide resistivities as a function of post metal deposition thermal budget. Annealing Ti- and Mo-based stacks generally induces an increase in material resistivity, while low temperature Sc silicidation benefits the contact electrical properties. Interestingly, the evaluated silicides do not exhibit any clear dependence on surface orientation.

5. Conclusions

The study proposes a systematic assessment of SiGe:B SD and Ti, Mo and Sc silicides deposited on Si surfaces relevant to nanosheet device applications. SiGe:B epitaxy using conventional growth conditions is affected by non Si{001} substrate orientations, which turns out being beneficial to enhance active doping in $Si_{1-x}Ge_x$:B / Si(111). On the other hand, the resistivity of silicides evaluated in this work is not affected by the starting surface. Contacting {111}-oriented $Si_{1-x}Ge_x$:B may therefore allow to improve contact performance in nanosheet devices.

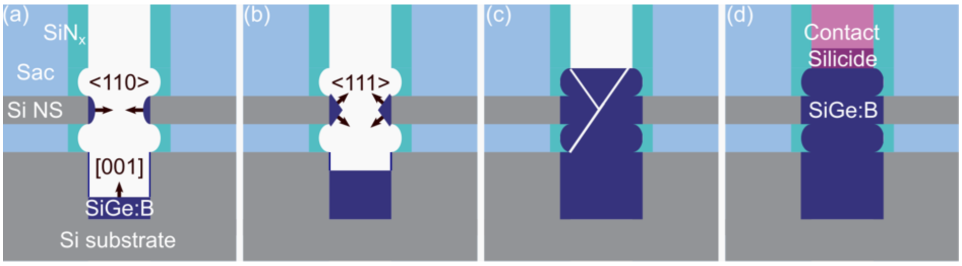

Fig. 1: Schematic representation of $Si_{1-x}Ge_x$:B source/drain-contact formation in simplified nanosheet device structures. (a) $Si_{1-x}Ge_x$:B nucleation from different surfaces, (b) formation of {111} facets, (c) merging of opposing SD possibly resulting in twin defects (white lines) and (d) contact processing and (germano)silicidation. 'Sac' stands for sacrificial layers later replaced by gates and dielectrics.

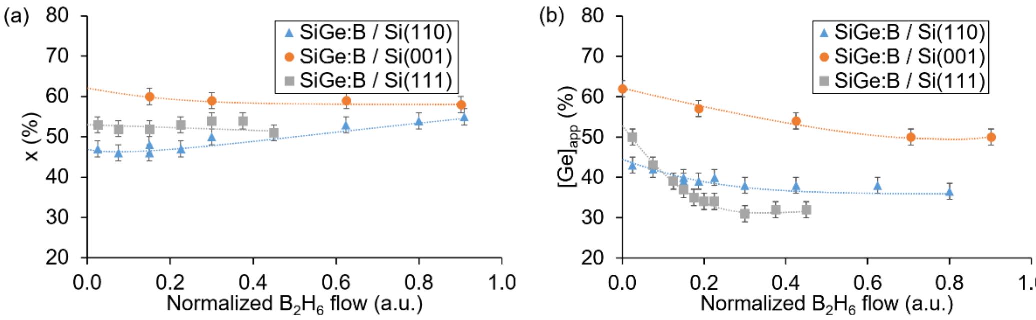

Fig. 2: Ge (a) chemical and (b) apparent concentrations in $Si_{1-x}Ge_x$:B grown on Si(001), Si(110) and Si(111) substrates, as extracted from SIMS and XRD, respectively. Apparent Ge contents obtained with XRD are lower due to B incorporation in substitutional lattice sites. Lines are guides for the eye. All B_2H_6 flows are normalized with respect to the highest flow used in this study, which is common to all curves.

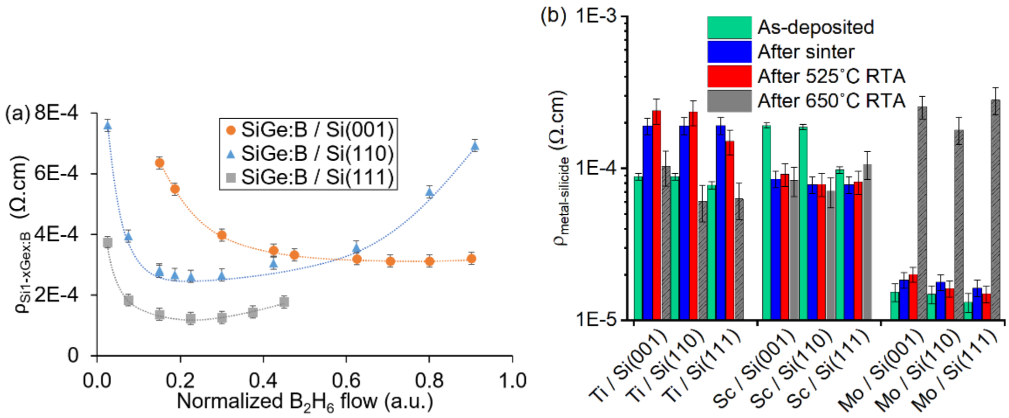

Fig. 3: (a) $Si_{1-x}Ge_x$:B resistivity curves as a function of the normalized B_2H_6 flow used during growth on Si(001), Si(110) and Si(111) substrates. Resistivity minima are obtained for different B_2H_6 flows. Lines are guides for the eye. (b) Ti, Sc and Mo silicides resistivities as a function of post metal deposition thermal budget. Data corresponding to Ti and Mo silicides after 650°C RTA (with patterned fill) assume the same thicknesses as measured after 525°C RTA, due to surface roughening preventing accurate thickness measurements, which reflects in larger error bars.

References

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Acknowledgements

Parts of the results were achieved using the NanoIC pilot line, which is supported by the Flemish government (Belgium) and received funding from the Chips Joint Undertaking through EU programs. For more information, please visit nanoic-project.eu. The imec core CMOS program members, local authorities and the imec pilot line are acknowledged for their support.