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TEM STUDY OF SILICIDE FORMATION AND MICROSTRUCTURAL DEVELOPMENT OF Ni/ $Si_{1-x}Ge_x$

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Nickel silicides are of considerable interest as contact and interconnect materials in modern semiconductor devices[1]. Low resistivity nickel germanosilicide, grown on high mobility, epitaxial $Si_{1-x}Ge_x$, is of particular interest[2,3]. We have produced nickel silicides on $Si_{0.8}Ge_{0.2}$ with varying resistivities, using plasma sputtering and rapid thermal annealing (RTA) techniques[4]. High-resolution transmission electron microscopy (HRTEM), in association with energy dispersive spectrometry (EDS) and nano-beam diffraction (NBD), was used to correlate microstructural features and compositions with measured resistivities.

Figure 1 shows that Ni reacts with $Si_{1-x}Ge_x$ at 500 °C to form a uniform crystalline layer on the $Si_{1-x}Ge_x$ substrate. The interface between the silicide and the Si substrate is sharp and flat, without evidence for the formation of any third phase, and the electrical resistivity is low. EDS results show that the Ge concentration increases sharply at the $Ni(Si_{1-x}Ge_x)$/ $Si_{0.8}Ge_{0.2}$ interface and in the adjacent areas, indicating that Ge strongly segregates to the Si rather than the silicide.

Figure 2 is a cross-sectional view of a Ni/ $Si_{0.8}Ge_{0.2}$ sample annealed at 700°C. It shows one side of a large hemispherical grain that grew through the SiGe layer and into Si substrate. This grain is identified as $Ni(Si_{1-x}Ge_x)$ ($x<0.5\%$) by EDS and NBD. EDS also reveals that no Ge is present within the Si substrate adjacent to the $Ni(Si_{1-x}Ge_x)$, whereas the $Si_{1-x}Ge_x$ layer adjacent to the silicide grain has a high Ge concentration (25%-35%). The Ge is definitely not distributed uniformly over the hemispherical interface. It is found that threading dislocation segments that arise from relaxation at elevated temperatures in $Si/Si_{1-x}Ge_x$ systems are related to this directional Ge segregation. When the $Si_{0.8}Ge_{0.2}$ strained layer is annealed at 700°C, the strain relaxes and threading dislocations pass through the $Si_{0.8}Ge_{0.2}$ layer to the Ni layer on the free surface. These dislocations provide heterogeneous nucleation sites for the $Ni(Si_{1-x}Ge_x)$ phase and may serve as fast Ni diffusion pipelines for continuous $Ni(Si_{1-x}Ge_x)$ crystal growth. Having penetrated the alloyed layer, $Ni(Si_{1-x}Ge_x)$ grows laterally, expelling Ge into the unreacted $Si_{0.8}Ge_{0.2}$ layer, and vertically, forming slightly facetted hemispherical bulges into the underlying Si. This nucleation and growth mechanism explains the heterogeneous distribution of Ge around $Ni(Si_{1-x}Ge_x)$ grain, and the observation of many dislocations in the plan-view images. The elevated sheet resistance at higher temperature is attributed to the lack of silicide film continuity.

References

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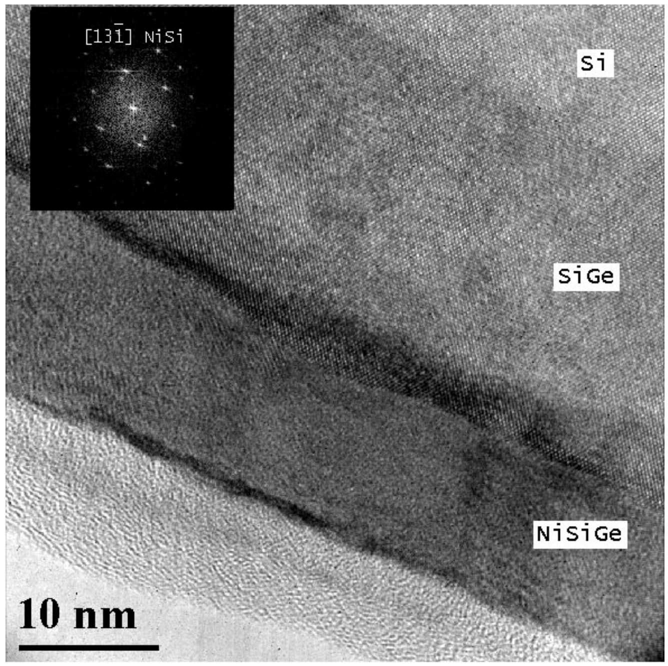

Fig. 1. HRTEM cross-sectional image of Ni/ $Si_{0.8}Ge_{0.2}$ sample annealed at 500 °C showing the uniform crystalline $Ni(Si_{1-x}Ge_x)$ layer formed on $Si_{0.8}Ge_{0.2}$/Si.

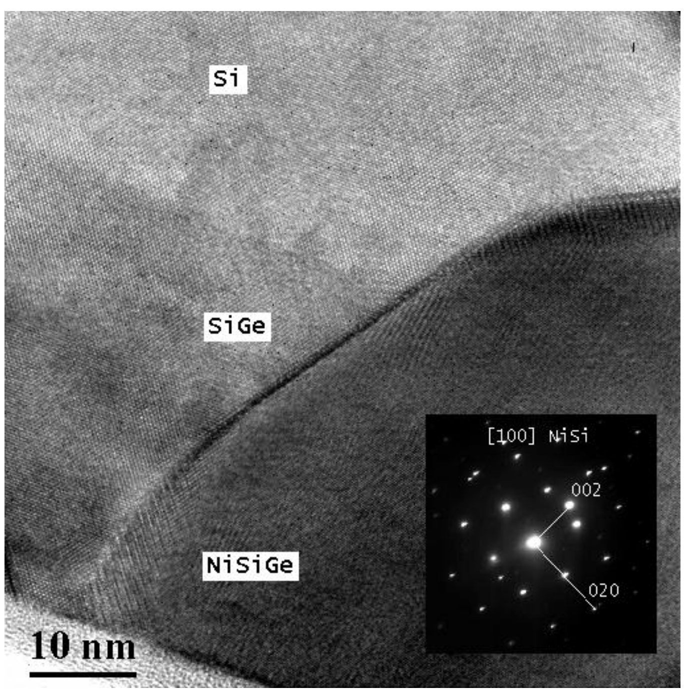

Fig. 2. HRTEM cross-sectional image of Ni/ $Si_{0.8}Ge_{0.2}$ sample annealed at 700 °C showing one side of a large hemispherical $Ni(Si_{1-x}Ge_x)$ (x<0.5%) grain.

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