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Electrical Properties and Solid-Phase Reactions in Ni/Si(100) Contacts

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1. Introduction

An increase in the contact resistance of metal/Si ohmic contacts becomes a very serious problem with decreasing the dimension in ultra-large scale integrated circuits (ULSIs). $TiSi_2$ is the silicide most commonly used in ULSIs. However, there is a problem that the sheet resistance of Ti-silicided polysilicon gate electrodes increases significantly as the linewidth reaches a sub-micron range[1]. $CoSi_2$ has been introduced to replace $TiSi_2$ but the degradation of junction integrity, such as the formation of pinholes and spikes, becomes a critical problem because of its high consumption ratio of Si to Co[2]. Recently, nickel monosilicide (NiSi) has been demonstrated to be a promising silicide candidate for sub-0.1 μ m CMOS device[3]. NiSi shows no resistance increase for narrowed linewidth. A main advantage using NiSi rely on its less consumption of Si to form NiSi than $TiSi_2$ and $CoSi_2$. In this study, we have investigated the electrical properties and solid-phase reactions at the interface of a Ni/Si system.

2.Experimental

Samples were prepared by the deposition of 20-nm-thick Ni films on Si(100) substrates at room temperature in an ultra-high vacuum chamber with a base pressure below 1×10^{-9} Torr followed by annealing at 350℃ for 30 min in the same chamber. Some samples were then annealed at 600-850℃ for 30 sec in a nitrogen atmosphere as a second-step annealing. X-ray diffraction (XRD) analysis and transmission electron microscopy (TEM) were employed to reveal the crystallographic structure and the film morphology. We determined the contact resistivity by a four-terminal Kelvin method. n^+-regions in p-Si substrates and p^+-regions in n-Si were formed by thermal diffusion of P and B, respectively, at 1000℃. The concentrations were measured to be 2×10^{20} for P and 1×10^{20} cm^{-3} for B.

3.Results and Discussion

Figure 1 shows XRD profiles of Ni/n-Si samples annealed at various temperatures. It is found that polycrystalline-NiSi phases were formed after annealing at 350-750℃. However, no specific peaks of NiSi cannot be seen after 800-850℃ annealing. From cross-sectional TEM observation of the silicide/Si interfaces of the 850 ℃ -annealed sample, we confirmed epitaxial growth of a $NiSi_2$ phase and the formation of {111} facet at the $NiSi_2$/Si(100) interface. These results are consistent with the results of the XRD analysis.

Figure 2 shows sheet resistance as a function of annealing temperature. The values of $NiSi_2$ is higher than those of NiSi. Furthermore, a gradual increase in the sheet resistance is observable with increasing the annealing temperature. From atomic force microscopy, we confirmed rougher surface morphologies of the NiSi films annealed at higher temperatures. Therefore the agglomeration of NiSi is one of the reason for the increased sheet resistance.

The contact resistivities, ρ_c , of Ni/n^+-Si and Ni/p^+-Si systems are shown in Figs. 3(a) and 3(b), respectively. As a reference, ρ_c of Ti and Co/n^+, p^+-Si systems are also shown [4,5]. ρ_c of NiSi, in 350℃-annealed sample, shows the lowest resistivity in these materials. The values of ρ_c, less than 1×10^{-7} $\Omega\cdot cm^2$ can be obtained for both n^+- and p+-type contacts. The low ρ_c for NiSi could result from high impurity concentration at the silicide-silicon interface.

5.Conclusions

We have investigated the electrical properties and solid-phase reactions at the interface of a Ni/Si system. It is found that contact resistivities less than 1×10^{-7} $\Omega\cdot cm^2$ can be realized in both n and p types of contact. This demonstrates one of capabilities of NiSi contacts which are applicable to the future CMOS devices.

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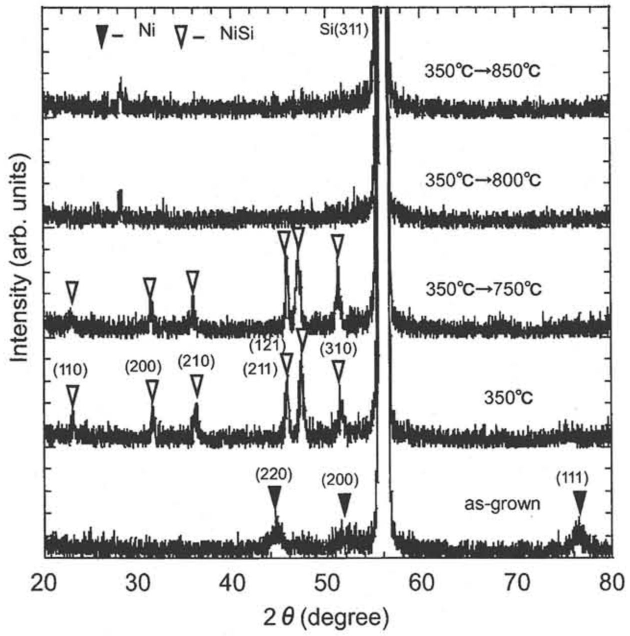

Fig. 1: XRD profiles of Ni/n-Si samples annealed at 350, 750, 800, and 850℃.

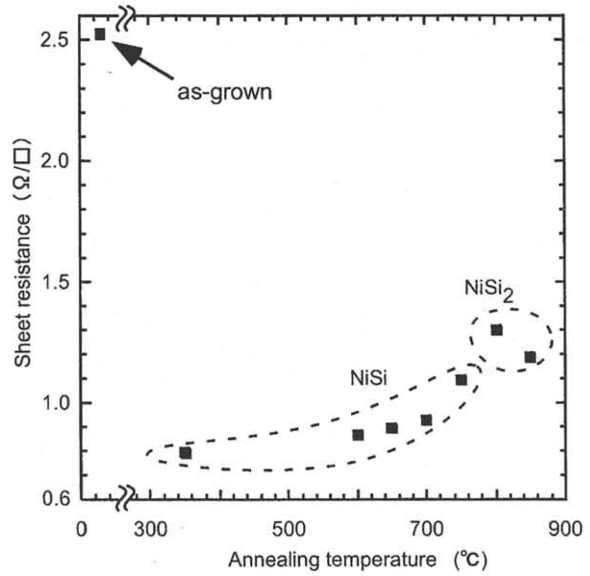

Fig. 2: Sheet resistance of the Ni/n-Si samples as a function of the annealing temperature.

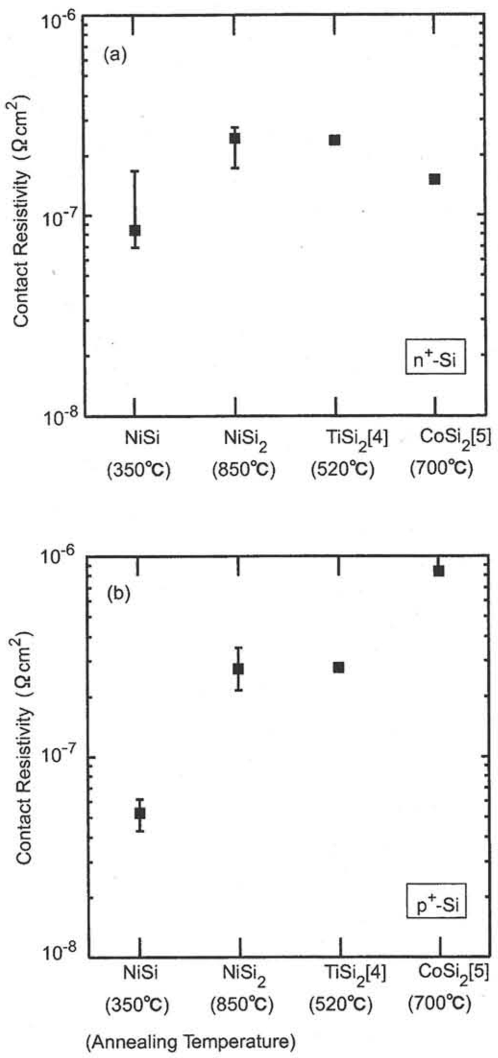

Fig. 3: Specific contact resistivities of (a) silicide/n$^+$-Si(100) and (b) silicide/p$^+$-Si(100) systems .