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Influence of structural variation of Ni silicide thin films on electrical property for contact materials

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1. Introduction

Realization of low resistance contacts at metal/Si interfaces has been a key issue in the fabrication of down-scaling metal-oxide-semiconductor field effect transistors. Recently, NiSi has been one of promising candidates as the contact materials to the next generation of ultra-large scale integrated (ULSI) devices [1, 2]. However, the agglomeration of NiSi and the phase transformation from NiSi to high-resistivity $NiSi_2$ phases occur due to process annealing and this severely influences the applicability of this material system to the ULSI devices. In order to provide a thermally stable Ni silicide film with low resistance, it is necessary to clarify the relationship between crystallographic and electrical properties of Ni silicides in detail. In this study, we investigated microscopic thin film structures and the sheet resistance of Ni silicides for various annealing conditions.

2. Experimental

Substrates were n-type Si(100) wafers with resistivities of 1.59-2.06 Ω·cm. A 20-nm-thick Ni was deposited on the substrate at room temperature in an ultra-high vacuum chamber with a base pressure below 1×10^{-9} Torr, followed by annealing at 350ºC for 30 min in the same chamber. Some samples were then annealed at 550-850ºC for 30-360 sec in a nitrogen atmosphere as a second-step annealing. Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) were employed to reveal the crystallographic structure and the film morphology. The sheet resistance of the film was measured by a linear four-point probe method.

3. Results and discussion

Figure 1 shows sheet resistances of Ni/Si samples as a function of the annealing time for various annealing temperatures. Below the annealing at 600ºC, the sheet resistances keep low values of about 4.7 Ω/□ regardless of the annealing time and the value corresponds to the sheet resistance expected from a conformal NiSi film. In samples annealed at 650-750ºC, the sheet resistance gradually increases with annealing time.

As shown in Fig.2, a SEM image of the sample annealed at 750ºC for 180 sec reveals the occurrence of agglomeration of the Ni silicide film and the exposure of the Si substrate surface as seen in the dark regions. Gradual enhancement of NiSi agglomeration with the annealing time has been also observed in the samples annealed at 650-750ºC.

On the other hand, as shown in Fig. 1, the sample annealed at 850°C has the stable sheet resistance of about 6.6 Ω/□. In this sample, we confirmed the epitaxial growth of $NiSi_2$ film by using cross-sectional TEM observations (not shown). This result indicates that the agglomeration of the film is effectively suppressed, once the epitaxial $NiSi_2$ film is formed.

Figure 3 shows the dependence of the sheet resistance on the Si exposed area over the 15×23 μm^2 surface area estimated from SEM images. It is seen that the agglomeration of NiSi has a clear correspondence to the increase in sheet resistance below 750°C. The electrical degradation of the Ni silicide film with agglomeration is found to be mostly enhanced at temperatures ranged from 650 to 750°C.

Figures 4(a) to (c) show plan-view TEM images of samples annealed at 350ºC for 30 min, 750ºC for 30 sec, and 750°C for 180 sec, respectively. With increasing the annealing temperature and the time, the average grain size of polycrystalline NiSi enlarges concomitantly with the NiSi agglomeration. Additionally, it should be noticed that the formation and growth of epitaxial $NiSi_2$ phases preferentially occurs at the sites where the Si substrate surfaces are exposed due to the agglomeration of NiSi. This phenomenon was also confirmed by the cross-sectional TEM image shown in Fig. 5. It is likely that these partly-formed epitaxial $NiSi_2$ effectively suppresses further agglomeration of the Ni silicides, leading to the reduced sheet resistance increase observed in the sample annealed at 750°C compared with that at 725°C as shown in Fig. 1.

4. Conclusions

We have investigated the relationship between the sheet resistance and the crystallographic change of Ni silicide films induced by annealing. The agglomeration and the phase transition which occurred in the polycrystalline NiSi films have been revealed microscopically. We found that the expansion of the Si exposed region with coalescence and agglomeration of NiSi grains is a dominant factor for increasing in sheet resistance at temperatures ranging from 650°C to 750°C. This result strongly suggests that controlling the grain structure change of poly-NiSi films is essential to suppress an electrical degradation of NiSi films.

References

[1] Y. Tsuchiya, A. Tobioka, O. Nakatsuka, H. Ikeda, A. Sakai, S. Zaima, and Y. Yasuda, Jpn. J. Appl. Phys. **41**, 2450 (2002).
[2] Y. Tsuchiya, O. Nakatsuka, A. Sakai, S. Zaima, and Y. Yasuda, Extended Abstracts of the 2002 International Conference on Solid State Devices and Materials, pp194-195, September 2002.

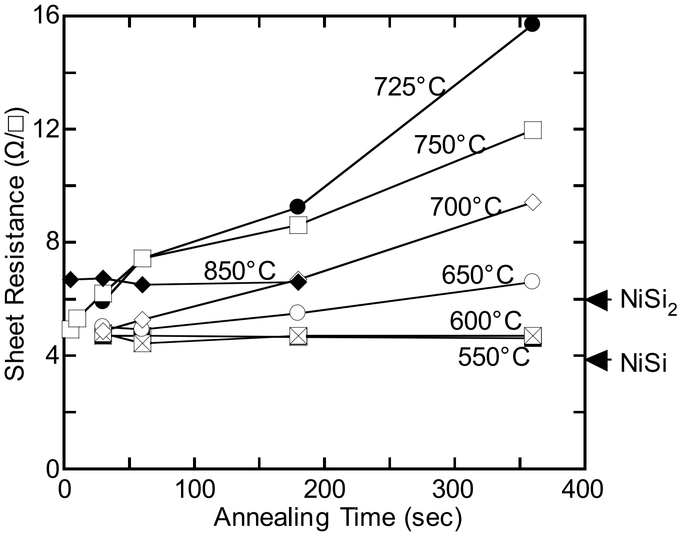

Fig.1:Sheet resistance of Ni/Si samples as a function of annealing time.

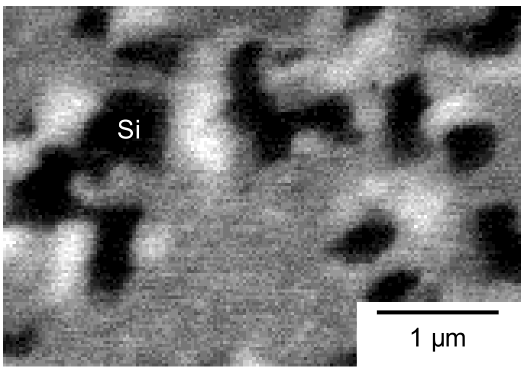

Fig.2: SEM image of Ni/Si sample annealed at 750°C for 180 sec

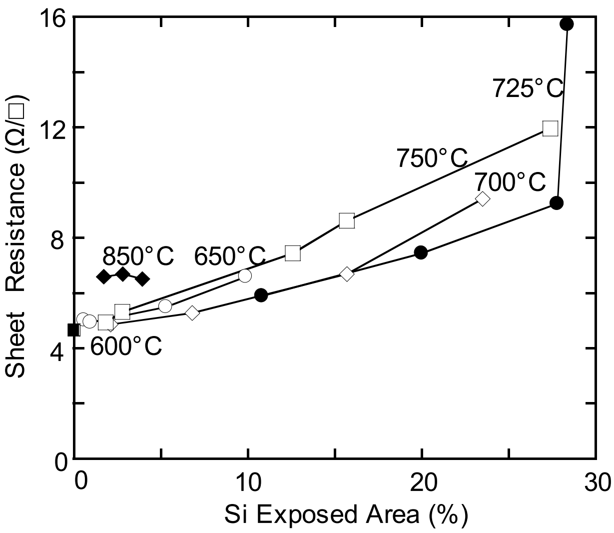

Fig.3: The sheet resistance of Ni/Si samples as a function of the Si exposed area.

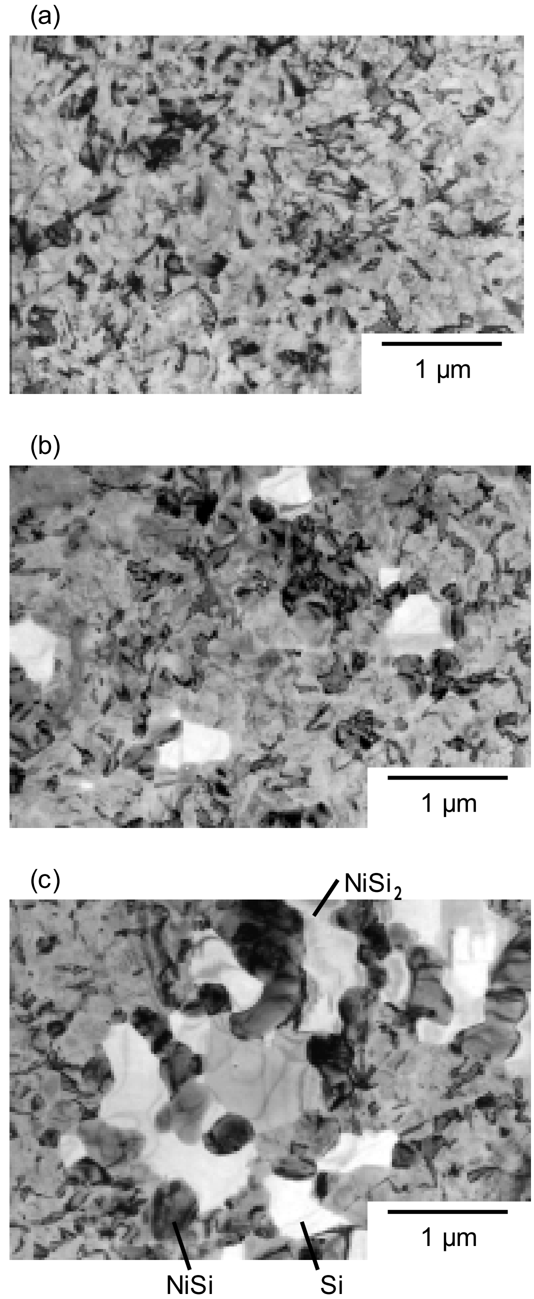

Fig.4: Plan-view TEM images of (a) Ni/Si sample after annealed at 350°C for 30 min, (b) at 750°C for 30 sec and (c) at 750°C 180 sec.

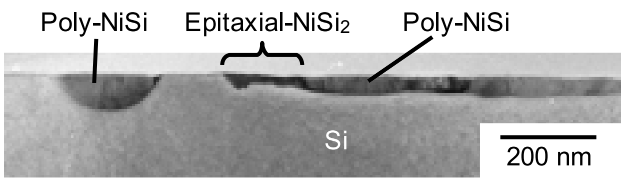

Fig.5: Cross-sectional TEM image of Ni/Si sample after annealed at 750°C for 30 sec