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Improvement of the thermal stability of NiSi films by using a thin Pt interlayer

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The effect of a thin interlayer of Pt on the stability of NiSi films on Si(111) substrates has been investigated. Both x-ray diffraction (XRD) data and sheet resistance measurements show a remarkable improvement in the thermal stability of NiSi due to the Pt interlayer. Detailed study on the XRD data shows PtSi and NiSi form a solid solution following a Vegard's law. It was found in Ni/Pt/Si samples that a transition in NiSi texture from (200)NiSi‖(111)Si to (002)NiSi‖(111)Si took place before the nucleation of $NiSi_2$, which may contribute to the enhanced stability of NiSi films. © *2000 American Institute of Physics.* [S0003-6951(00)01140-2]

Owing to its linewidth independence, low resistivity and relatively low consumption of Si, NiSi has become an attractive candidate for contact material in future generation deep submicron Si devices.[1–4] However, the phase transition from NiSi to high resistivity $NiSi_2$ at temperatures greater than 750 °C poses a serious problem.[5] In the past few years, great efforts have been made to study the thermal stability of NiSi films.[6–12] Recently, it has been reported that addition of 5 at. % Pt can significantly improve the thermal stability of NiSi.[12] In this letter, the effect of a thin interlayer of Pt on the thermal stability and texture of NiSi is presented.

An 8 nm thin layer of Pt and a 100-nm-thick layer of Ni were sequentially electron-gun evaporated on the Si(111) substrate, forming a Ni/Pt/Si bilayered film. The base pressure of the vacuum chamber was 1×10^{-8} Torr and during the deposition, the vacuum was better than 3×10^{-8} Torr. The deposition rates were 0.4 Å/s for Pt and 2 Å/s for Ni. To make a comparison, 100-nm-thick Ni films without Pt interlayers were also deposited with the same experimental parameters. Rapid thermal annealing of the samples was carried out in a high vacuum of 3×10^{-6} Torr at temperatures ranging from 600 to 900 °C for 2 min. The films were analyzed by x-ray diffraction (XRD) to identify crystallographic phases and the orientation of the silicides. Auger electron spectra (AES) was used to investigate the composition of the films. Sheet resistance of the samples was measured to evaluate the electric properties of the silicide films.

Figure 1 shows the XRD patterns of Ni/Si samples annealed at different temperatures. It can be seen that when annealed at 740 °C, polycrystalline NiSi films were formed [Fig. 1(a)]; while annealed at 800 °C, only peaks corresponding to (111) $NiSi_2$ and (222) $NiSi_2$ planes are present [Fig. 1(b) and its inset], indicating that epitaxial $NiSi_2$ films were formed. From these data, it is concluded that the transition from NiSi to $NiSi_2$ is completed at 800 °C. For Ni/Pt/Si samples, however, this phase transformation was not completed even after annealing at 900 °C [Fig. 2(d)], indicating a remarkable enhancement of thermal stability of NiSi. It is interesting to see that with the increase of temperature, the preferred orientation of NiSi films changes from (200)NiSi‖(111)Si to (002)NiSi‖(111)Si [Figs. 2(a)–2(d)]. While the texture of (200)NiSi was also observed in Mangelinck's recent work[12] where Pt was added into NiSi films by using a Ni(Pt) alloy target, such conversion in the texture of NiSi films at an elevated temperature was not reported. Since the sample annealed at 640 °C has a good (200) texture of NiSi, it is expected that the interface energy σ(NiSi/Si) is reduced so that nucleation of $NiSi_2$ can be retarded.[12] Thus, the sample was further annealed at 900 °C for 2 min to test its thermal stability. XRD pattern [Fig. 2(e)] shows that no $NiSi_2$ was formed after this high temperature annealing. Comparing Fig. 2(d) with Fig. 2(e), it is clear that the reduced interface energy σ(NiSi/Si) caused by (200)NiSi texture really contribute to the enhanced stability of NiSi films. By contrasting Fig. 2(a) with Fig. 2(e), we can see that the texture of NiSi film was also changing from

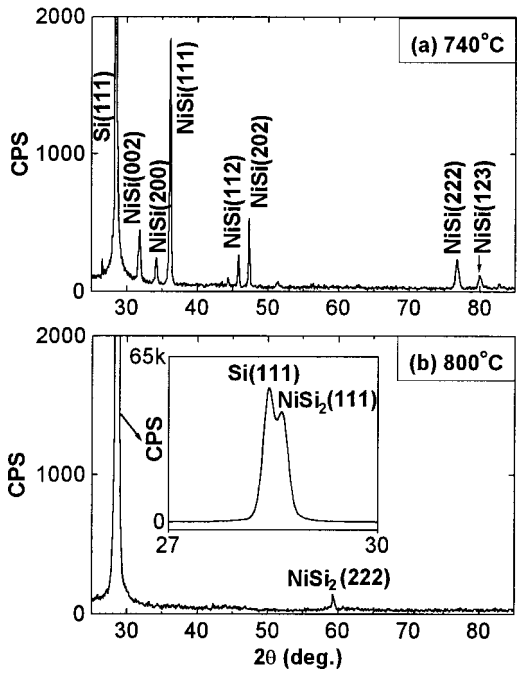

FIG. 1. XRD patterns of the Ni/Si samples annealed at (a) 740 and (b) 800 °C for 2 min.

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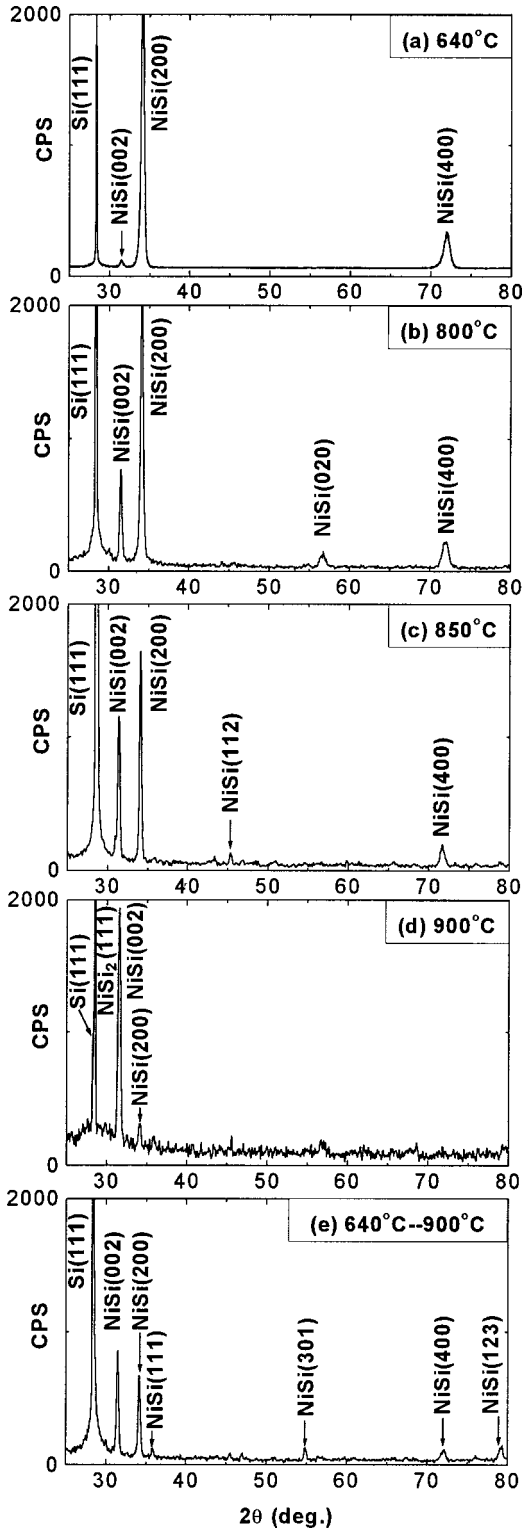

FIG. 2. XRD patterns of the Ni/Pt/Si samples annealed at (a) 640, (b) 800, (c) 850, and (d) 900 °C for 2 min, and (e) the 640 °C treated sample further annealed at 900 °C for 2 min.

(200)NiSi‖(111)Si to (002)NiSi(111)Si after annealing at an elevated temperature, although the conversion was not completed. From Figs. 2(a)–2(e), it seems that the nucleation of $NiSi_2$ begins only after this conversion in NiSi texture. The transition in the preferred orientation of NiSi films seems to have consumed the increased kinetic energy of the atoms caused by the rise in temperature and therefore delayed the nucleation of the $NiSi_2$ phase. Although the reason for the alteration in NiSi orientation is not clear, it is probable that the texture of (002)NiSi‖(111)Si is more beneficial for the nucleation of $NiSi_2$ at NiSi/Si interface than the texture of (200)NiSi‖(111)Si.

TABLE I. Comparison of XRD peak positions of pure NiSi and Ni(Pt)Si solid solution. (Cu $K\alpha$ irradiation).

	(002)		(200)		(123)	
	2θ (°)	d(Å)	2θ (°)	d(Å)	2θ (°)	d(Å)
NiSi[a]	31.62	2.829	34.26	2.617	79.94	1.200
Ni(Pt)Si[a]	31.52	2.838	34.14	2.626	79.34	1.208
Ni(Pt)Si[b]	31.53	2.837	34.14	2.627	79.50	1.206

[a]Experimental data.
[b]Calculated data using Vegard's law.

As shown in the XRD patterns of Ni/Pt/Si samples (Fig. 2), no peak corresponding to PtSi appears. By comparing the positions of NiSi diffraction peaks in Fig. 1 with those in Fig. 2, one can notice subtle differences in peak positions. These are listed in Table I. The reason for this discrepancy is attributed to the formation of NiSi–PtSi solid solution. Since the original thickness of Pt and Ni films is 8 and 100 nm, respectively, it can be calculated that the atomic percentage of PtSi in this solid solution is 5.5%. Both NiSi and PtSi have an orthorhombic MnP structure, with lattice constants $a=5.233$ Å, $b=3.258$ Å, $c=5.659$ Å for NiSi[13] and $a=5.595$ Å, $b=3.603$ Å, $c=5.932$ Å for PtSi.[14] By applying a Vegard's law, the lattice parameters of NiSi(94.5%)–PtSi(5.5%) solid solution should be $a=5.253$ Å, $b=3.277$ Å, and $c=5.674$ Å. This result agrees quite well with the positions of NiSi(002), (200), and (123) diffraction peaks in Ni/Pt/Si samples as listed in Table I. Moreover, it is shown in AES depth profile (Fig. 3) that although Pt was deposited before Ni, it distribute evenly through the depth of the Ni(Pt)Si film after annealing at 640 °C. From the experimental data earlier, we can conclude that PtSi solute in NiSi solvent in such a manner that Pt substitute some of the Ni atoms in NiSi lattice. This adjusts $\sqrt{3}b/c$ to 1, which is considered favorable for the texture of (200)NiSi‖(111)Si.[12]

Figure 4 shows the sheet resistance of the Ni/Si and Ni/Pt/Si samples annealed at different temperatures. For Ni/Si samples, the sheet resistance increased dramatically from 0.60 to 1.40 Ω/□ after annealing at 800 °C due to the formation of epitaxial $NiSi_2$ films, as revealed in correspond-

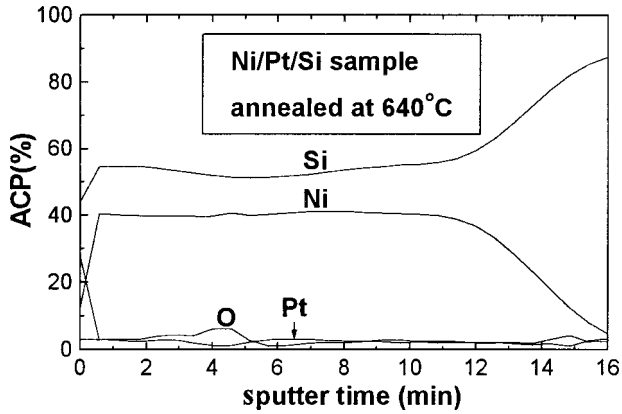

FIG. 3. AES depth profile of the Ni/Pt/Si sample annealed at 640 °C for 2 min.

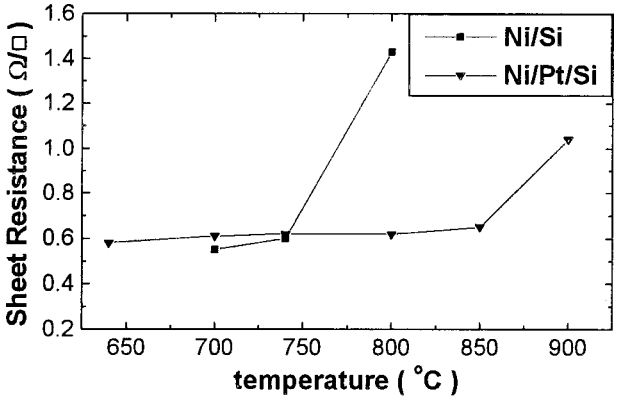

FIG. 4. Sheet resistance of the Ni/Si and Ni/Pt/Si samples as a function of the annealing temperature.

ing XRD data [Fig. 1(b)]. AES analysis with a sputter rate of 20 nm/min shows the thickness of pure NiSi and $NiSi_2$ films to be approximately 260 and 380 nm, respectively. So it can be calculated that the resistivity of NiSi and $NiSi_2$ films are 16 and 53 $\mu\Omega$ cm, which is in good agreement with previous reports.[15] For Ni/Pt/Si samples, however, this dramatic increase in resistivity did not take place until they were annealed at 900 °C. Even after annealing at this temperature, the sheet resistance of the sample (1.0 Ω/□) was still lower than that of the pure $NiSi_2$ film. This is consistent with the corresponding XRD data [Fig. 2(d)], which shows the film to be a mixture of NiSi and $NiSi_2$. Moreover, the sheet resistance of the sample annealed at 900 °C after heat treatment at 640 °C remains to be 0.60 Ω/□, in good agreement with the XRD pattern shown in Fig. 2(e) indicating that no $NiSi_2$ was formed after further annealing at 900 °C.

In conclusion, a thin interlayer of Pt was found to greatly enhance the thermal stability of the NiSi films. Detailed study on the XRD data shows PtSi and NiSi form a solid solution following a Vegard's law. It was found in Ni/Pt/Si samples that a transition in NiSi texture from (200)NiSi‖(111)Si to (002)NiSi‖(111)Si took place before the nucleation of $NiSi_2$, which may contribute to the enhanced stability of NiSi films. The reason for the texture transition requires further research.

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