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Formation of C54 $TiSi_2$ thin films by using high-temperature sputtering and rapid thermal annealing

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C54 $TiSi_2$ thin films have become particularly attractive because in comparison with other silicide thin films, they have the unique physical property of lower resistivity with larger thermal stability, as well as a higher possibility of magnetic ordering [1, 2]. C54 $TiSi_2$ thin films have attracted much attention due to their potential applications in ultra-large-scale integrated devices such as contacts and gate electrodes [3, 4]. Even though several techniques, such as preamorpholization of the Si substrate, growth at high temperature, and insertion of ultra-thin metals [5–8], have been employed to form C54 $TiSi_2$ thin films, the achievement of high-quality C54 $TiSi_2$ thin films still requires two-step annealing, which is very complicated. Therefore, the development of a process for the formation of C54 $TiSi_2$ thin films on p-Si substrates using a one-step method has become very important for device applications. Furthermore, studies on the formation of C54 $TiSi_2$ thin films using high-temperature sputtering and rapid thermal annealing have not been performed.

This letter reports data on the one-step formation process of C54 $TiSi_2$ thin films by using a high temperature sputtering and rapid thermal annealing method. X-ray diffraction (XRD) measurements were carried out in order to investigate the phase transitions of the annealed $TiSi_2$ thin films. X-ray fluorescence (EDX) measurements were performed to characterize the structure and the composition of the $TiSi_2$ thin films, and sheet resistance measurements were carried out in order to investigate their electrical properties. On the basis of experimental results, a possible formation process is presented for C54 $TiSi_2$ thin films deposited by using a one-step high-temperature sputtering and rapid thermal annealing method.

The samples used in this study were grown on B-doped p-Si substrates with a (100) orientation. The resistivities of the p-Si substrates at room temperature were approximately between 5 and 10 Ω· cm. The substrates were degreased in trichloroethylene (TCE), rinsed in de-ionized water, etched in a solution of H_2SO_4 and H_2O_2 (4:1) at 40 °C for 5 min, etched in a mixture of HF and H_2O (1:10) at room temperature for 5 min, and rinsed in TCE again. After the chemical process for the Si substrates had been finished, the chemically cleaned wafers were dried at 100 °C in a nitrogen atmosphere for approximately 10 min, and then the substrates were mounted onto a susceptor in the growth chamber. Polycrystalline Ti with a purity of 99.995% was used as the source target material and was precleaned by repeated sublimation. After the chamber had been evacuated to 1×10^{-6} Torr, the deposition was carried out at substrate temperatures of 27, 150, 200, and 250 °C. The rapid thermal annealing process was performed in a nitrogen atmosphere with a tungsten-halogen lamp as the thermal source at temperatures ranging from 450 to 800 °C for various durations.

Fig. 1 shows the XRD curves for titanium-silicide thin films grown on p-Si substrates at 250 °C and subsequently annealed at (a) 450 °C, (b) 500 °C, (c) 550 °C, (d) 600 °C, (e) 650 °C, and (f) 700 °C. While the peak corresponding to the $TiSi_2$ (210) phase is dominant for the titanium-silicide thin films annealed at 450 °C, the peaks related to the $TiSi_2$ (210) and the C54 $TiSi_2$ (040) phase are comparable for the titanium silicide thin films annealed at 500 °C. For the titanium-silicide thin films annealed at 650 °C, the peaks corresponding to the C54 $TiSi_2$ phase are dominant. Fig. 1 shows that the intensities of the peaks corresponding to C54 $TiSi_2$ increased significantly with increasing substrate temperature. Therefore, the thickness and the quality of C54 $TiSi_2$ films are enhanced by increasing both the substrate and the annealing temperatures.

EDX measurements were performed to clarify the chemical components of the thin films after thermal treatment. Fig. 2 shows EDX fluorescence spectra of the $TiSi_2$ thin films grown on p-Si (100) substrates at (a) 27 and (b) 250 °C and subsequently annealed at 650 °C for 60 s. The results of the EDX measurements show that the grown $TiSi_2$ thin films consisted of Ti and Si, the stoichiometry of the annealed thin film grown at 27 °C was $TiSi_x$ ($x < 2$), and the ratio between the Ti and the Si compositions of the annealed thin film grown at 250 °C was approximately 1:2, which was consistent, within experimental errors, with stoichiometric $TiSi_2$. Therefore, EDX measurements revealed that the thin layer grown at 250 °C and annealed at 650 °C for 60 s was $TiSi_2$.

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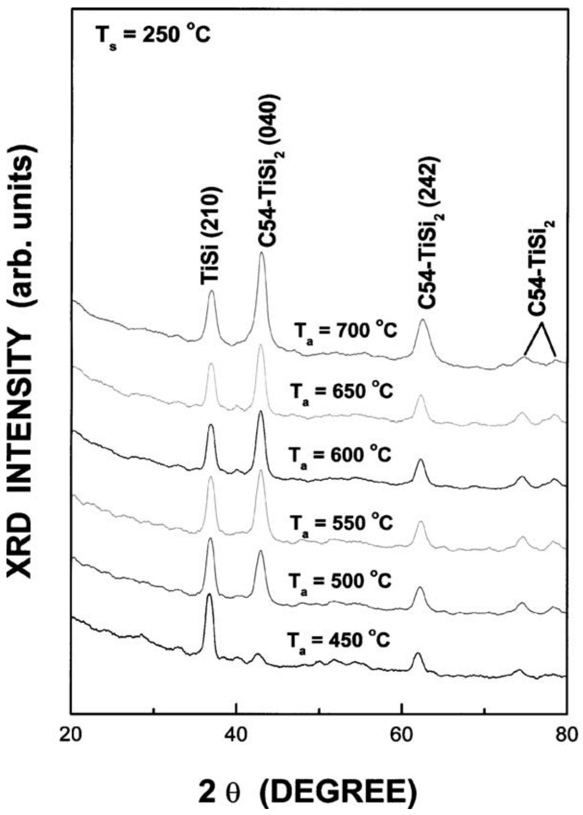

Figure 1 X-ray diffraction curves for titanium-silicide thin films grown on p-Si substrates at 250 °C and subsequently annealed at: (a) 450 °C, (b) 500 °C, (c) 550 °C, (d) 600 °C, (e) 650 °C and (f) 700 °C.

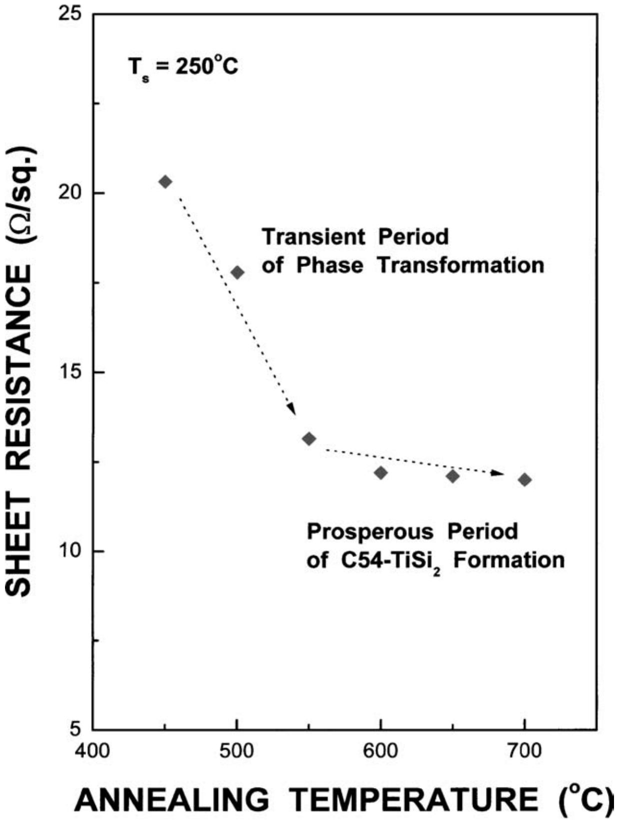

Figure 3 Sheet resistance of titanium silicide thin films grown on p-Si substrates at 250 °C as a function of the annealing temperature.

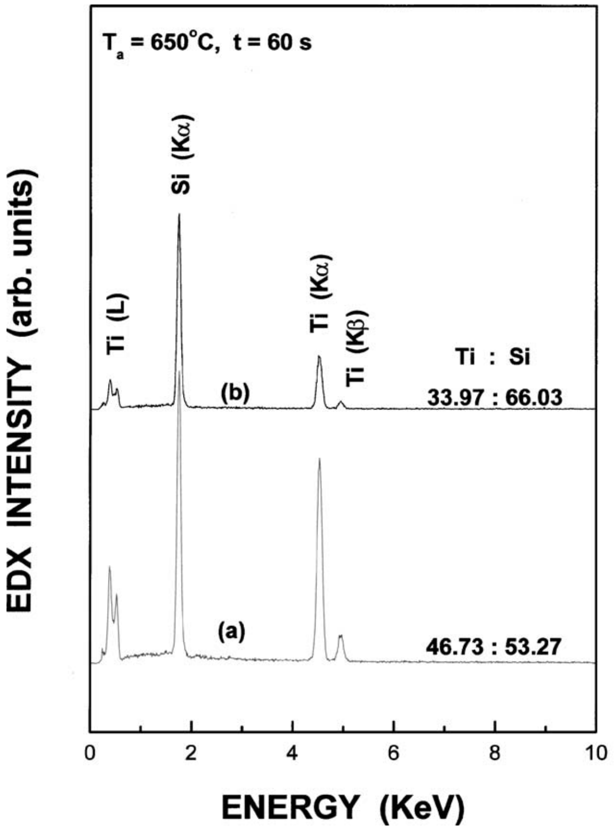

Figure 2 Energy dispersive X-ray fluorescence spectra of titanium-silicide thin films grown on p-Si (100) substrates at: (a) 27 °C and (b) 250 °C, and subsequently annealed at 650 °C for 60 s.

Fig. 3 shows that the sheet resistance of the C54 TiSi$_2$ thin films grown on p-Si (100) substrates at 250 °C as a function of the annealing temperature. The sheet resistance decreased with increasing annealing temperatures. The dramatic decrease in the sheet resistance at and above 550 °C originated from more C54 TiSi$_2$ being formed due to a phase transformation from TiSi$_2$ to C54 TiSi$_2$. Therefore, increasing of the annealing temperatures reduces the sheet resistance of TiSi$_2$ thin films.

A possible formation process for C54 TiSi$_2$ thin films deposited by using high temperature sputtering and rapid thermal annealing can be described on the basis of the XRD results. Even though C54 TiSi$_2$ thin films are generally formed from C49 TiSi$_2$ thin films through a two-step process [9, 10], when high-temperature sputtering and rapid thermal annealing is used, the C54 TiSi$_2$ thin films are formed directly from the TiSi$_2$ thin films in a one-step process, as shown in Fig. 4.

In summary, C54 TiSi$_2$ thin films were grown on p-Si (100) substrates by using a high-temperature sputtering method at 270 °C, followed by annealing, and the structural and the electrical properties of the TiSi$_2$/p-Si (100) heterostructures were investigated using XRD, the EDX, and sheet resistance measurements. The results of the XRD and the EDX measurements showed that the amount of the C54 TiSi$_2$ formed increased with increasing annealing temperature. The sheet resistance of the C54 TiSi$_2$ thin films decreased with increasing annealing temperature. A possible one-step formation

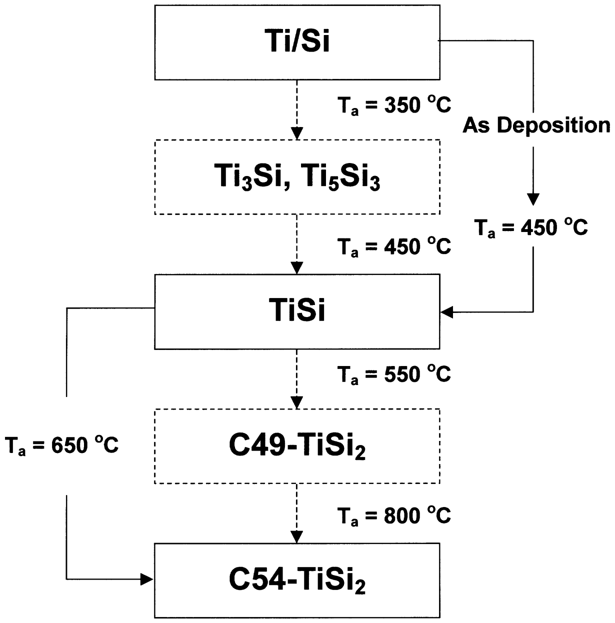

Figure 4 Formation process for C54 $TiSi_2$ thin films on p-Si substrates. The solid line represents the formation process used in this study for C54 $TiSi_2$ thin films, and the dashed line indicates the conventional formation process.

process was proposed for C54 $TiSi_2$ thin films deposited by using high temperature sputtering and rapid thermal annealing.

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