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Applied Surface Science 252 (2005) 1679–1684
applied surface science
www.elsevier.com/locate/apsusc

Effect of Ni interlayer on stress level of $CoSi_2$ films in Co/Ni/Si(1 0 0) bi-layered system

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Received 31 January 2005; received in revised form 3 March 2005; accepted 4 March 2005
Available online 11 April 2005

Abstract

The effect of Ni interlayer on stress level of cobalt silicides was investigated. The X-ray diffraction patterns (XRD) show that low temperature formation of $Co_{1-x}Ni_xSi_2$ solid solution was obtained while Ni interlayer was present in Co/Si system, which was confirmed by Auger electron spectrum (AES) and sheet resistance measurement. XRD was also used to measure the internal stress in $CoSi_2$ films by a $2\theta_\psi - \sin^2\psi$ method. The result shows that the tensile stress in $CoSi_2$ films evidently decreased in Co/Ni/Si(1 0 0) system. The reduction of lattice mismatch, due to the presence of Ni in $Co_xNi_{1-x}Si_2$ solid solution, is proposed to explain this phenomenon.

PACS: 68.35.−p; 68.60.−p

Keywords: $CoSi_2$; Stress; The solid solution; Lattice mismatch

1. Introduction

Cobalt disilicide has been an leading candidate material for future complementary metal-oxide semiconductor (CMOS) device generations due to its line-width independent low resistivity, low Schottky barrier, good thermal stability and small lattice mismatch with Si substrates (only 1.2%) [1–3]. Owing to the different thermal expansion coefficient and lattice mismatch between $CoSi_2$ films and Si substrates, the high value of tensile stress (approximately 1.3 GPa) [4,5] in $CoSi_2$ films may cause some defects such as pinholes in the $CoSi_2$ films, which can lead to large current leakage and subsequent device failure. On the other hand, the high value of stress also brings about a remarkable stress field in the active area of the devices and may cause degradation in their performance. So it is desirable and significant to find some methods to reduce the stress in $CoSi_2$ films [4,6–8].

In the previous studies, the introduction of C atoms in Co/Si system was found to be effective in reducing

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0169-4332/$ – see front matter
doi:10.1016/j.apsusc.2005.03.147

the internal stress in $CoSi_2$ films [9,10]. However, carbon may not be a most appropriate impurity element because its presence not only significantly retard the $CoSi_2$ nucleation but also obviously increase the resistivity of $CoSi_2$ films [11–13].

On the other hand, the effects of nickel in Co/Si system have been investigated by several groups [14–18]. But most of these studies focused on its influence on the phase formation in Co/Si system, few reports about the effect of nickel on the stress level of $CoSi_2$ films have been found.

In this paper, we introduce a Ni interlayer into Co/Si system for several reasons. Firstly, it was confirmed by previous studies [14–18] that the nickel impurity could decrease the nucleation temperature of $CoSi_2$ and consequently lead to better quality films and a lower thermal budget. Secondly, nickel silicides (such as NiSi and $NiSi_2$) also have many excellent electrical properties especially for low resistivity [19,20]. So the resistivity of $CoSi_2$ films will not significantly increase while nickel is present. Thirdly and most importantly, the nickel impurity in Co/Si system will form $Co_{1-x}Ni_xSi_2$ solid solution and increase the lattice constant of $CoSi_2$ [16–18], potentially leading to a better matched interface between the $CoSi_2$ films and Si substrate and possibly lower the stress level in $CoSi_2$ films should be obtained in the present system. In our very recent work [21], it has been found that the stress level of $CoSi_2$ could be effectively reduced by pre-Co-deposition Ni ions implantation. The decreased mismatch between $CoSi_2$ films and Si substrates was proposed to explain this result. If this mechanism is reliable, similar result should be obtained in present system.

For all the reasons above, in the present work, we introduce a Ni interlayer into Co/Si system, focusing its effects on the stress level of $CoSi_2$ films. Its influence and mechanism on the phase transformation of Co/Si system is also discussed.

2. Experimental details

Single-crystal Si(1 0 0) wafer with the resistivity of 2–4 Ω cm was used in our experiment. A 10-nm-thick layer of Ni and a 100-nm-thick layer of Co were sequentially e-gun evaporated on the Si(1 0 0) substrates at a rate of 0.2 nm/s with a constant substrate temperature of 150 °C, forming a Co/Ni/Si bi-layered film. The base pressure of the vacuum chamber was 1×10^{-8} Torr. During the process of deposition, the vacuum was better than 3×10^{-8} Torr. Before deposition, the wafers were ultrasonically cleaned in acetone, thoroughly rinses in de-ionized water, etched in $HF:H_2O_2$ (1:1), and rinsed in de-ionized water again. As soon as the chemical cleaning process was finished, the samples were then placed into the same vacuum chamber. For comparison, 100-nm-thick Co films without Ni interlayer were also deposited with the same experimental parameters. Rapid thermal annealing (RTA) apparatus were carried out in a high vacuum of 2.5×10^{-4} Pa at temperatures ranging from 400 to 820 °C for 3 min.

X-ray diffraction (XRD) was used to identify the phases and measure the internal stress in polycrystalline $CoSi_2$ films. The Auger electron spectroscopy (AES) was employed to investigate the depth profile of the elements in $CoSi_2$ films. The sheet resistance of the samples was measured by a D41-5/ZM type four-point probe to evaluate the electrical properties of the silicides films and sequentially used to judge the phase transformation due to large differences in resistivity between different cobalt silicides.

3. Results and discussion

Fig. 1 shows the XRD patterns of Co/Si samples annealed at 620, 670 °C and Co/Ni/Si sample annealed at 620 °C. As shown in Fig. 1(a) and (c), CoSi phase still exists in the sample of Co/Si system annealed at 620 °C while pure $CoSi_2$ films have been obtained under the same anneal process in the Co/Ni/Si system. The lowest formation temperature of $CoSi_2$ is 670 °C in the Co/Si system, as shown in Fig. 1(b). This result shows that low temperature formation of $CoSi_2$ films has been obtained while Ni interlayer is present, which is consistent with the previous studies [14–18]. The measurement of sheet resistance of the samples in both systems annealed at different temperatures confirms the results from the XRD patterns (as shown in Fig. 2). From this figure, we can also conclude that even at high temperature such as above 720 °C the resistance of Co/Ni/Si samples is still a little lower than that of Co/Si samples. Apparently, the slightly larger thickness and good