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Atomic diffusion and interface reaction of Cu/Si (111) films prepared by ionized cluster beam deposition

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Cu thin films were deposited on P type Si (111) substrates by ionized cluster beams at different acceleration voltage. The interface reaction and atomic diffusion of Cu/Si (111) system were studied at different annealing temperatures by X-ray diffraction (XRD) and Rutherford backscattering spectrometry (RBS). Some significant results were obtained. For the Cu/Si (111) samples prepared by ionized cluster beams at $V_a = 1$ and 3 kV, the interdiffusion of Cu and Si atoms occurs in the as deposited samples. For the Cu/Si (111) samples prepared by ionized cluster beams at $V_a = 5$ kV, the interdiffusion of Cu and Si atoms occurs when annealed at 450 °C. The formation of the copper silicides phase was observed by XRD in all the samples annealed at 450 °C and 600 °C.

1. Introduction

The interface reaction and diffusion characteristics of metal-on-semiconductor systems have been studied extensively, owing to the increasing application of functional coating and materials in microelectronics. The use of copper for metallic interconnects in ULSI technology has drastically revived the interest in an increased attention to the physics of copper in silicon and dielectrics in the last few years [1–3]. Consequently, understanding of the behavior of copper in silicon and evaluation and prediction of its potential effect on device performance has become an increasingly important problem of semiconductor materials science and device technology [4–9].

Ionized cluster beam (ICB) deposition is an ion-assisted film deposition technique by which high quality films of metals, dielectric and semiconductor can be formed at a low substrate temperature [10–15]. ICB technique can produce extremely low energy ion beams of the order of several eV to several hundreds eV with equivalently high intensity, and which is suitable for film deposition. The atomic diffusion in Cu/Si systems is of considerable interest in the electronics industry, so it has been extensively investigated, but these studies were almost carried out on the samples prepared by conventional sputtering and evaporation technique. There have been very few reports about the Cu/Si samples prepared by ICB technique. Compared to the conventional sputtering and evaporation technique [4,5], the ICB technique has some advantages, such as higher surface migration and diffusion in the depositing film.

In the experiment, the Cu films were deposited on P type Si (111) substrates by ionized cluster beams at $V_a = 1$, 3 and 5 kV. The behavior of Cu atoms and the formation of copper silicides in Cu/Si (111) system are studied before and after annealed at different temperatures, by Rutherford backscattering spectrometry (RBS) technique and X-ray diffraction (XRD) analysis respectively.

2. Experiment

In the experiment, we took P type Si (111) wafers with the resistivity of 8–13 $\Omega\cdot$cm as substrates for the deposition of Cu films. The deposition of Cu films is carried out by an ICB source in the Department of Physics, Kyungsung University, South Korea. The ICB system has been reported in these papers [10–15]. Before being loaded into the evaporator, the wafers were successively degreased in acetone, isopropyl alcohol, followed each time by distilled water rinsing, in an ultrasonic tank. Then the wafers were etched in 5% diluted hydrofluoric acid (HF) solution, immersed into distilled water and isopropyl alcohol. After blowing dry with N_2 gas, the wafers were mounted on the sample holder and immediately loaded into the vacuum chamber.

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The Cu films were deposited on P type Si (111) substrates by ionized cluster beams at $V_a = 1$, 3 and 5 kV. High pure Cu (99.999%) was used as source material, and it was heated at above 1800 °C. The base pressure of the ICB system was maintained in the low 2×10^{-6} Torr during the film deposition. The deposition rate was about 0.2 Å/s and the thickness of the resultant Cu films was controlled at about 100 nm by an in situ quartz crystal oscillator. The Cu/Si (111) samples were then annealed for 30 min under the atmosphere of high pure argon (99.999%) in the temperature range of 230–600 °C in a tubular annealing furnace.

The interdiffussion of Cu and Si was studied by RBS technique. The RBS measurement for the samples as-deposited and annealed was carried out by using the 2×1.7 MV serial static accelerator (The Opening Laboratory of Ministry of Education in the Institute of Heavy Ions, Peking University). A beam of 2.0 MeV $^4He^+$ ions was used in the present work. A Au–Si surface barrier detector with an energy resolution of 18 keV was placed at a scattering angle of 165° to detect the scattered particles. Moreover, Interface reaction was investigated by XRD analysis (Philips X'pert automated diffractometer) using monochromated Cu K-Alpha radiation of 1.5406 Å for phase identification. The x-ray tube was operated at a voltage of 40 kV and a current of 60 mA.

3. Results and discussion

Fig. 1(a) and (b) present the RBS spectra of Cu/Si (111) films using ionized cluster beam ($V_a = 1$, 3 and 5 kV) deposition in as-deposited samples and after annealed at 230 °C. In the RBS spectra, the mark of Si denotes the highest energy of backscattering $^4He^+$ obtained from the surface where the collision between $^4He^+$ and Si occurred, the marked channel of Si is about 266. It is found that the interdiffusion between Si and Cu atoms occurs in the as deposited samples at $V_a = 1$ and 3 kV. For the samples deposited at $V_a = 5$ kV, the backscattering yields in between Cu (above channel no.320) and Si (below channel no.266) signals is zero, which indicates that there is no interdiffusion between Si and Cu atoms in as-deposited samples and after annealed at 230 °C. From Fig. 1(a) and (b), it can be seen that the spectra features remain practically unchanged for the samples deposited at $V_a = 3$ and 5 kV annealed at 230 °C. For the sample deposited at $V_a = 1$ kV annealed at 230 °C, the spectra features have a very small step compared with as deposited samples in Fig. 1(a), it is because the formation of copper-silicides between Cu and Si atoms shown in Fig. 2(b). Fig. 1(c) shows that the RBS spectra of Cu/Si (111) films using ionized cluster beam ($V_a = 1$, 3 and 5 kV) deposition after annealed at 450 °C. It is found that the interdiffusion between Si and Cu atoms occurs in the samples deposited at $V_a = 1$, 3 and 5 kV. The diffusion cofficient (D) of the samples deposited at $V_a = 1$, 3 and 5 kV can be calculated by using the relation $L^2 = Dt$, where t is the annealing time and L the duffusion distance [15–18]. For the samples deposited at $V_a = 1$, 3 and 5 kV, the diffusion cofficient at an annealing temperature of 450 °C was 2.25×10^{-14} cm^2/s, 1.61×10^{-14} cm^2/s and 8.5×10^{-15} cm^2/s respectively. The relation of diffusion cofficient is $D_{1kV} > D_{3kV} > D_{5kV}$. It may be interpreted that the (111) preferential orientation of the film increased with increasing accerlation voltage. When the clusters bombard a depositing surface, adatom

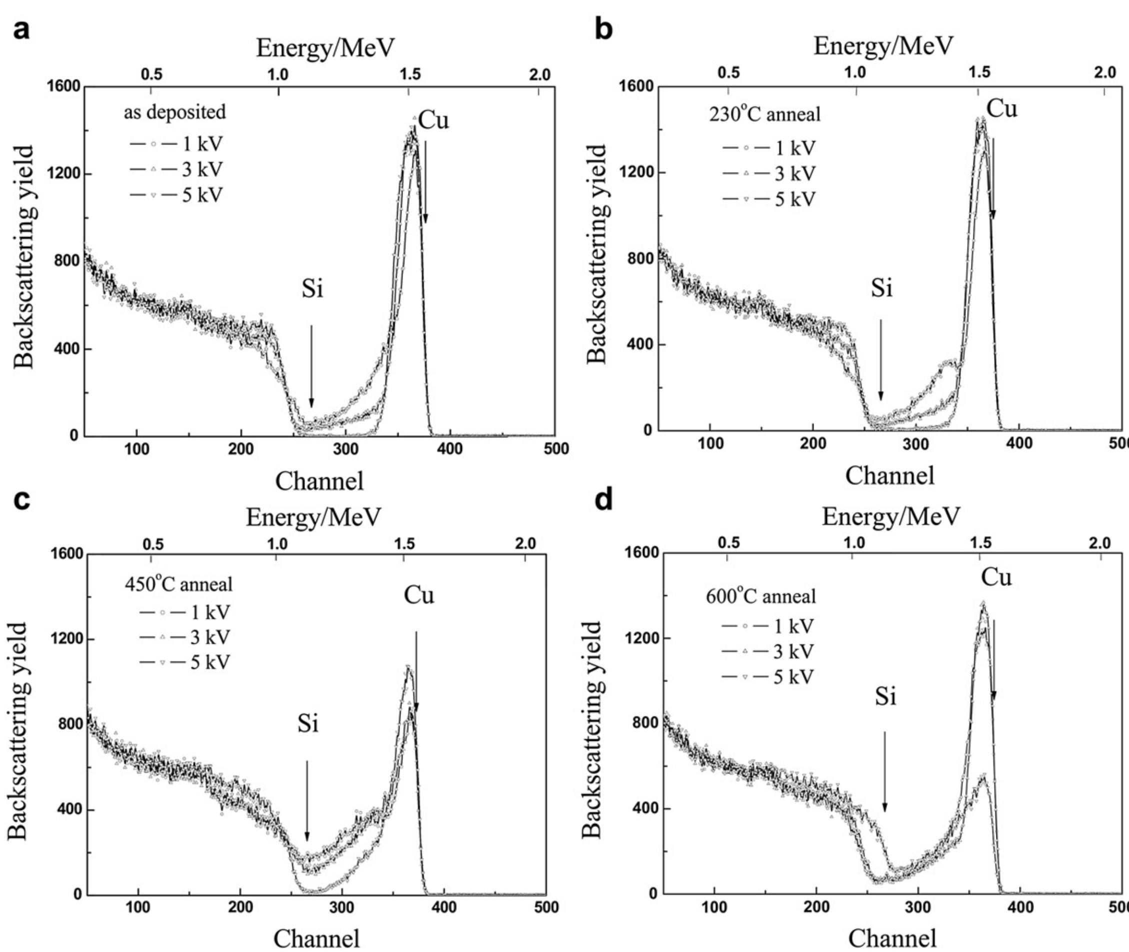

Fig. 1. The RBS spectra of Cu/Si (111) films using ionized cluster beam ($V_a = 1$, 3 and 5 kV) deposition in as-deposited (a) and after annealed at 230 °C (b), 450 °C (c) and 600 °C (d).