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Annealing Effects on the Structural Properties of Gold Films on Si by the RF Magnetron Sputtering

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Abstract. We have investigated the effect of annealing temperature on the structural property of Au thin films deposited on Si(100) substrate using the radio frequency (RF) magnetron sputtering technique. X-ray diffraction revealed that the relative intensities and FWHM of (111), (200), and (311) peaks increased and decreased, respectively, after thermal annealing at 600℃. Scanning electron microscopy indicated that after annealing at 600-700℃, Au structures agglomerated on Si(100) surfaces. Energy dispersive x-ray spectrometry (EDX) revealed that the agglomerated structure was composed of pure Au.

Introduction

Gold (Au) thin films, due to its inertness, can be used as reflective optics from infrared to x-ray region [1], substrates for scanning tunneling microscopy, and have potential applications in corrosion prevention, wear protection, and biosensing devices [2]. In addition, the Au films on silicon (Si) have been studied for interconnection in integrated circuit (IC) fabrication, because the Au has a high conductivity.

Although there are numerous papers describing the Au deposition [3-7], to our best knowledge, there is no report on the systematic investigation of the annealing effects on the structural properties of Au/Si structures. In this study, we deposited the Au thin film on Si(100) substrates using the radio frequency (RF) magnetron sputterer and investigated the effect of annealing temperature on the structural property of Au thin films.

Experiments

The p-type (100) Si substrate was cleaned in acetone for 10 minutes then rinsed by de-ionized water for one minute. Deposition was carried out in a 20 sccm of argon (Ar) (99.99% purity) gas atmosphere by supplying 300 W of RF power with a frequency of 13.56 MHz. The Au film was grown at temperature and pressure of 25℃ and 2.0 x 10^{-2} Torr, respectively, for one minute. After the RF magnetron sputtering, the samples were annealed in a furnace using quartz tube reactor at the temperature in the range of of 250- 700℃ in an Ar ambient. The structural characteristics of the films were analyzed by x-ray diffraction (XRD) using CuKα1 radiation (λ = 0.154056 nm) and by scanning electron microscopy (SEM) (Hitachi S-4200).

Results and discussion

Fig. 1a, b and c shows the cross-sectional SEM images, respectively, of as-deposited, 400℃-annealed and 700℃-annealed Au films. Cross-sectional SEM images indicate that the Au film with a thickness of about 150 nm has been deposited and the structural morphology does not change significantly after the annealing at 400℃. However, the sample annealed at 700℃ shows the cluster-like structure on the substrate. The energy dispersive x-ray spectrometry (EDX) reveals that the cluster-like structure (Fig.1d) and the substrate (Fig.1e), respectively, are pure Au and Si.

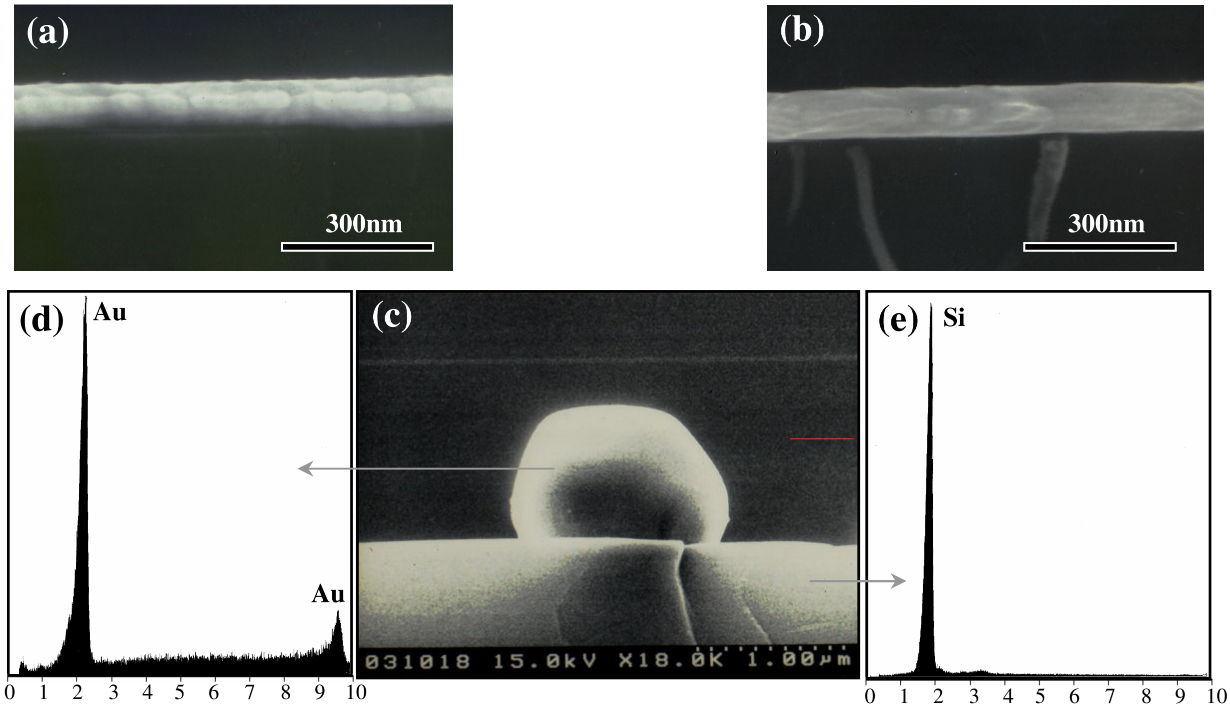
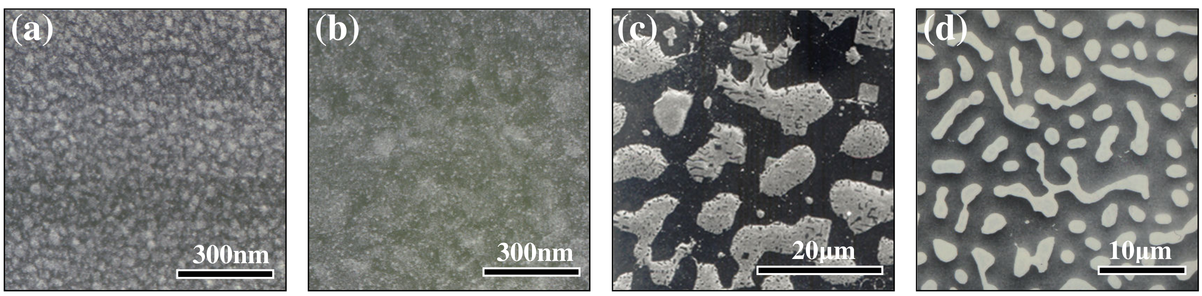


Fig. 1. Cross-sectional SEM images of Au thin films on Si substrate (a) without annealing, (b) with annealing at 400℃ and (c) with annealing at 700℃. (d,e) EDX spectra of Au structure on Si



substrate with annealing at 700℃.

Fig. 2. Plan-view SEM images of Au thin films on Si substrate (a) without annealing, (b) with annealing at (b) 400℃, (c) 600℃, and (d) 700℃.

Fig. 2a, 2b, 2c, and 2d shows the plan-view SEM images, respectively, of as-deposited, 400℃ -annealed, 600℃-annealed and 700℃-annealed Au films. Close examination of Fig. 2a and 2b indicates the slight increase of grain size on the top of the film after the thermal annealing at 400℃. Fig. 2c and 2d reveal that severe islanding has occurred and the size and nember of the Au islands (which was also confirmed by EDX), respectively, decrease and increase with increasing the annealing temperature from 600℃ to 700℃. We surmise that the Au is pulled together from the nearest surface to form the cluster or island after the thermal annealing at 600-700℃, because Au has a rather high surface tension [8].

Fig. 3 shows the θ-2θ XRD patterns of the Au thin film on Si substrate annealed at different temperatures, indicating that the Au films is in face-centered cubic phase with (111), (200), (220), and (311) diffraction peaks. The relative intensities of (111), (200), and (311) diffraction peaks become prominent after thermal annealing at 600℃.

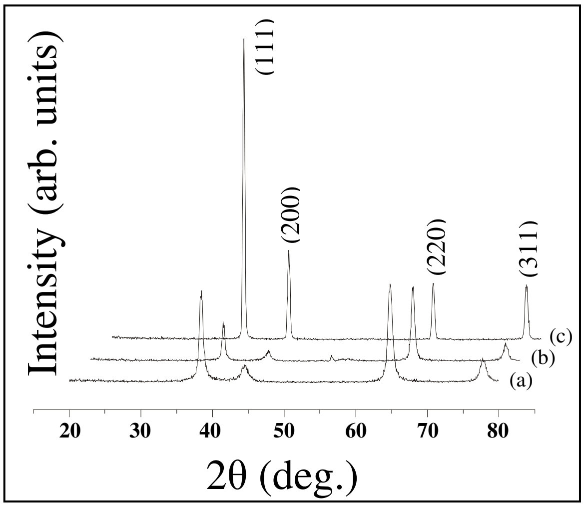


Fig. 3. X-ray diffraction patterns of Au thin films on Si substrate (a) without annealing and with annealing (b) at 250℃ and (c) at 600℃.

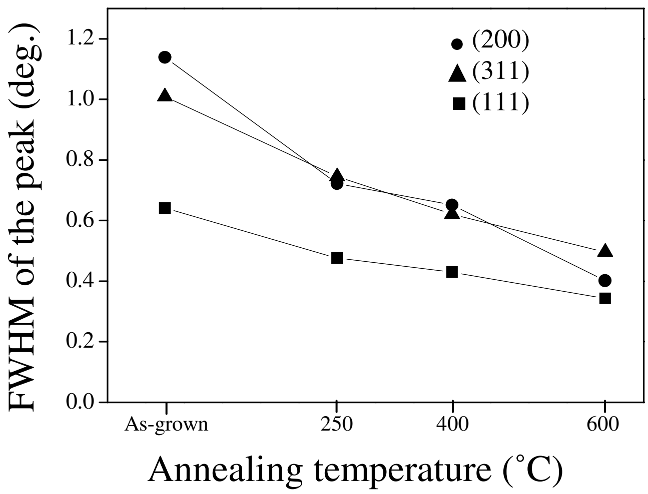


Fig. 4. Variation of the full width at half-maximum (FWHM) of the Au diffraction peaks by varying the annealing temperature.

Fig. 4 shows the full width at half-maximum (FWHM) of the diffraction peaks according to the annealing temperature. The FWHMs of (111), (200), and (311) peaks decrease by increasing the annealing temperature. The FWHM of the (111) diffraction peak becomes less than 0.4° by annealing at a temperature of 600℃. Since the FWHM of the diffraction peak is inversely proportional to the grain size of the film, we reveal that the grain sizes of the (111), (200), and (311) grains increase by increasing the annealing temperature. (We define (hkl) grains as grains with a (hkl) plane parallel to the film surface.) Based on the above XRD analysis (Figs. 3 and 4), we surmise that at least (111), (200), and (311) grains are much more developed in the Au cluster generated by the thermal annealing at 600℃. Further systematic study is needed to investigate the mechanisms regarding the grain orientation of Au on Si(100) substrate.

Summary

We have deposited the Au thin film on the Si(100) substrate using the RF magnetron sputtering technique and have investigated annealing effects in the range of 250-700℃. The relative intensities and FWHMs of (111), (200), and (311) XRD peaks increase and decrease, respectively, after thermal annealing at 600℃. The cluster-like Au structures agglomerate on Si(100) surfaces and the size of the Au structures decreases with increasing the annealing temperature from 600℃ to 700℃. This study will contribute to the potential applications of Au/Si to the interconnection in IC fabrication.

Acknowledgements

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