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Thermal effects on LPCVD amorphous silicon

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Abstract

The effects of thermal annealing on amorphous silicon deposited using low-pressure chemical vapour deposition (LPCVD) are presented in this paper. The amorphous silicon film is being subjected to different annealing conditions ranging from 600 to 900 °C for a varying period of 30 to 90 min holding time in nitrogen ambient. X-Ray diffraction (XRD) shows that crystallization of amorphous silicon to poly-silicon starts to occur after 30 min of thermal cycle at 600 °C. Atomic force microscope (AFM) has been used to study the surface roughness and grain size of the films after different annealing times and temperatures. The nanocrystalline grains result in photoluminescence behavior. Stress measurement, using curvature analysis, shows that the stress magnitude reduces with decreasing annealing temperature and time. This is likely due to stress relief during grain growth and crystallization at higher temperatures. The detailed study of the structural, morphology and property changes in amorphous silicon upon annealing will be presented.

Keywords: Amorphous Si; Crystallization; LPCVD

1. Introduction

Low pressure chemical vapor deposition (LPCVD) poly-crystalline silicon (poly-Si) has been intensively studied because of its important applications in the ultra-large scale integrated (ULSI) technology as gate materials for field effect transistors, as emitters in bipolar transistors and as part of interconnects. Surface roughness, grain size and trap density of active poly-Si layers are very important variables which affect the properties and functionalities of the films [1–3].

Amorphous silicon (α-Si) continuously gains interest in nanoelectronics mainly because of its small homogeneous grains and photoluminous properties. α-Si can potentially replace poly-Si as gate electrode in sub 50 nm transistors mainly because of its smaller grains and lower temperature of deposition. Besides the use as control gates and floating gates, α-Si is also investigated as an important material for its application in nano-structures and for thin film transistors (TFTs). Re-crystallized α-Si TFTs are used to form simple integrated circuits, such as static shift registers, that have enormous potential for other applications.

>Deposition studies of silicon films conducted at 500 °C$<T<$600 °C revealed that α-Si was in a metastable state with respect to its crystalline allotrope. The deposition temperature strongly influenced the crystallization rate [3]. From previous studies, LPCVD α-Si was not uniformly flat but had its own structure consisting of many amorphous grains [4,5]. The sizes of these amorphous grains changed in accordance to the deposition conditions because of the change in nucleation and growth rates. If the film nucleation rate was relatively fast compared to the film growth, the silicon film was composed of many small amorphous grains. Conversely, if the film growth rate was relatively fast compared to the film nucleation rate, the silicon film was composed of a few large amorphous grains.

It was also found that an LPCVD amorphous film has two different phases, amorphous-I and amorphous-II. The amorphous-I was a well-known phase in which the amorphous grains grow in size as the deposition temperature reduces. The amorphous-II was a phase in which the amorphous grains decrease in size as the deposition temperature falls. The kinetics of LPCVD film growth was governed by the relative magnitude of the surface reaction to the gas-phase mass transfer.

This paper reports the effects of thermal cycles on LPCVD deposited α-Si with assessment made on the grain orientation,

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grain size, grain growth, surface roughness, morphology and stress measurement. Optical properties such as photoluminescence are also reported with the recrystallization into nanocrystalline Si.

2. Experimental

A 1000 Å SiO_2 was thermally grown on p type (100) Si substrates. Si thin films were deposited by LPCVD at 550 °C, 475 mTorr on these oxidized Si substrates. The as-deposited Si films were of 1000 Å thick as measured using an ellipsometer. The samples were subjected to various annealing temperatures of 600, 700, 800 and 900 °C for holding time of 30 min, 60 min, 90 min and 4 h. Samples were placed into a horizontal tube furnace for annealing with a constant injection of 10,000 sccm N_2 gas into the tube. Ramping time was set at 4 °C/min. After the annealing temperature was reached, a stabilization time of 5 min was used for each annealing process. The annealed silicon films were characterized using AFM, XRD, film stress measurement (FSM) and photoluminescence (PL). The PL measurements were performed at room temperature using the 488 nm line of an argon laser as the excitation source. Stress measurement was done using wafer curvature analysis with the reference film at the oxidized silicon substrate.

3. Results and discussion

Fig. 1 shows the XRD spectra of the α-Si films after various annealing times. After annealing at 600 °C for 30 min, the presence of XRD peaks at 28.55°, 47.5° and 56.3° correspond to Si (111), (220) and (311), respectively. All the annealed samples show a strong preferential orientation of (111) plane. Similar results are obtained for samples annealed at 700, 800 and 900 °C. Crystallization of α-Si is shown to have started to occur after annealing at 600 °C for 30 min. As the annealing temperature increases, the intensity of the XRD peaks increases which shows the increment in the degree of crystallization in the silicon film. Detailed analysis shows that the peak width of the XRD peaks reduces and indicates a growth in the crystallites diameter as a function of temperature and time. This will be further studied in detail using AFM analysis.

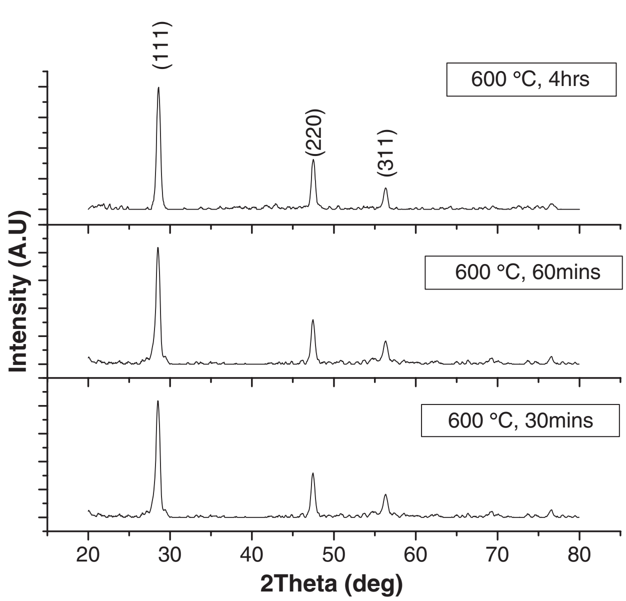

Fig. 1. XRD spectra of α-Si after annealing at 600 °C for 30 min, 60 min and 4 h.

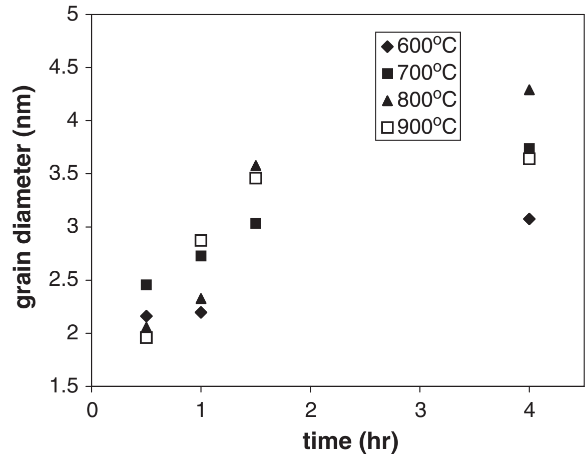

Fig. 2. Comparison of grain size of the α-Si annealed at different conditions.

Fig. 2 shows the comparison of average grain sizes of α-Si estimated from AFM analysis after annealing at different conditions. The grain size of α-Si increases as the annealing time increases for each temperature. The percentage increment in grain size is greater as a function of temperature compared to annealing time. It is observed that at 900 °C, the grain size seems to reach a saturation grain size quickly when subjected to annealing time for more than 1.5 h. It is clearly seen that all the annealed films possess nanocrystalline grains.

Fig. 3 shows the comparison of the roughness value obtained from AFM analysis of α-Si after annealing at different conditions. It is observed that as annealing time increases, the surface roughness reduces. For a lower annealing temperature, the surface roughness of the recrystallized α-Si is reduced to a larger extent as compared to higher thermal annealing temperature of 800 and 900 °C. At 900 °C, the surface

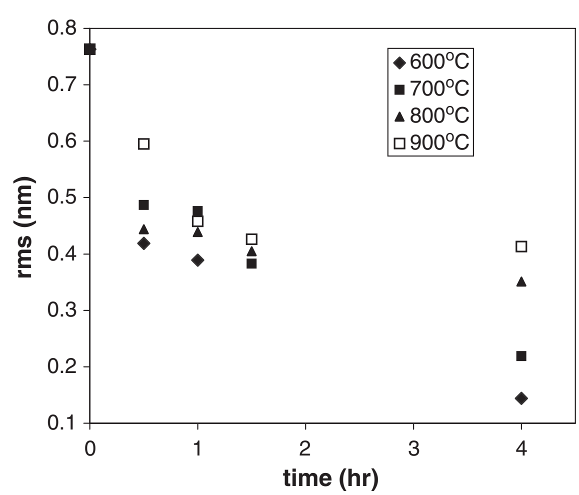

Fig. 3. Comparison of roughness of α-Si annealed at different conditions.