

Local Characterization of Electronic Transport in Microcrystalline Germanium Thin Films by Atomic Force Microscopy Using a Conducting Probe

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1. Introduction

The formation of crystallized films of group IV element(s) at temperatures as low as 200 °C has become a subject of great interest because of its potential importance for developing thin-film devices applications to overcome limits of amorphous silicon-based devices such as thin film transistors and solar cells. Intense efforts have so far focussed on the improvement of the crystallinity at a higher growth rate in plasma-enhanced chemical vapor deposition (PECVD). In the growth of microcrystalline films on amorphous substrates, the formation of amorphous incubation layer with a thickness of typically a few tens nanometer is always observed in the early stages prior to microcrystalline nucleation and deteriorates the device performance. In that regard, the reduction of such an incubation layer is one of major concerns on the microcrystalline film growth. Thus, the monitoring of the nucleation and growth of microcrystallites with progressive films growth becomes increasingly of great importance. As for in-situ monitoring of the growing film surfaces of hydrogenated silicon and its germanium alloys, several optical techniques such as infrared attenuated-total-reflection (IR-ATR) [1, 2] and spectroscopic ellipsometry (SE) [3, 4] have been so far applied and characteristic changes in hydrogen-bonding features and average optical constants being attributed to the evolution of microcrystallites have been reported. We have also demonstrated that, by applying a surface sensitive Raman scattering technique, the crystallinity of the films is examined non-destructively with nanometer depth resolution [5]. Recently, for $\mu\text{c-Si:H}$ films grown on evaporated metals and indium tin oxide (ITO), a relation between the surface microstructure of the film and the local conductivity through the film has been demonstrated by an atomic force microscopy (AFM) with a conductive cantilever [6, 7]. However, the very early stages of microcrystallization have not been well characterized yet.

In this work, we focused on the growth of $\mu\text{c-Ge:H}$

from a highly H_2 -diluted GeH_4 plasma and applied AFM measurements, in which topographic and current images were simultaneously taken, to characterize the nucleation and growth of Ge microcrystallites.

2. Experimental

Hydrogenated germanium (Ge:H) films in the thickness range of 16-98nm were prepared at 150 °C on HF-last $\text{n}^+\text{Si}(100)$ and quartz in a capacitively-coupled plasma CVD reactor connected with a 13.56MHz generator through a matching box. To promote the microcrystallization, 0.2% GeH_4 diluted with H_2 was used, the gas pressure and rf power density were maintained at 0.2Torr and 88mW/cm², respectively. The average crystallinity of films so prepared was evaluated by Raman scattering measurements. Raman scattering measurements were carried out under a right-angle scattering geometry in which a p-polarized 441.6nm line from a He-Cd laser was incident to the sample surface in ambient Ar at a glancing angle of 10°.

Using a Rh-coated Si_3N_4 cantilever with a tips apex of ~100nm, surface morphologies and local electric transport properties were measured simultaneously with a contact AFM mode in an ambience of clean room at room temperature. A dc voltage was applied between the cantilever and the Al-evaporated back side of the Si(100) substrate and the current flowing through the sample to the cantilever was registered to render the current images.

3. Results and Discussion

Raman scattering spectra for the films on quartz show that the incubation layer thickness is ~16nm and the evolution of the microcrystalline phase with progressive film growth tends to be saturated for films thicker than 65nm as shown in Fig. 1. In contrast, in the film growth on $\text{n}^+\text{Si}(100)$, the signals peaked at 300cm⁻¹ due to the Ge-Ge TO phonon mode are clearly observed even for a 16nm-thick film. And we found that there is no significant difference in the average crystallinity between the saturated states on quartz and Si(100). The formation of nanometer grain is confirmed from topographic

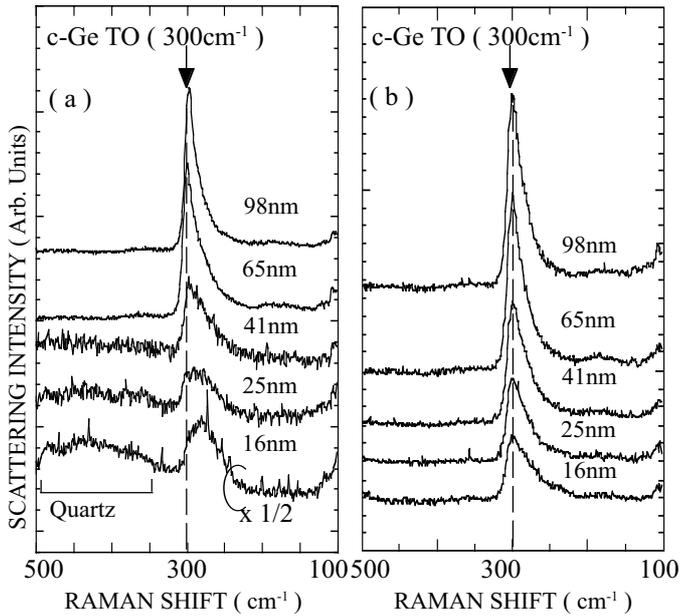


Fig. 1 Raman scattering spectra for Ge:H films with different thicknesses grown on quartz (a) and n⁺Si(100) (b).

images and corresponding current images for the films grown on n⁺Si(100) as indicated in Fig. 2. The fairly large protrusion compared with the film thickness indicates that the evolution of the crystalline phase after nucleation is faster than the growth of the disordered phase. From the correlation between the protrusion and local current seen in the case of the 16 nm-thick film (Fig. 2 (a) and (b)), the transport in the periphery of protrusions is markedly poor but the center of each protrusion shows better conduction. With progressive film growth, the conduction in the grains is significantly improved, which results in clear current images with a high contrast among grains and their boundaries. Such a significant increase in current level with the grain growth indicates a reduction of the contact potential between the tip and the grains and can be interpreted in terms of the shrinkage of the energy bandgap due to the structural change from highly-disordered to well-ordered network (crystalline phase). The conductivity of grains for the 41 nm-thick film was estimated in the range of 5.1~7.4 S/cm by assuming a contact area of AFM probe to be 100 nm², being about one order of magnitude larger than the average in-plane conductivity.

4. Conclusions

Topographic and current images taken with AFM measurements with a conductive probe are quite useful for non-destructive diagnostics of the formation of grain

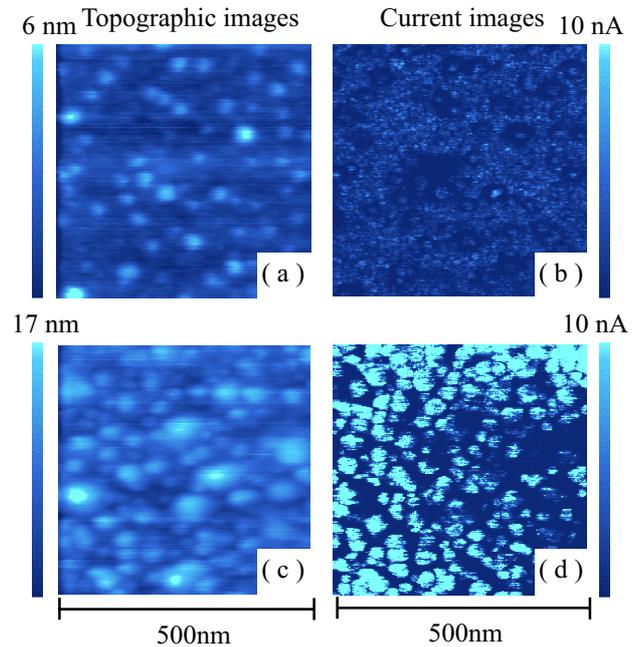


Fig. 2 AFM topographic images ((a) and (c)) and corresponding current images ((b), (d)) for μc-Ge:H films on n⁺Si(100). The film thickness for (a) and (b) is 16 nm and for (c) and (d) 41 nm, respectively. Current images were taken by biasing the tip at 1.5 V (b) and 1.0 V (d), respectively.

boundaries as well as the microcrystalline grain growth. Also, local transport properties through the grains will lead us to a better understanding of inhomogeneities in microcrystalline films and to their improvement.

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