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RAMAN ANALYSIS ON NANOCRYSTALLINE SILICON FILM

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Abstract: A compact dot marker using a cw laser on a microcrystalline silicon (μc-Si:H) thin film is demonstrated. Annealing process using a laser leads to a continuous crystallization from nano to sub-micron domain (>50 nm) of Si nanocrystals within the thin film. This patterning is quite useful because we can manipulate 2-D process of silicon structural forms for an efficient thin-film transistor (TFT) devices with respect to uniform electron mobility. A Raman microscope is quite useful to reveal a crystal volume fraction with a calculation from the population ratio between crystalline and amorphous phase.

Keywords: Laser, Fluence, Silicon Film, Raman Crystallinity.

1. INTRODUCTION

Low temperature polycrystalline silicon (LTPS) thin-film transistors (TFTs) made with poly-Si on glass substrates have been developed for the applications of liquid crystal-display panels and organic-electroluminescence panels [1]. Excimer-laser annealing (ELA) has been used to crystallize poly-Si films. In general, those grain sizes are several hundred nanometers. Although the enlargement of grain size improves TFT performance residual grain boundaries randomly lay across TFT channels resulting in inhomogeneous characteristic of integrated circuits [2].

Recently, continuous wave laser lateral crystallization (CLC) technique was developed, which allows the growth of crystals so large as $3 \times 20\ \mu m^2$ extending along the channel direction. It becomes more important to control the electrical properties in miniatured scale as poly-Si devices become smaller for a high integration. In addition, fabrication of uniform poly-Si resistance is also required with designed patterning. In the case of ELA, seeds of growth are nuclei randomly generated at the Si/substrate interface. The solidification proceeds radial from nuclei. For a single-shot laser with a narrow range of energy density, nearly complete melting of films leaves small density of nuclei leading to the super-lateral growth (SLG). The solidification proceeds only to the scanning direction of a continuous-wave laser leading to a growth of long shaped grains apparently larger than the size of ELA poly-Si [3].

In this research, a poly-Si with high conductivity is produced using a cw laser annealing process on LTPS thin film. The crystallite size and the distribution of poly-Si are investigated with Raman microscopy and transmission electron microscopy (TEM).

2. EXPERIMENT DETAILS

The LTPS thin film was used in the laser marking experiment. By using the plasma-enhanced chemical vapor deposition (PECVD), the SiO_2 film with a thickness of 230 nm is deposited onto the glass substrate. Above that layer, by using SiH_4, the amorphous Si is deposited using PECVD method and the annealing is executed under N_2 atmosphere, creating a poly-Si film with a thickness of 50 nm. (Fig. 1)

For the laser annealing of poly-Si, the Si thin films were irradiated with a cw diode laser (532 nm) beam from 8 mW to 34 mW power for 2 min. The laser beam profile is Gaussian with a spot size of 1 μm. The crystallization is monitored with a Raman microscope at a backscattering geometry. No polarization analyzer was put in the optical path of the scattering light. Briefly, a diode laser (λ_{ex} = 532 nm, 8 mW), a 50× objective lens and a TE-cooled CCD detector are used to collect the Raman scattered light from the Si after removal of Rayleigh scattering. Raman spectra are obtained at multiple locations for each sample with an integration time of 4 s for all measurements. The intensity and FWHM are estimated by fitting the Pearson function to spectra.

The poly-Si film crystal structure has been confirmed with TEM of accelerating voltage at 300 kV and multiple images are taken at multiple locations. Electric conductivity is measured with micro I-V instrument.

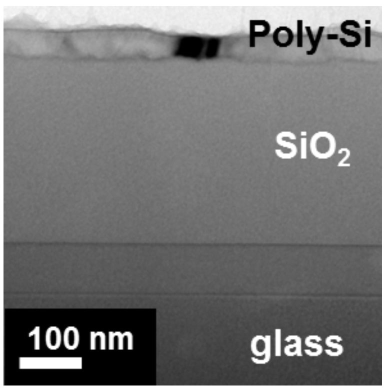

Fig. 1. Representative cross-sectional TEM image showing multilayers of poly-Si, SiO_2 buffer and glass substrate.

3. RESULTS AND DISCUSSION

Cross-sectional TEM image in Fig. 1 clearly presents a poly-Si layer deposited on SiO_2 structure. From the glass substrate, the initial growth region (SiN bottom layer) is followed by a SiO_2 phase. Many lattice points are observed in μc-poly Si domain, while slight fractions are monitored in a-Si layer, indicating nanocrystals are still mixed in amorphous region. The film thickness of a poly-Si film is estimated to be 50 nm, in which a-Si:H/μc-Si:H transition occurs by a silane concentration change during deposition process.

Figure 2 illustrate the Raman spectra from 470 to 540 cm^{-1} of LTPS film obtained with the Raman microscope using a 50× objective. Apparently, the intensity, FWHM and Δω of the optical-phonon mode were estimated by fitting the data (Pearson function) to spectra. Obtained values of for c-Si (520 cm^{-1}) versus poly- Si (516 cm^{-1}) were 4.0–4.3 cm^{-1}. The sharp phonon peak near 520 cm^{-1} indicates that the silicon material is c-Si structure. The line width and shift of the poly-Si band in silicon films indicates the size of the nanocrystals [4-6]. The Raman microscope characterizes the structural properties of the crystal size and the degree of crystalline silicon films. Raman transverse optical (TO) mode contains an intermediate component in addition to a-Si and c-Si species. In the case of poly-Si, composed of various nanocrystalline Si (often denoted as μc-Si), the Raman peak gets slightly broader than that of c-Si and shifted to 514 cm^{-1} (~7 nm crystallite) and 504 cm^{-1} (<3 nm crystallite) depending on the nature of crystal size and strength. The bandwidth and shift of the μc-Si peak indicates the size of the nanocrystals (as the crystallite size increases the bandwidth becomes broader or shifts to lower energy). Fig. 2 shows a gradual Raman spectrum shift of poly-Si thin film on LPTS sample with increasing laser power. As the annealing power increase, Raman shift converges towards c-Si with a maximum peak at 520 cm^{-1} by crystallization.

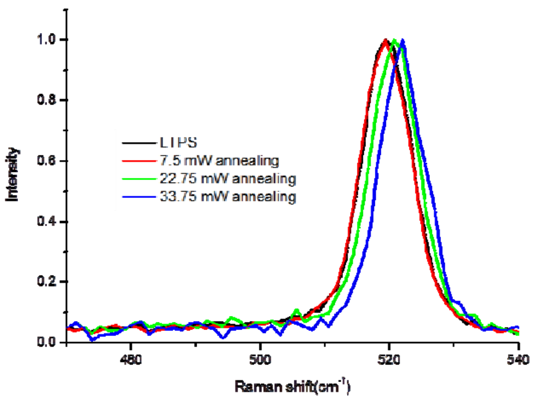

Fig. 2. Normalized Raman spectra of LTPS sample with various laser powers. Influence of the annealing process is reflected with Raman shift.

HR-TEM image (here not shown) reveals that these nanoparticles are grown as μc-poly Si with faceted morphology presenting compressive spherical shape. The d-spacing of 0.313 nm, which corresponds to the (111), planes of the cubic Si phase view along to (111) direction according to JCPDS card number 27-1402. We observe smaller lattice distances from 0.29 nm to 0.30 nm than d-spacing of 0.313 nm, because the small crystallite has the compressive stress in its 2-dimensional projection. In the case of the samples with (111) surfaces only Si atoms cluster are revealed in the HR-TEM images.

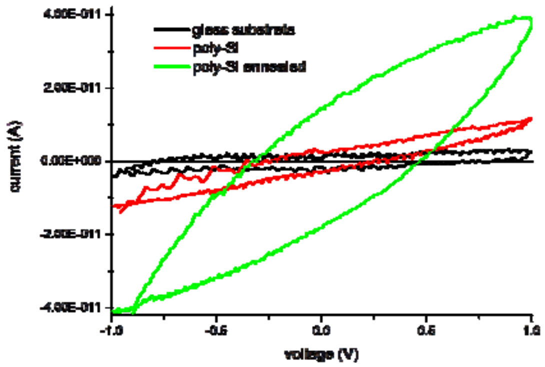

Fig. 3. Electric conductivity measured with micro I-V instrument.

Fig. 3 shows electric conductivity measured with micro I-V instrument. From the I-V curve, the slope is regarded as conductivity. The resistivity of bare LTPS is measured at $\rho = 1.4 \times 10^6$ Ω·cm and for annealed poly-Si at $\rho = 4.0 \times 10^5$ Ω·cm. Combined with TEM results, the poly-Si sheet resistance is much related with the poly grain size. The larger the grain size, the lower the resistivity in poly-Si. Consequently, cw laser irradiation induces the transformation from a few nanometers to large crystallites via solid phase crystallization to improve conductivity.

4. CONCLUSION

We have investigated the annealing effect of LTPS on glass using Raman and TEM measurement. Using diode laser (532 nm with beam spot size <1 μm), micropatterning on the poly-Si film has been achieved with high integrated efficiency. The reliable structure analysis of poly-Si was also confirmed by combining the Raman Spectra and I-V curve. Distribution and structural characterization via a Raman microscope can be achieved as a bulk probe at a few micron scales. The observed crystal-size distribution in HR-TEM images is strongly correlated with the intensity variations for Raman signal.

5. REFERENCES

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