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STRUCTURE AND CHARACTERISTICS OF LASER CRYSTALLIZED THIN AMORPHOUS SI FILMS

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Abstract

Pure amorphous Si thin films deposited on oxidized crystalline Si surface (111) were crystallized by picosecond UV laser pulses. The Raman scattering spectra show that pulse energy of 330 mJ/cm2 is enough to fully crystallize Si film and further increase of the energy does not improve crystallinity. A large grained polycrystalline Si was obtained as revealed by surface analysis. A significant increase in carrier mobility was observed after laser crystallization.

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KEYWORDS: Laser crystallization; a-Si; p-Si; Raman scattering spectra; AFM

1. Introduction

For the last decade polycrystalline silicon (p-Si) has been studied intensively. It is viewed as an attractive material for thin film electronic devices, such as field effect transistors (FET) and high-efficiency low-cost thin film solar cells [1; 2; 3]. Also there are potential applications for integral circuits due to its resemblance to crystalline silicon (c-Si) electronic properties. A way to obtain p-Si is by first sputtering amorphous silicon (a-Si) on the desired substrate and then applying some sort of crystallization method. Common approaches to crystallize a-Si are solid phase crystallization (SPC) [4] and metal induced crystallization (MIC) [4]. SPC is based on isothermal annealing of a-Si at temperatures of about 600°C, but in many cases such high temperature is not permitted due to substrate material or underlying structures. MIC is based on the effect that certain metals in contact with amorphous silicon induce the transformation from the amorphous to the crystalline phase at temperatures well below the eutectic temperature of the metal-silicon system, however an unintentional doping takes place in this case. Therefore attractive method to obtain p-Si is to use of laser crystallization (LC) process. It is relatively fast and flexible method to obtain large-grained poly-silicon [6; 7], and it allows to crystallize selected parts of the sample. LC process is based on local melting of amorphous Si film for a very short time, and then letting it cool down rapidly. In order to achieve that, pulse UV laser is desired. UV light has high absorption coefficient in silicon, so all of the laser energy is adsorbed in thin a-Si film. Pico- or nanosecond pulses reduce the amount of energy that is lost due to heat conduction thus it is possible to melt the a-Si film without damaging the underlying substrate. Also it is possible to influence optical and electrical properties of the p-Si film by changing LC parameters such as pulse energy and

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number of impulses. In this report we discuss our findings on p-Si properties after LC process was performed with different energies and number of UV laser pulses.

2. Experimental

In our experiments we used a-Si samples that were deposited from high purity Si target using electron beam evaporation. This method allows producing high purity a-Si film [8]. The samples were deposited on oxidized Si wafer (111) surface (SiO_2). The layer thickness of SiO_2 and a-Si were 400 nm and 270 nm respectively.

For laser treatment of the samples we used unfocused third harmonic (355 nm) Nd:YAG laser system "Ekspla SL-312", with pulse duration 135 ps and 10 Hz repetition rate. The LC process was performed in vacuum at pressure $<1x10^{-5}$ torr.

Surface topography was measured by "VECCO CP-II AFM" using silicon tips (HA_NC, Etalon). Raman scattering spectra were measured using "DeltaNu Inc. Advantage NIR". The wavelength was 785 nm and resolution 5 cm^{-1}.

Electrical properties of the samples were determined by Hall measurements using van der Pauw technique. The aluminium contacts were deposited by thermal evaporation in vacuum. The magnetic field was 0.6 T, the current was measured by "KEITHLEY Picoammeter 6485" and the voltage was measured by "KEITHLEY Multimeter 2000".

For better surface topography some of the samples were etched for 5 seconds in SECCO etch diluted by water four times ($SECCO/H_2O$ = ¼).

3. Results

In order to study influence of laser crystallization on a-Si electrical properties, 1x1 cm^2 a-Si square was crystallized. Typical pulse energy to perform LC is from 200 to 450 mJ/cm^2 [7], so we chose 265 mJ/cm^2 to crystallize sample. The laser beam was approximately 4 mm in diameter, therefore to crystallize large enough area beam was moved over the surface, and nine overlapping pulses were applied. Afterwards aluminium contacts were deposited on treated and as-deposited samples to get ohmic contact and Hall measurements were performed. The results show that as-deposited sample has carrier density $6x10^{13}$ cm^{-3} whereas after LC it increases to $2x10^{15}$ cm^{-3}. Typically LC process is followed by significant increase in carrier density (more than three orders of magnitude) which is a result of dopant activation [9], but in this case carrier density does not change much as a result of high purity of the initial material. Another parameter that can be obtained from Hall measurements is carrier mobility. Here we see an increase from 4.3 $cm^2/(ms)$ to 1008 $cm^2/(ms)$ for as deposited and crystallized samples respectively. For comparison typical mobility for crystalline silicon at room temperature is ~1400 $cm^2/(ms)$, thus we can conclude that the obtained p-Si film consists of highly ordered structures with small amount of defects on which the carriers would scatter.

A convenient method to determine crystallinity of silicon materials is to analyze Raman scattering spectra. Crystalline silicon has one sharp peak at ~520 cm^{-1}, but amorphous silicon has broad Raman band centred at 480 cm^{-1}. In the case of polycrystalline silicon the Raman peak gets broader than that of c-Si and is shifted to 517 cm^{-1} [7].

In our case the laser used for exiting Raman scattering (785 nm) has relatively low absorption coefficient in a-Si therefore strong background signal from underlying c-Si was present in all measurements, but after some processing of the data we managed to remove it. In Fig. 1 and 2 the resulting spectra are shown.

For the as-deposited sample a single broad band is observed in Raman spectra and the maximum is located at approximately 480 cm^{-1} (Fig. 1), but for the sample that has been laser treated with pulse energy 330 mJ/cm^2 a new peak has appeared, located at 515 cm^{-1}. The absence of any other peaks in untreated sample spectra clearly indicates that as-deposited sample indeed is amorphous silicon with no crystalline grains in it. As for the laser treated sample, the position of the new peak is in good agreement with expected 517 cm^{-1} for p-Si. Therefore a conclusion can be made, that after laser treatment a transformation from amorphous to polycrystalline silicon has occurred.

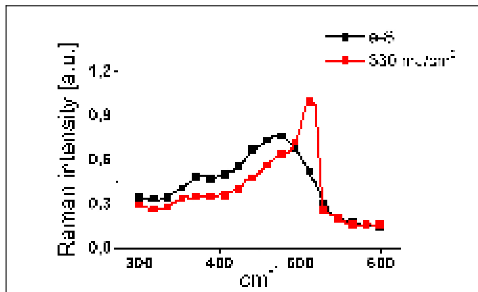

Fig. 1. Raman spectra of as-deposited amorphous silicon layer and after LC process.

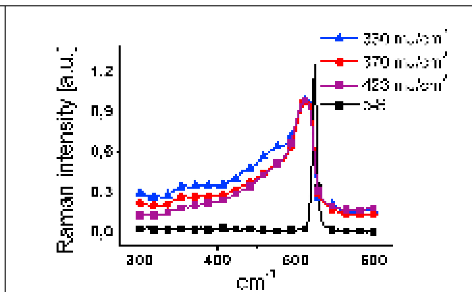

Fig. 2. Raman spectra of silicon wafer and polycrystalline silicon obtained after LC at different energies.

A comparison has been made between Raman spectra obtained from samples that have been crystallized at different pulse energies (Fig. 2). As can be seen the graph spectra does not change much by increasing the energy. That indicates that the samples are fully crystallized at energies less or equal to 330 mJ/cm^2 and further increase of energy does not lead to increase of crystallinity. The crystalline silicon spectrum in Figure 2 is given just for visual comparison of broadening of Raman spectrum line in the case of p-Si.

Although crystallinity of the p-Si film does not change by increasing laser pulse energy, same cannot be said about surface roughness and grain size of the film. As revealed by AFM measurements the starting a-Si film is very smooth and has surface roughness of approximately 2.5 nm, and it stays relatively smooth (<12 nm) for energies up to 200 mJ/cm^2. After this threshold energy the surface roughness and grain size increases significantly. In Figures 3 and 4 polycrystalline silicon films surface is shown after LC process was performed by single laser impulse. As can be seen, by increasing pulse energy from 312 to 418 mJ/cm^2 the grain size increases approximately five times, but surface roughness only two times from 41 to 81 nm. This means that the polycrystalline grains are getting bigger laterally faster than perpendicularly to the surface. It is a key property of laser crystallized p-Si film to get large-grained poly-silicon film.

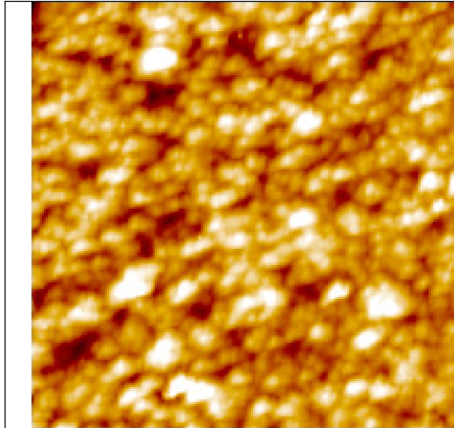

Fig. 3. AFM image (1x1 μm) of p-Si film after 1 pulse of 312 mJ/cm^2. Surface roughness is 41 nm.

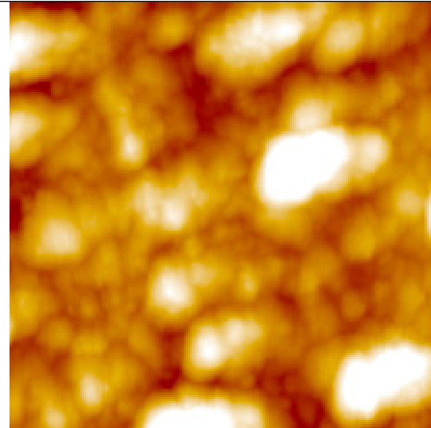

Fig. 4 AFM image (1x1 μm) of p-Si film after 1 pulse of 418 mJ/cm^2. Surface roughness is 81 nm.

4. Conclusions

It is shown that thin films of amorphous silicon can be crystallized using UV picosecond laser pulses. A single pulse of energy 330 mJ/cm^2 is enough to transform a-Si to p-Si. After LC process the carrier mobility becomes comparable to that of crystalline silicon.

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