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Epitaxial growth of polycrystalline films formed by microwave plasma chemical vapor deposition at low temperatures

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Abstract

We report epitaxial growth of polycrystalline silicon films using microwave-induced PECVD from initial laser crystallized silicon formed on glass substrates. Undoped silicon was first crystallized by a method of pulsed laser-induced rapid melt-regrowth. Crystalline volume ratio of 100 nm thick microcrystalline silicon layer subsequently deposited on the bottom laser crystallized layer increased from 0.2 to 0.37 as the ratio of the bottom layer increased from 0.69 to 0.8. Epitaxial growth ratio was determined as 0.45 for the present CVD method. The electrical conductivity of doped microcrystalline silicon top layer also increased because of increase crystalline volume ratio. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Microcrystalline silicon; PECVD; Laser annealing; Epitaxial growth

1. Introduction

The amorphous incubation layer was commonly found in microcrystalline silicon formed on insulating glass substrate. It is desirable that crystalline films are formed directly on the glass substrate without amorphous incubation layer in order to apply in many devices such as thin film solar cells. On other hand, laser crystallization is suitable method for forming good-quality silicon thin films. But there is a thickness limitation for laser crystallization [1].

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Table 1
Experimental conditions of the preparation of the microcrystalline silicon

Layer	Top		Bottom
	Undoped	P-doped	Undoped
H_2 flow rate	120 sccm	100 sccm	120 sccm
SiH_4 flow rate	6, 18 sccm	6 sccm	6 sccm
PH_3/SiH_4 flow ratio	—	8×10^{-4}	—
Total gas pressure	0.4 Torr	0.45 Torr	0.4 Torr
Substrate temperature	200, 250°C	200°C	200°C
Microwave power	40 W	40 W	40 W

In this study, we report epitaxial growth of polycrystalline silicon films using hydrogen-radical-induced CVD method on laser crystallized silicon films. And we report epitaxial efficiency and show a possibility of a function of a high-quality thick polycrystalline silicon films with a combination of PECVD method and laser crystallization method.

2. Experimental

We used double-layered structure to investigate epitaxial growth of polycrystalline silicon. The silicon films were formed by remote-type PECVD method [2]. Experimental condition is shown in Table 1. Both thicknesses of top and bottom layer were 100 nm. The first undoped layer was crystallized by laser irradiation. The silicon films for first layer were rapidly heated in vacuum at 2×10^{-4} Pa by a 28-ns-pulsed XeCl excimer laser with a wavelength of 308 nm. Multiple-step energy irradiation was carried out. The laser energy density was increased stepwise from 160 to 360 mJ/cm^2 with a 40 mJ/cm^2 increment. Five pulses were irradiated at each step.

Crystalline properties at surface regions of top films were investigated by measurements of optical reflectivity spectra in ultraviolet wavelength regions [3]. Crystalline silicon has a peak around 276 nm (E_2 peak) in optical reflectivity spectra, which is caused by large joint density of states at the X point in Brillouin zone, while amorphous silicon has no peak around 276 nm. Because the optical absorption coefficient is large $\sim 10^6\,\text{cm}^{-1}$ in the ultraviolet region, crystalline states at surface regions can be investigated with 10 nm resolution in the depth direction. We fitted the calculated reflectivity spectra in order to estimate the crystalline volume ratio (x) of the silicon films with complex reflective index which was xn c-Si $+ (1-x)n$ a-Si using a program including surface roughness and optical interface effects. The electrical conductivity of the silicon films of the double-layered structure was measured using Al coplanar electrode. Al electrodes with a gap of 20 μm and width of 2000 μm were formed on the silicon films by photolithography and wet-etching process. The bias voltage of 0.05 V was applied.

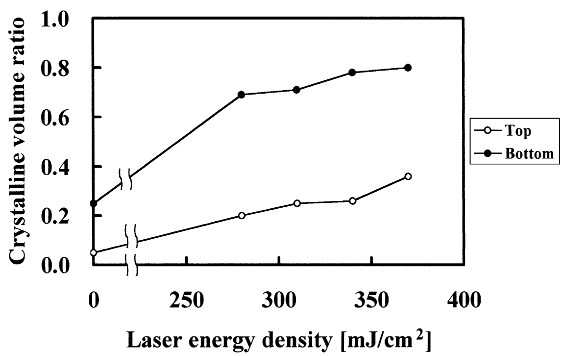

Fig. 1. The crystalline ratio of the top layer as a function of laser energy density irradiated to bottom layer.

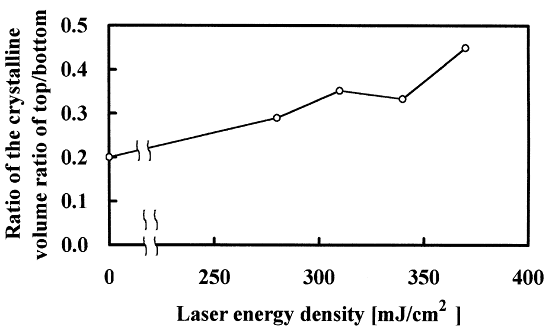

Fig. 2. Ratio of the crystalline volume ratio of top/bottom as a function of laser energy density irradiated to bottom layer.

3. Results and discussions

Fig. 1 shows that the crystalline volume ratio of the undoped top and bottom layers as a function of laser energy density irradiated to the bottom layer. For no laser irradiation case, the crystalline ratio was very low. This means that it was almost amorphous state. However, the crystalline volume ratio at surface of the bottom layer markedly increased as laser energy density increased from 280 to 360 mJ/cm^2 because of laser-induced crystallization. The crystalline volume ratio at the top surface also increased from 0.2 to 0.37 as the laser energy density increased from 280 to 360 mJ/cm^2 as shown in Fig. 1. This means that crystalline states of top layer depend on the crystalline states of the bottom surface. This result of Fig. 1 clearly means that the epitaxial crystalline growth occurred during formation of the top layer. The epitaxial growth efficiency was obtained as ratio of crystalline volume ratio of top to bottom layers top/bottom for different laser energies, as shown in Fig. 2. It was 0.2–0.45 for the present laser energy range. The epitaxial efficiency gives upper limit of crystalline volume ratio of CVD system.

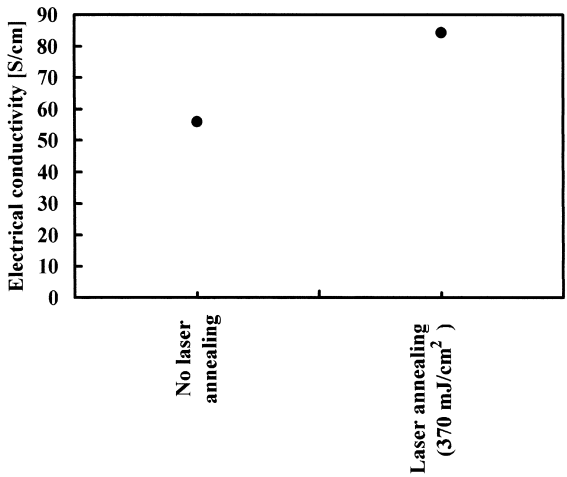

Fig. 3. The difference of no laser-irradiated films and laser-irradiated films of the electrical conductivity.

We investigated the electrical conductivity of P-doped layer deposited on the bottom laser crystallized layer. The difference between no laser-irradiated films and laser-irradiated films of the electrical conductivity of the films was shown in Fig. 3. The electrical conductivity of the double-layered films increased from 56 (no laser irradiation) to 84 S/cm as laser irradiated to the bottom silicon layer. Increasing the electrical conductivity means that the carrier mobility of the top silicon layer would be increased by laser crystallization to the bottom silicon layer because of the increase of crystalline volume ratio as well as the grain boundary properties. We confirmed that epitaxial growth was occurred by combination of microwave-induced PECVD with laser crystallization, and these results gives a possibility of a function of a high-quality thick polycrystalline silicon films.

4. Conclusions

We used the double-layered structure in order to investigate epitaxial growth of polycrystalline silicon films. The crystalline volume ratio of top surface increased from 0.05 to 0.36 as that of bottom layer increased 0.25–0.8. It suggested that the top silicon layer took over the crystalline property at bottom layer when bottom crystalline silicon acted as the crystalline nucleation site by using the laser crystallized silicon films as the bottom layer. And we calculated the epitaxial growth efficiency of our CVD system. It was 0.2–0.45 for the present laser energy range. And we found that the carrier mobility would be increased by laser irradiation to the bottom silicon layer because the electrical conductivity increased from 56 to 84/cm by laser irradiation to bottom layer.

Acknowledgements

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