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Crystallization of silicon films by rapid joule heating method

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Abstract

We report on the crystallization of silicon films by the joule heating method using Cr strip heater. We report on the lateral crystalline grain growth of silicon thin films by induced holes fabricated in Cr strip. A temperature gradient is generated by the holes, which causes lateral crystalline grain growth. The duration of the electrical current flow in the Cr strip heater is 5 μs. The crystallization experiment is evaluated by Raman scattering spectra in particular by analyzing the sharp crystalline TO phonon peak around 517 cm^{-1}.

Keywords: Lateral crystalline growth; Rapid heating; Joule heating

1. Introduction

The formation of polycrystalline silicon films on cheep substrates such as glass has been important for device application such as thin film transistors (TFTs) and solar cells. Many technologies have been reported for the formation of polycrystalline silicon films at low processing temperature [1–10]. Lateral crystalline grain growth is very important for the formation of large crystalline grain in thin films. We recently reported the lateral crystalline grain growth using the electrical current induced joule heating of silicon films and metal films [11–14]. In these methods, the lateral crystalline grain growth was achieved by the spatial distribution of joule heating intensity in the lateral direction.

In this paper, we report crystalline grain growth in the lateral direction by the joule heating method induced by an electrical current flowing in the metallic thin film heater. Some holes are formed in the metal thin film heater in order to generate a temperature gradient in the silicon films. We investigate the distribution of joule heating energy in the metal thin film heater. Raman scattering spectra and optical micrographs are used in order to investigate the crystalline properties.

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2. Experimental

50-nm-thick and 150-nm-thick amorphous silicon films were deposited on glass substrates by low pressure chemical vapor deposition (LPCVD). 300-nm-thick silicon dioxide (SiO_2) layer was formed on silicon films by a sputtering. A 100-nm-thick chromium layer serving as a thin film heater was formed on the SiO_2 layer by sputtering in strip shape with 110 μm width. 100-nm-thick Al electrodes with 250-μm gap were then formed on the Cr strip for the voltage application to the Cr strip heater. Voltage source, resistances, Cr heater and metal oxide semiconductor field effect transistor (MOS FET) were connected, as shown in Fig. 1. The voltage was applied to capacitor and the capacitor was accumulated when MOS FET was off. Electrical current flow and the joule heating in the Cr strip were induced by switching the MOS FET to the on-state by application of a pulsed voltage to gate. The heat diffuses to the silicon film and forwards to the glass substrate through the intermediate SiO_2 layer.

Upon heating, the silicon films were melted. In order to form a temperature gradient in the silicon films, holes were formed in the Cr strip as shown in Fig. 2. The diameter of holes was either 12 μm or 20 μm. The initial electrical resistance of the Cr strip was 100 Ω. The temperature of the silicon films under the area between the holes in the Cr strip was high because the increased current density induced joule heating. On the other hand, the temperature of the silicon

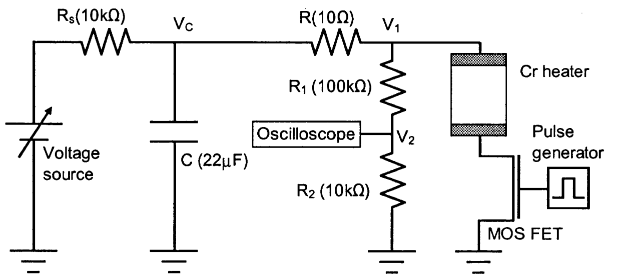

Fig. 1. Electrical circuit using the rapid joule heating method. Applied voltage to Cr strip, V_1 was calculated from measured V_2 at the voltage divides resistance of R_1 and R_2.

films under the hole area was low because of zero electrical current above the area. Consequently, a temperature gradient was generated in the lateral direction between hole areas.

The silicon films were inspected by an optical microscope. The color of the crystallized silicon was changed due to the change of the refractive index. Raman scattering spectra were used for the investigation of the crystalline properties after the joule heating. The wavelength of the incident laser was 514.5 nm. The spot size was the diameter of 0.75 μm. For these measurements, Cr and SiO_2 layers were etch out using liquid solutions.

3. Results and discussion

Fig. 3a–c shows optical micrographs of 150-nm-thick silicon films after heating by the present method for several voltages applied to the Cr strip (170, 190, and 220 V). The silicon films were inspected by illumination from the rear side.

The dark gray region in Fig. 3a–c is the amorphous phase. The bright region is silicon crystallized by the joule

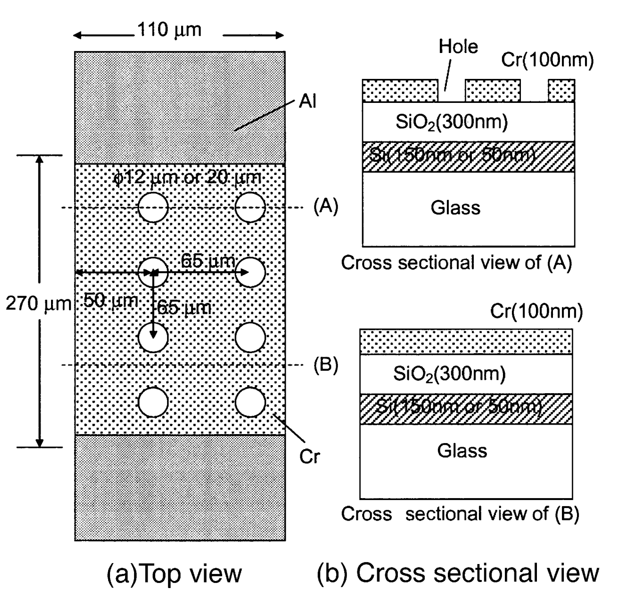

Fig. 2. Sample structure using the present heating method. Panel (a) indicates top view and (b) indicates cross-sectional views of sample.

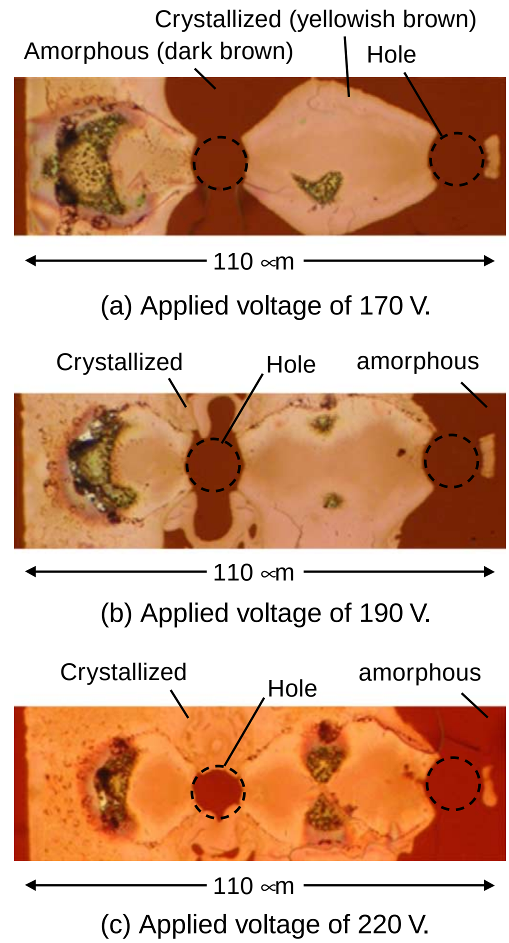

Fig. 3. Photograph of the optical microscope of 150-nm-thick silicon films heated by the present method. Panels (a), (b) and (c) indicate the photos for applied voltage of 170, 190 and 220 V, respectively. Areas indicated by color of yellowish brown and dark brown are crystallized and amorphous regions, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

heating. The crystallized area increased as the applied voltage increased, because the joule heating energy density increased as the voltage increased. In the case of the applied voltage of 170 V, the crystallized area resides in the region between the holes. In the case of the applied voltage of 190 and 200 V, the crystallized area is further increased because of the higher joule heating intensity.

Fig. 4a–c shows optical micrographs for silicon films 50-nm thickness after crystallization. The dark region is amorphous, the bright color indicates a crystalline state. The diameter of the hole is 20 μm in this case. The applied voltage was 80, 110 and 125 V. Because latent energy per unit area is low due to thin, the applied voltage is low. Because the joule heating intensity is low, the crystallized area is small. The crystallize area increases as the applied voltage increases.

Raman scattering spectra as obtained from the 50-nm-thick films, crystallized with an applied voltage of 125 V case shown in Fig. 4c are shown in Fig. 5 of different points indicated in Fig. 4c. Fig. 5 shows also a deconvolution of

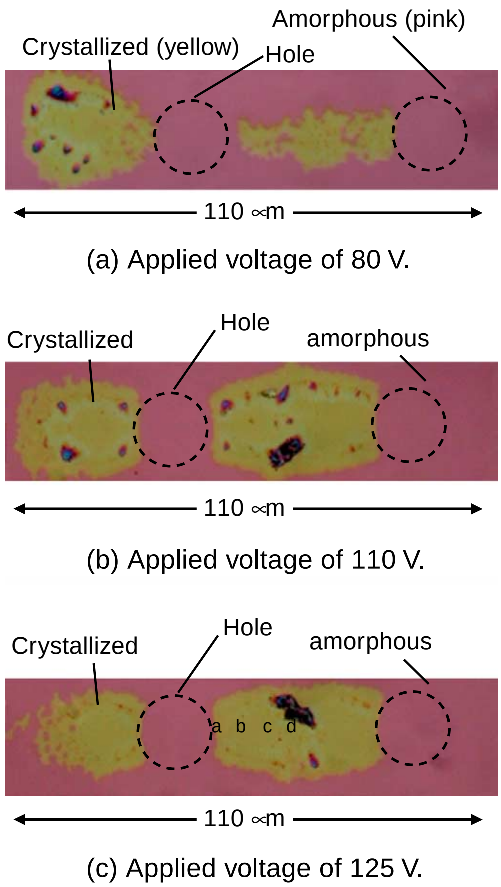

Fig. 4. Photograph of the optical microscope of 50-nm-thick silicon films heated by the present method. Panels (a), (b) and (c) indicate the photos for applied voltage of 80, 110 and 125 V, respectively. Areas indicated by color of pink and yellow are crystallized and amorphous regions, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

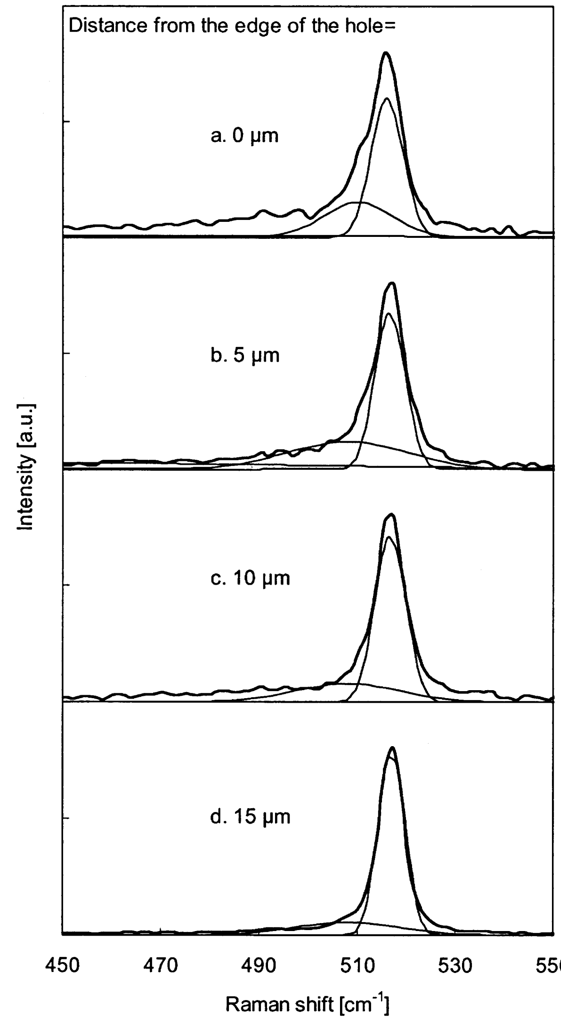

Fig. 5. Raman scattering spectra. (a)–(d) indicate the measured points shown in Fig. 4c.

the Raman data. The distance between every measured point "a", "b", "c", "d" in Figs. 4c and 5 was 5 µm. The crystalline TO phone peak around 517 cm^{-1} was observed at all four points "a" to "d". The analysis of the shape of the spectra indicates that the peak associated with the disordered silicon was always very low. The spectrum at position "a" in Fig. 5 shows a rather large nano-crystalline peak at around 500 cm^{-1} [15]. This peak becomes smaller for positions "b", "c" and "d". This difference exists because of the temperature gradient in the heating which causes insufficient crystallization near the hole. The peak shape is similar to that one of a single crystal at a large distance from the edge of the hole. Consequently, the TO phonon peak of crystalline silicon at the position "d" is practically without a contribution from disordered silicon.

Fig. 6 shows the full width at half maximum (FWHM) and the peak wavenumber of crystalline TO phonon peak in Raman scattering spectra as obtained from Fig. 5. The FWHM decreases from 5.0 to 4.0 cm^{-1} as the distance from the hole edge increases. This reduction is associated by a shift in the peak position indicating that the tensile stress also decreases with distance. The tensile stress is calculated

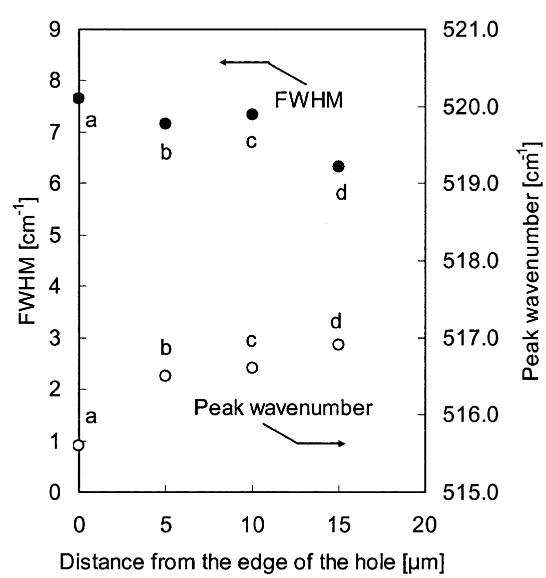

Fig. 6. Full Width at Half Maximum (FWHM) and peaks wavenumber of crystalline TO phonon peak of Raman scattering spectra. Distance of 0 µm means the edge of hole, i.e. the point is the point "a" in Fig. 4c.

from the peak wavenumber of the crystalline TO phonon peak [16] expressed by,

$$\omega = \omega_c + 5.2 \times 10^{-9} P, \quad (1)$$

where ω is the peak wavenumber of the silicon films, ω_c is that of a stress-free single bulk silicon and P is the strength of the stress. The tensile stress decreases from 1.0×10^9 Pa (position "a") to 7.1×10^8 Pa (position "d"). The area around the position "d" was the best heated area., i.e. the melt duration is comparably long. Thus there is a good possibility that large crystalline grains 3 to 5 μm would grow.

4. Summary

Silicon films were crystallized by the rapid joule heating method. A Cr strip heater is used as the heat source in this method. In order to generate a temperature gradient and to enhance the formation of large crystalline grains by lateral growth in the silicon films, some holes were formed in the Cr strip heater. The inspection with optical microscopy reveals the crystallization of 150-nm-thick films above an applied voltage of 170 V; for 50-nm-thick silicon films we need above 80 V. The difference in the voltages applied to the 150-nm-thick and 50-nm-thick silicon films is due to the difference in the latent heat per unit area. Raman scattering spectra reveal the formation of crystalline grains, they appear like single crystalline silicon.

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