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A novel method for laser doping of Poly-Si thin films using XeF excimer laser irradiation in acid solution

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Abstract

In this paper, we propose a new method that achieves implantation of phosphorus (P) to poly-silicon (poly-Si) thin films and dopant activation simultaneously at room temperature. We crystallized amorphous-silicon (a-Si) into poly-Si by xenon fluoride (XeF) excimer laser annealing under atmospheric condition. Then the poly-Si film was irradiated by a XeF excimer laser in a phosphoric acid solution. After laser irradiation in the phosphoric acid solution, the concentration of P atoms in the poly-Si films was approximately 6.7×10^{18} cm^{-3}, and the resistivity of the poly-Si films decreased dramatically from 4.3×10^{4} Ω・cm to 1.4 Ω・cm. Through this method, the implantation of P atoms and dopant activation can be performed simultaneously.

Keywords: Laser Doping ; XeF Excime Laser ; Poly-Si ; Flexible Display ; Thin Film Transistor(TFT)

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1. Introduction

Low temperature poly-Si(LTPS) is used as a channel material in a thin film transistor (TFT), which is widely used as a switching device in flat panel displays such as liquid crystal displays. LTPS can not only be used for switching devices but also for integrating peripheral circuits on glass substrates because it has higher mobility than a-Si [1], [2]. In the future, this LTPS process could be applied to flexible displays with plastic substrates [3], [4]. LTPS is developed using excimer laser annealing (ELA).

In fabricating a TFT, we have focused on two steps in the entire process. The first one is the dopant implantation process involving the implantation of P into poly-Si. The second focus area is the dopant

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activation process. After the doping process, we need to activate the dopants to obtain an n-type semiconductor by annealing it.

To utilize a plastic substrate, the process temperature must be below 200 °C. Current fabrication methods require a dopant activation temperature of approximately 400 °C after the doping process [5], [6]. We focused on achieving dopant implantation and dopant activation simultaneously at a low temperature using excimer laser irradiation in an acid solution. If successful, this process would be a powerful tool for flexible display fabrication [7].

In this paper, we report the investigation into the doping of phosphorus to LTPS, which is fabricated by ELA, using XeF excimer laser irradiation in a phosphoric acid solution.

2. Experiments

For the experiments, we used a XeF excimer laser (Gigaphoton Inc., wavelength: 351 nm, pulse duration: 53 nsec) and the material sample was SiO_2 (100 nm)/SiN (50 nm)/ on a glass substrate. On this substrate, we deposited 50-nm-thick a-Si films by low pressure chemical vapor deposition (LPCVD). The a-Si films were crystallized by ELA using the XeF excimer laser (the number of laser shots: 20, laser fluence: 380 mJ/cm^2). Figure 1 shows a schematic of the XeF excimer laser irradiation during ELA. Figure 2 shows an FESEM image of the Secco-etched poly-Si of the laser-irradiated region in this process. As shown in Fig.2, grain boundaries with a grain size of 200-300 nm are clearly seen in the FESEM image [8].

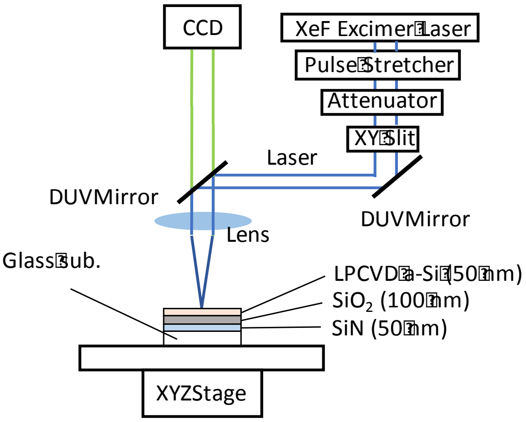

Fig. 1. Schematic of excimer laser irradiation during ELA

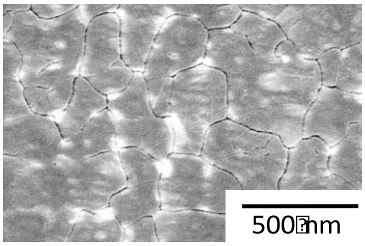

Fig. 2. FESEM image of the poly-Si of the laser-irradiated region

Additionally, we irradiated the LTPS/SiO_2/SiN/Glass system, which is fabricated in this process, in a phosphoric acid solution by using a XeF excimer laser (number of shots: 20, laser fluence: from 50 mJ/cm^2 to 530 mJ/cm^2). Figure 3 shows a schematic of the XeF excimer laser irradiation in phosphoric acid solution as well as the in-situ observation system. The in-situ observation system allowed us to observe the surface melting and solidification during the irradiation. The excimer laser light was projected by a lens and was irradiated on a sample on the stage. A continuous wave (CW) laser with a wavelength of 640 nm was used to probe the center of the region irradiated by the XeF excimer laser. The CW laser light was reflected from the poly-Si surface, and then, the reflected light intensity was measured using a photodetector. Energy intensity was adjusted using a beam attenuator and the beam size was adjusted by an XY slit. The pulse repetition rate of the laser was 10 Hz and the laser beam spot size on the sample surface was 700 µm ×200 µm. The sample was scanned in the short axis direction of the laser beam, and the number of laser shots was fixed at 20 per location by controlling the scan velocity [7], [9].

To evaluate the prepared sample, we measured its resistivity, the depth profile of phosphorus concentration, reflected light intensity, carrier concentration and mobility, and the activation rate. The resistivity was determined from the sheet resistance measured by a four point probe and the film thickness (50 nm). The depth profile of phosphorus was measured using secondary ion mass spectrometry (SIMS). The reflected light intensity was measured by using the photodetector as mentioned above, and we also studied the Hall effect measurement of this sample to evaluate the carrier concentration and mobility.

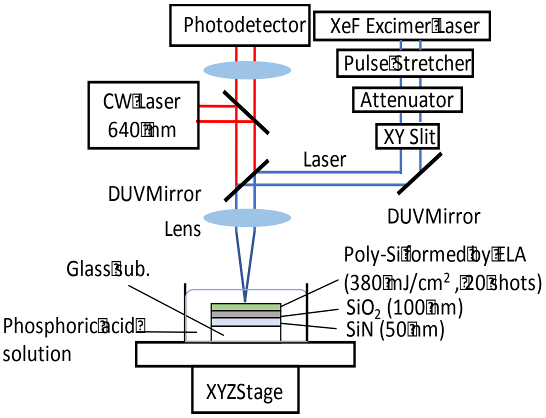

Fig. 3. Schematic of excimer laser irradiation in phosphoric acid solution and the in-situ observation system

3. Results

Figure 4 shows the resistivity of the laser-irradiated region in the phosphoric acid solution. The resistance was almost constant up to a laser fluence of 280 mJ/cm^2, but it decreased dramatically at laser fluence greater than 300 mJ/cm^2. The minimum value of resistivity measured was approximately 0.21 Ω・cm at a laser fluence of 380 mJ/cm^2. Therefore, we believe that it is possible to achieve phosphorus implantation and activation simultaneously.

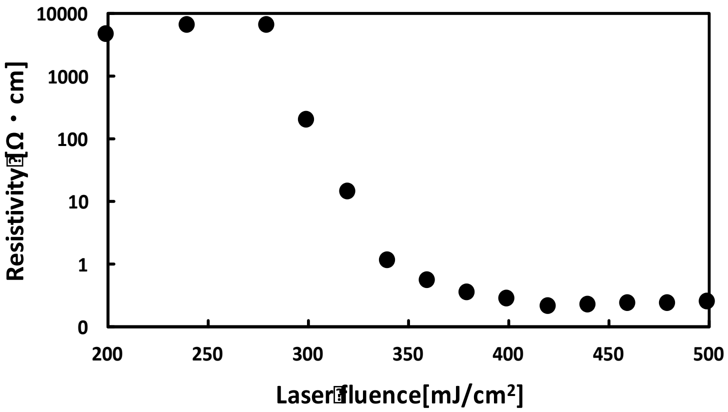

Fig. 4. Resistivity as a function of laser fluence in the laser-irradiated region in phosphoric acid solution

Figure 5 shows the depth profile of phosphorus measured by SIMS for a sample irradiated at laser fluences of 230 mJ/cm^2, 330 mJ/cm^2, 380 mJ/cm^2, and 430 mJ/cm^2. Figure. 6 shows the plot of phosphorus concentration at a 30-nm depth versus laser fluence. As shown in Fig. 5, the phosphorus was implanted in poly-Si above a laser fluence of 230 mJ/cm^2, and the poly-Si was doped to a depth of 50 nm uniformly. We estimated that the phosphorus concentration in the poly-Si films at a fluence of 420 mJ/cm^2 was approximately 6.7×10^{18} cm^{-3}. This result indicates that it is possible to achieve uniform phosphorus doping.

Furthermore, as shown in Fig. 6, the phosphorus concentration increases dramatically at a laser fluence greater than 330 mJ/cm^2, and the phosphorus concentration was approximately 6.7×10^{18} cm^{-3} in the poly-Si films. While the phosphorus concentration rate increase was slow, the resistivity decreased substantially between 230 mJ/cm^2 and 330 mJ/cm^2. These results indicate that the phosphorus was activated at 330 mJ/cm^2. Therefore, we propose that phosphorus activation can be achieved with laser fluences above 330 mJ/cm^2.

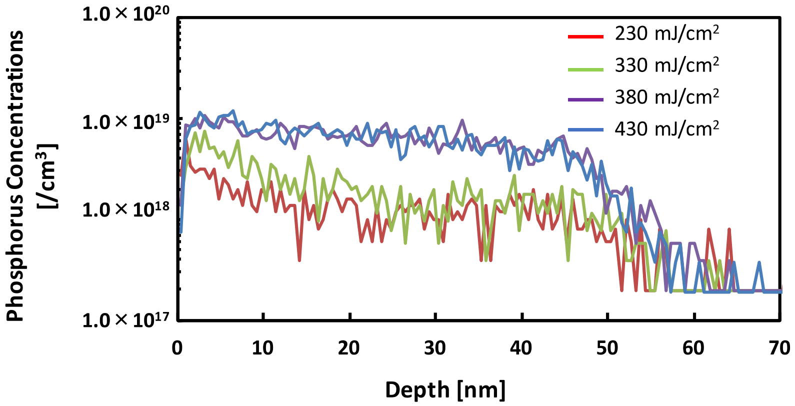

Fig. 5. Depth profile of phosphorus

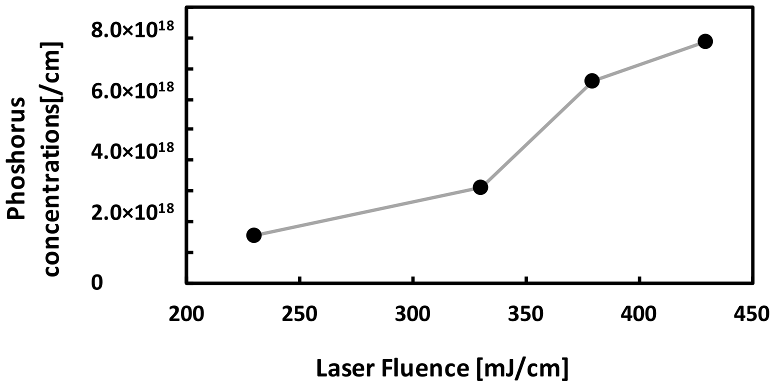

Fig.6.Phosphorus concentration at 30 nm depth versus laser fluence

Figure 7 shows the results of in-situ observation measurements of the reflected light intensity of the CW probe laser during excimer laser irradiation in the phosphorus acid solution. Region 0 in Fig.7 indicates the time period before the excimer laser irradiation. In Region 1, partial melting of the poly-Si is observed, because the reflected light intensity of partially melted poly-Si is decreased by multiple scattering of the laser radiation. In Region 2, the poly-Si is completely melted, because the reflected light intensity of completely melted poly-Si is greater than the reflectivity of solid state poly-Si. In Region 3, the poly-Si is solid, and the reflected intensity is reduced because of the cavitation bubbles generated by laser irradiation. As shown in Fig.7, the poly-Si is completely melted during excimer laser irradiation at laser fluences higher than 330 mJ/cm^2. However, the poly-Si does not completely melt at a fluence of 230 mJ/cm^2. This result indicates that the phosphorus doping is achieved by partial melting of the poly-Si thin film, and the phosphorus activation is achieved by completely melting the poly-Si film

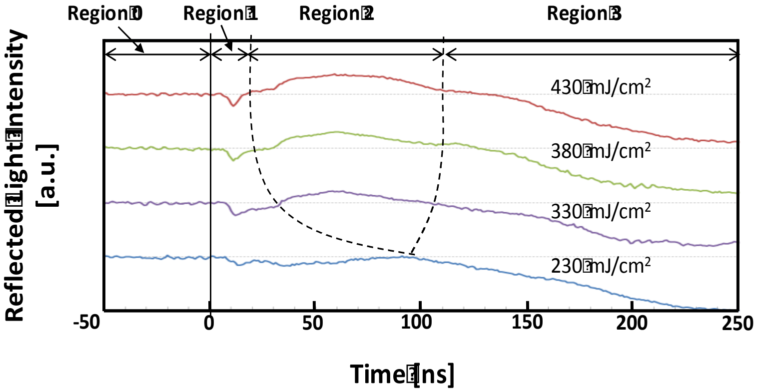

Fig. 7. Reflected intensity of the probe laser during excimer laser irradiation

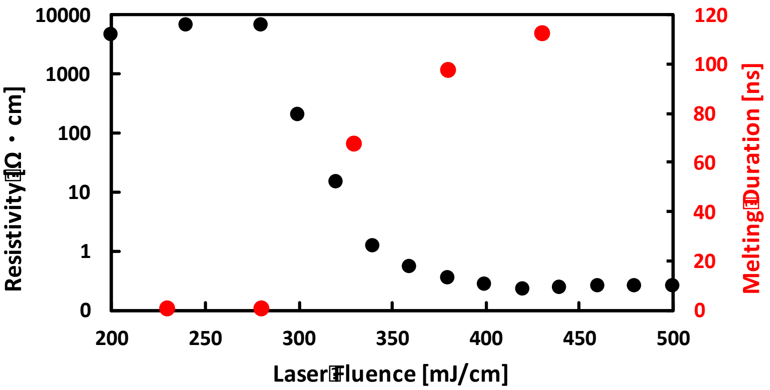

Fig.8. Melting duration overlaid with resistivity

Fig. 8 shows the plot of melting duration versus laser fluence overlaid with the resistivity from Fig. 4. The resistivity started to decrease when the melting duration started to increase and continued to decrease as the melting duration increased. This result indicates that the doping activation can be achieved by the melting of of the poly-Si film.

From the Hall effect measurements, the carrier mobility of the poly-Si film after laser doping with a fluence of 420 mJ/cm^2 was 75 cm^2/Vs, which is equivalent to that in the conventional doping methods of ion implantation and furnace annealing.

Based on these results, phosphorus implantation and activation can be achieved simultaneously by XeF excimer laser irradiation in a phosphoric acid solution.

4. Conclusion

We proposed a novel method for laser implantation of P atoms to poly-Si thin films using XeF excimer laser irradiation in a phosphoric acid solution. After laser doping, the P concentration in the poly-Si film was approximately 6.7×10^{18} cm^{-3}, and concentration profile was almost uniform. In addition, the resistivity of the poly-Si films decreased dramatically from 4.3×10^4 Ω・cm to 1.4 Ω・cm. Finally, the carrier mobility of the poly-Si film was 75 cm^2/Vs, which is equivalent to that in the conventional doping methods of ion implantation and furnace annealing. Therefore, we conclude that the implantation of P atoms and dopant activation can be simultaneously performed at room temperature by XeF excimer laser irradiation in a phosphoric acid solution.

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