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Excimer Laser Doping of LTPS Thin Films for Printable Device Fabrication

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Abstract

We propose excimer laser doping of low-temperature poly-Si thin films for printable device fabrication. In this method, solutions containing dopant atoms, are coated on the poly-Si surface, and dopant atom diffusion into the poly-Si film and activation are simultaneously achieved by KrF excimer laser irradiation of the poly-Si films. This method does not require the use of heavy manufacturing equipment such as ion implantation and furnace annealing systems. In addition, it is a very simple method in which dopant coating and laser annealing are performed under atmospheric conditions. Therefore, we expect that this method will be suitable for doping processes in thin film devices for printable electronics.

In our previous study, we reported that laser doping of phosphorus to poly-Si thin films can be achieved using excimer laser irradiation in phosphoric acid solution. However, cavitation bubbles were generated on the irradiated area in the solution during laser irradiation; as a result, laser irradiation damage to the poly-Si was induced by optical scattering of the laser light at the bubble/solution interface.

By irradiation of the poly-Si coated with the solution instead of irradiation in the solution, poly-Si films with no irradiation damage were obtained. When phosphoric acid was used as the coating solution, high-quality n-type poly-Si thin films with no damage and low resistivity (~0.14 Ω·cm) were fabricated.

1. Introduction

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

We have focused on two steps in the TFT fabrication process. The first is the dopant implantation process, in which P is implanted in poly-Si. The second focus area is the dopant activation process. After the doping process, we need to activate the dopants by annealing to obtain an n-type semiconductor.

To use a plastic substrate, the process temperature must be below 200 °C, but current fabrication methods require a dopant activation temperature of approximately 400 °C after the doping process [4]. 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 [5].

In this paper, we report an investigation of phosphorus doping of LTPS, which is fabricated by ELA, using excimer laser irradiation after thin films are coated with phosphoric acid solution.

2. Experiments

We used a KrF excimer laser (Gigaphoton Inc., wavelength: 248 nm, pulse duration: 80 nsec) on a sample consisting of a-Si(50 nm)/SiO_2 (100 nm)/SiN (50 nm)/ on a glass substrate. The a-Si films were deposited by low-pressure chemical vapor deposition and crystallized by ELA using the KrF excimer laser (20 shots, 380 mJ/cm^2).

After crystallization, the LTPS film was coated with a phosphoric acid solution. The coating process was (1) dilute hydrofluoric acid cleaning (10 s), (2) deionized (DI) water cleaning, (3) UV treatment (10 s), (4) dipping into phosphoric acid solution (10 s), and (5) DI-water cleaning(10 s). The UV treatment in step (3) was performed by KrF excimer laser irradiation (20 shots, 150 mJ/cm^2). This UV laser treatment enhanced the hydrophilicity of the surface of the LTPS film. The DI water cleaning in step (5) removes surplus phosphoric acid solution. After the coating process, approximately 10^{14} cm^{-2} of phosphorus was adsorbed on the LTPS surface as estimated by secondary ion mass spectrometry (SIMS).

The pulse repetition rate of the laser was 100 Hz, and the laser beam spot size on the sample surface was 2000 μm × 500 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.

We measured the sample's resistivity, the depth profile of the phosphorus concentration, the carrier concentration and mobility, and the activation rate. The resistivity was determined from the sheet resistance as measured by a four point probe and from the film thickness (50 nm). The phosphorus depth profile was measured using SIMS, and we also performed Hall effect measurement of this sample to evaluate the carrier concentration and mobility.

3. Results

Figure 1 shows the resistivity of the laser-irradiated region. The resistivity in the non-irradiated area was 48 Ω·cm, and that in the UV-treated area was 55 Ω·cm. This result shows that the UV treatment had little effect on the resistivity. In contrast, the resistivity decreased dramatically after laser doping at laser fluences of 300 and 350 mJ/cm^2. The minimum value of the resistivity, approximately 0.14 Ω·cm, was obtained at a laser fluence of 350 mJ/cm^2. Therefore, we believe that it is possible to achieve phosphorus implantation and activation simultaneously.

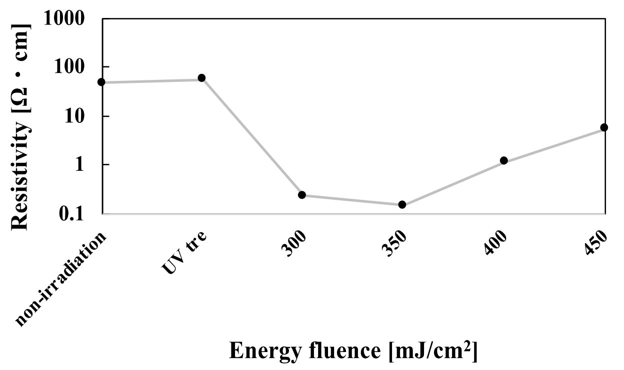

Fig. 1 Resistivity as a function of laser fluence in the laser-irradiated region

Figure 2 shows the phosphorus depth profile measured by SIMS, of a sample after doping at a laser fluence of 350 mJ/cm^2. The poly-Si was uniformly doped to a depth of 50 nm. We estimated that the phosphorus concentration in the poly-Si films at a fluence of 350 mJ/cm^2 was approximately 9.9×10^{18} cm^{-3}. This result indicates that it is possible to achieve uniform phosphorus doping.

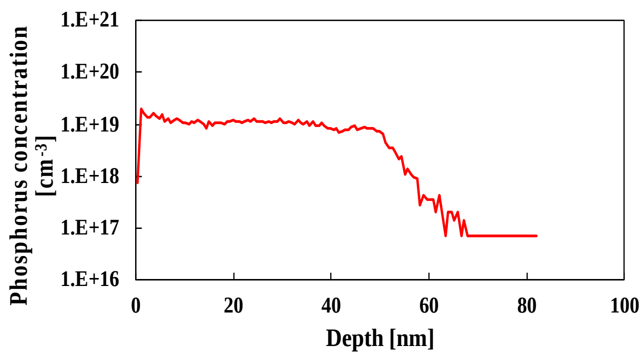

Fig. 2 Phosphorus depth profile

Additionally, from the Hall effect measurements, the carrier mobility of the poly-Si film after laser doping at a fluence of 350 mJ/cm^2 was 61 cm^2/Vs, which is consistent with those obtained by the conventional doping methods of ion implantation and furnace annealing. Further, the phosphorus activation rate was 14.6 %. This activation rate was low; we think the reason is that some of the P atoms implanted in the poly-Si film were segregated at the poly-Si grain boundaries. This problem would be solved by hydrogen annealing, which is the last process in the fabrication of a poly-Si TFT.

4. Conclusions

We proposed a novel method for laser implantation of P atoms into poly-Si thin films by using KrF excimer laser irradiation. After laser doping, the P concentration in the poly-Si film was approximately 9.9×10^{18} cm^{-3}, and the concentration profile was almost uniform. In addition, the resistivity of the poly-Si films decreased dramatically from 48 Ω·cm to 0.14 Ω·cm. Finally, the carrier mobility of the poly-Si film was 61 cm^2/Vs, which is consistent with those obtained by the conventional doping methods of ion implantation and furnace annealing. Therefore, we conclude that implantation of P atoms and dopant activation can be simultaneously performed at room temperature using this method.

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