Fabrication of excimer laser annealed poly-si thin film transistor by using an elevated temperature ion shower doping

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Abstract

We have investigated the effect of an ion shower doping of the laser annealed poly-Si films at an elevated substrate temperatures. The substrate temperature was varied from room temperature to 300 ℃ when the poly-Si film was doped with phosphorus by a non-mass-separated ion shower. Optical, structural, and electrical characterizations have been performed in order to study the effect of the ion shower doping. The sheet resistance of the doped poly-Si films was decreased from 7×10^6 $\Omega/\square$ to 700 $\Omega/\square$ when the substrate temperature was increased from room temperature to 300 ℃. This low sheet resistance is due to the fact that the doped film doesn't become amorphous but remains in the polycrystalline phase. The mildly elevated substrate temperature appears to reduce ion damages incurred in poly-Si films during ion-shower doping. Using the ion-shower doping at 250 ℃, the field effect mobility of 120 cm^2/(V · s) has been obtained for the n-channel poly-Si TFTs.

Keywords : Excimer laser annealing, poly-silicon, Thin film transistor (TFT), Ion shower doping

1. Introduction

Polycrystalline silicon thin film transistors (poly-Si TFT's) have been used in great deal for active matrix liquid crystal displays (AMLCD's)[1] and static random access memories (SRAMs). Compared with a-Si TFT, the poly-Si TFT has several advantages, including high field effect mobility, low temperature sensitivity, and the possibility of simultaneous processing of display driver IC on the peripheral area of the LCD panel, as well as FED[2]-[3]. Recently, high quality poly-Si thin films have been obtained using an excimer laser annealing. To obtain high field effect mobility, it is necessary to lower the sheet resistance of the source-drain region of the poly-Si TFT's. There are several methods for introducing impurities, such as ion implantation, thermal diffusion, and ion shower doping[4].

Among them, the ion-showering is performed with dopants which are non-mass separated species, extracted from RF plasma discharge of doping gases. And, this non mass separated ion-showering has several advantages, such as low temperature process, high throughput, and large area doping capability. In order to increase the doping efficiency, some post-doping treatments are used. So far, laser annealing[5]-[6] and low temperature furnace annealing[7] have been reported. In the present work, we have investigated the characteristics of phosphorus doping of the excimer laser annealed poly-Si films done by the ion-showering at the mildly elevated substrate temperatures.

2. Experimental details

Laser recrystallized poly-Si films were ion-

showered with phosphorus. 300 nm thick SiO_2 buffer layers were deposited on Corning 7059 glass substrates and followed by 60 nm thick of hydrogenated amorphous silicon (a-Si:H) films grown by plasma enhanced chemical vapor deposition (PECVD). Before laser annealing, the a-Si:H films were pre-annealed at 450 ℃ for 4 hours in N_2 ambience to prevent the explosive eruption of hydrogen. For the laser annealing, a *XeCl* excimer laser (λ = 308 nm) was used to crystallize the amorphous silicon films. The typical grain size of the poly-Si films was about 400 nm after the laser annealing. The phosphorus atoms were doped into the poly-Si films using the ion showering with a radio frequency plasma ion source[8]. The acceleration voltage was 10 kV and the dose was 1×10^{16} ions/cm^2. 1 % PH_3/H_2 diluted with helium was used as the ion doping source gas. The doping temperature was varied from room temperature to 300 ℃. For all samples, the sheet resistance was measured with a four point probe. The crystallinity of these films was analyzed by UV spectroscopy, Raman spectroscopy, and TEM. The doping concentrations of P and H atoms were measured by the Secondary Ion Mass Spectrometry (SIMS). To fabricate the poly-Si TFTs, an amorphous silicon film of 60 nm thick was deposited by PECVD at 250 ℃.

The amorphous silicon film became poly-crystallized by the *XeCl* excimer laser irradiation at room temperature. The poly-Si film was patterned and followed by a 100 nm-thick gate insulator SiO_2 film deposited by PECVD at 350 ℃. Subsequently, a gate metal was evaporated and patterned. After patterning the gate oxide, source and drain regions were doped by the ion-showering. The acceleration voltage was 10 kV. Next, an interlayer SiO_2 was deposited by the atmosphere pressure chemical vapor deposition (APCVD) at 330 ℃. After forming contact holes, source and drain metal was evaporated and patterned. Finally, a 500 nm thick SiO_2 was deposited as a passivation layer. Important device parameters such as threshold voltage (Vth), field effect mobility (FE), subthreshold slope (S) of the poly-Si TFTs were measured.

3. Results and Discussion

Figure 1 shows the sheet resistance of the ion-showered poly-Si films as a function of the substrate temperature. The sheet resistance of the laser-annealed ion-showered poly-Si films was inserted for comparison. The thickness of the films was 60 nm, the dose 1×10^{16} ions/cm^2, and the acceleration voltage 10 kV. The sheet resistance of the doped poly-Si films was decreased from 7×10^6 Ω/□ to 700 Ω/□ when the substrate temperature was increased from room temperature to 300 ℃. Above 250 ℃, the sheet resistance was saturated at 700 Ω/□.
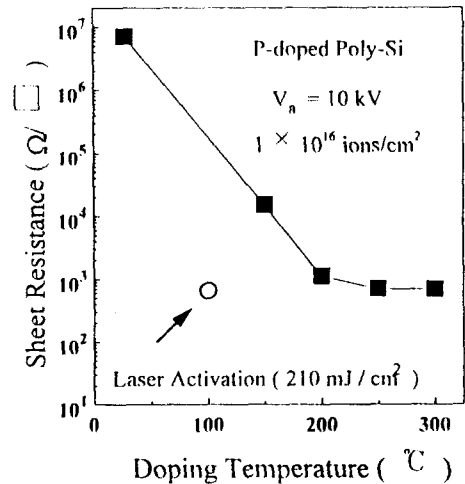
Fig. 1. The dependence of sheet resistance of the ion shower doping of poly-Si films on the doping temperature (○ : laser activation after the ion shower doping at room temperature)

Figure 2 shows the depth profile of P and H atoms of the poly-Si films doped at two different substrate temperatures. The peak concentration of the P atoms was about 10 nm from the surface, which is due to the low acceleration voltage of 10 kV. The distribution of the P atoms was relatively broad for the ion-shower doping process with the substrate temperature at 250 ℃. And, the H atom profile was different from that of the phosphorus.

After the ion showering, the concentration of the hydrogen at the surface became lower than that of the room temperature sample, and gradually increased as the depth increased. Thus, the hydrogen atoms were evolved from the surface layer of the poly-Si films during the ion shower doping with the substrate temperature at 250 ℃. To further evaluate the effect of ion showering, the films were investigated by UV reflectance spectroscopy, Raman spectroscopy and TEM.
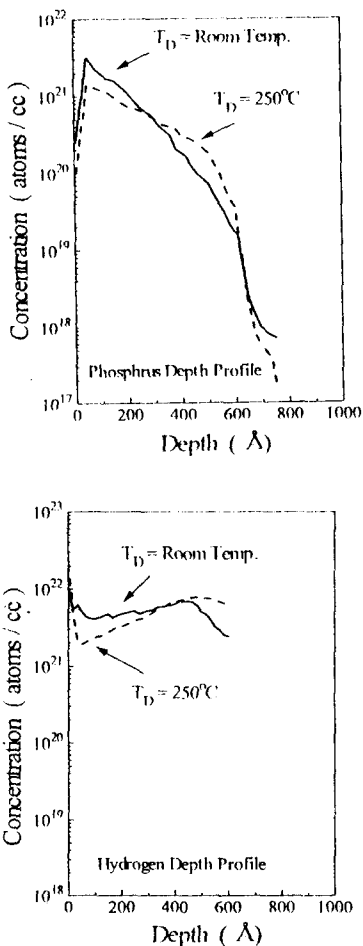
Figure 3 shows the Raman spectra of the poly-Si films doped at the two different substrate temperatures. The poly-Si film doped at room temperature has very small peak around 480 cm^{-1} which is the peak position corresponding to the amorphous phase. Whereas, the poly-Si film doped at 250 ℃ has a strong peak around 520 cm^{-1} which is the peak position corresponding to the polycrystalline phase[9].
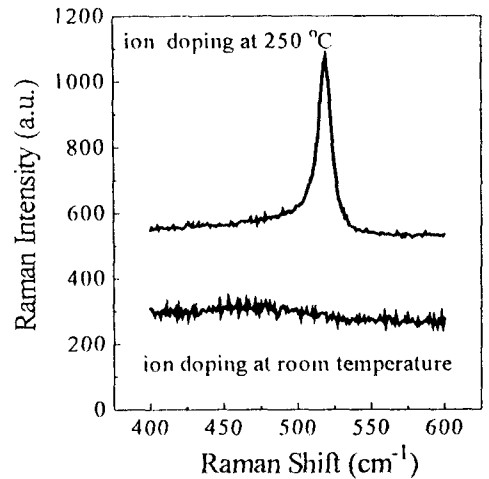

Fig. 3. The Raman intensity of poly-Si films done by the ion showering at 250℃ and room temperature

Figure 4 shows the UV reflectance spectra of the silicon films doped at the two different substrate temperatures, and those of the single crystalline silicon and starting poly-Si film for comparison. The peak intensity around 280 nm indicates the surface crystallinity of the silicon film. The crystallinity of the starting poly-Si film was similar to that of the single crystalline silicon. And, the spectral reflectance of the as-doped poly-Si film at the room temperature shows no peak, indicating the film transformed to the amorphous phase. The small crystalline peak of UV reflectance spectrum of the poly-Si film doped with the substrate temperature at 250℃ indicates that it remains in the poly-crystalline phase. It is clear that the crystallinity of the film

Fig. 2. The depth profiles of (a) phosphorous, (b) hydrogen atoms for poly-Si films after ion shower doping at room temperature and at 250℃

was degraded by the ion shower doping.

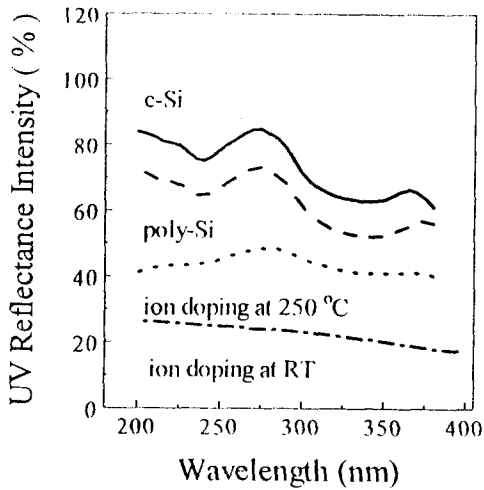
Fig. 4. The dependence of UV reflectance intensity of ion shower doped sample at RT and 250 ℃, and those of C-Si and ELA poly-Si films

Figure 5 shows the TEM bright field images of the poly-Si film, the as-doped poly-Si film, and the poly-Si film doped with the substrate at 250 ℃. The starting poly-Si film has only small amount of defects such as twins or stacking faults(Fig. 5-a). The as-doped at room temperature poly-Si film was changed to the amorphous phase with a small degree of polycrystalline phase (Fig. 5-b). However, in the case of the poly-Si film doped at 250 ℃, the structure of grains was not changed, only with intra-grain defects generated by the ion shower doping(Fig. 5-c).

The film ion-showered at room temperature has a high resistance because of its transformation to the amorphous phase. But the film doped at 250 ℃ has a low resistance since it remained in the polycrystalline phase during the ion shower doping. It is due to the reduced ion damage by the elevated substrate temperature. If the sample is annealed after ion-shower doping while no heating involved during the doping, it requires more than 400 ℃ anneal in order to obtain this
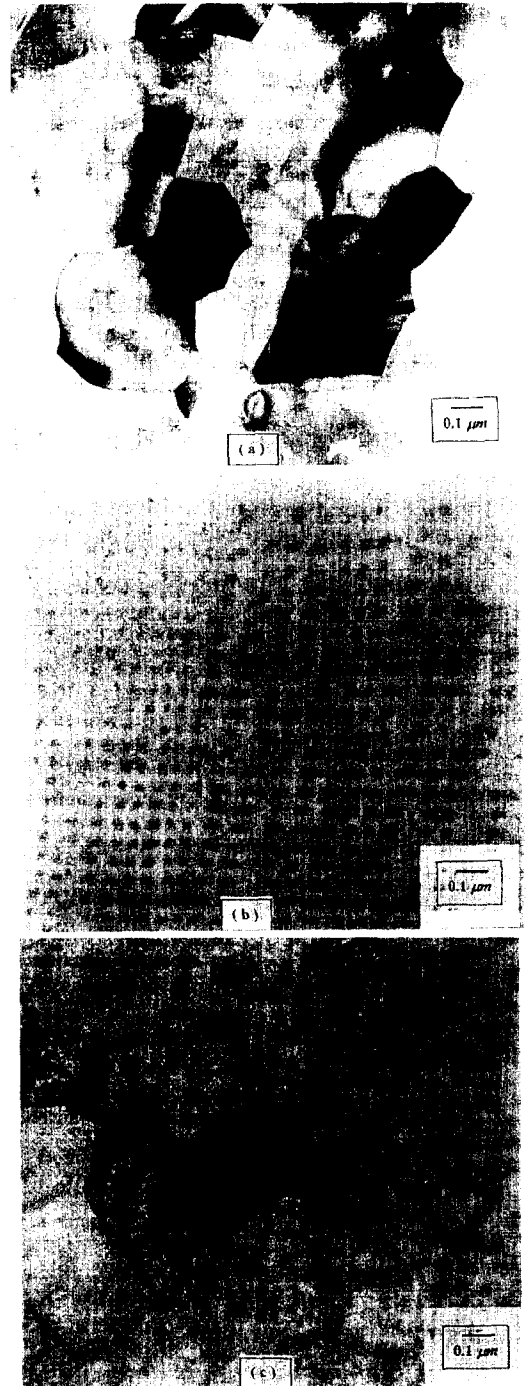

Fig. 5. Plane-view TEM images of poly-Si films; (a) Excimer laser annealed poly-Si film, (b) after ion shower doping at room temperature, 10 min, 10 kV, (c) after ion shower doping at 250 ℃, 10 min, 10 kV

degree of crystallinity.

Figure 6 shows the transconductance and transfer characteristics of the poly-Si TFT fabricated on 100×100 mm^2 substrate by the 10 kV, 10 min doping with the substrate at 250 ℃, no laser activation. The W/L of the channel was 20 μm / 20 μm, the threshold voltage around 1.2 V, the subthreshold slope 0.37 V/decade, and the field effect mobility 120 cm^2 / (V · s). The field effect mobility (μn) was obtained from the transconductance (gm) in the linear region at VDS = 0.1 V, i.e., gm = ID/VG = CiVDSμnW/L, where W/L is the ratio of channel width to channel length[10].
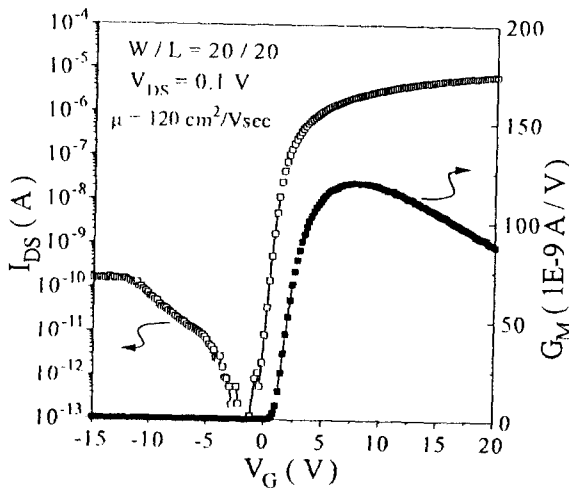

Fig. 6. Transfer characteristics of poly-Si TFT doped by the ion-showering with the substrate at 250℃

Figure 7 shows the output characteristics of the fabricated poly-Si TFT. The current crowding effect does not appear because of the ion doped poly-Si layer has low contact resistance (below 1000 $\Omega/\square$). This shows the good ohmic contact characteristics of the elevated temperature ion showering doping with the elevated substrate temperature, especially, no current crowding effect.

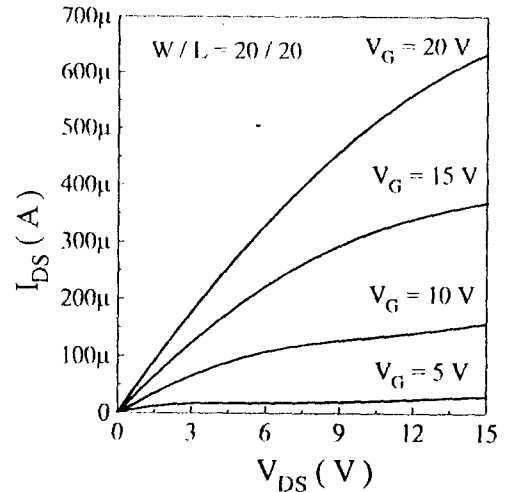## 4. Conclusion

We have investigated the effect of the ion

Fig. 7. Output characteristics of poly-Si TFT doped by the ion-showering with the substrate at 250℃

shower doping at the elevated substrate temperatures. The sheet resistance of the doped poly-Si films was decreased from 7×10^6 $\Omega/\square$ to 700 $\Omega/\square$ when the substrate temperature was increased from room temperature to 300 ℃. This low sheet resistance is due to the remaining of the polycrystalline phase and high activation of dopants. It seems that the substrate temperature of 250 ℃ contribute to the reduced ion damage of the poly-Si films and activate the dopants during the ion shower doping. And, it has been shown that formation of sources and drains by the ion shower doping at 250 ℃ is very useful for the fabrication of the poly-Si TFTs. This technique enables us to eliminate the activation annealing process.

Acknowledgment

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