Ultra low sheet resistance on poly silicon film by Excimer laser activation

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Abstract

In this study, we performed excimer laser activation on Phosphorus or Boron-doped a-Si (amorphous silicon) film. We've got a very low sheet resistance (Rs), Rs was 60 ohm/sq. with phosphorus doping and was 65 ohm/sq. with boron doping at each optimized laser irradiation condition. We've found Rs on activated thin film showed an unprecedented behavior in both cases, because Rs had a strong dependency on the crystallinity of the activated Si film.

1. Introduction

As dimensions of VLSI (very-large-scale-integrated) devices continue to decrease, the main challenge in the area of junction formation involves decreasing the junction depth [1] while simultaneously decreasing the sheet resistance. [2] In order to meet these requirements, researchers have devised activation methods that can anneal the doped layer intensively for a short duration. Though rapid thermal annealing (RTA) is effective in obtaining low resistivity, it also results in redistribution of highly diffusive dopants in Si such as boron. [3] Laser annealing has been developed as an alternative to RTA to repair the damage from ion implantation and to activate the dopants. [4-6]

At the same time, Si thin film such as a-Si or poly-Si (polysilicon) on insulating substrates, SOI (silicon on insulator), or SiOG (silicon on glass) has become attractive for flat panel displays and as a system on panel applications. In these applications, high-performance junction formation is required as mentioned above, as well. Therefore, the effect of laser activation on thin films of silicon such as single-crystal Si or poly-Si is of much interest.

This paper reports and discusses the activation behaviors of phosphorus-implanted amorphous silicon film and boron-implanted amorphous silicon film irradiated by excimer (XeCl) pulsed laser, comparing these with that of the RTA method

2. Experiment

Using ion beam deposition (IBD) [7], 50nm-thick a-Si was deposited on quartz wafers. During deposition, the pressure was kept at 0.1 mTorr, and the Ar ion beam was generated by an rf gun operated at 600V, 300mA. After a-Si deposition, dopant ions were injected by ion implantation. The accelerating voltages were 21keV for phosphorus injection and 10keV for boron injection, and the doses was 5E15 /cm^2. To this doped a-Si as a precursor material, we performed laser annealing for the dopant activation.

For laser activation, we used a pulsed (308nm) XeCl laser with a pulse duration of 160ns. In order to investigate the effect of the laser activation energy and shot number on the resistivity and crystallinity, we irradiated the film from 1 to 10 shots using laser energies ranging from 200mJ/cm^2 to 750mJ/cm^2. As a comparison, additional RTA activation was performed. 50nm amorphous Si samples were annealed using RTA for 180 sec. at 800^{o}C, 850^{o}C, and 900^{o}C, respectively.

A 4-point probe (4-PP) was used to measure the sheet resistance of each activated sample. The surface reflectance of the films in the UV range [8] was plotted into a curve, under which the integrated area from 240nm to 320nm (a characteristic Si crystalline peak) was calculated to indicate the crystallinity. With transmission electron microscopy (TEM) analysis and scanning electron microscopy (SEM) analysis, we observed the micro-structural features of the laser-annealed Si such as crystal planes and grain size. SIMS was used to measure the dopant concentration profile into the silicon layer.

3. Results and discussion

Figure 1(a) shows laser activation energy dependence of the sheet resistance (Rs) under single-shot irradiation. For phosphorus-doped sample, at laser energies below 450mJ/cm^2, as the energy increases, the Rs decreases. At 450mJ/cm^2, the minimum value of Rs, which is 83 ohm/sq., was reached. At laser energies above 450mJ/cm^2, Rs increased again and then was saturated. Boron-doped sample shows similar behavior, in which at 500mJ/cm^2, the minimum Rs value, around 90 ohm/sq. was acquired.

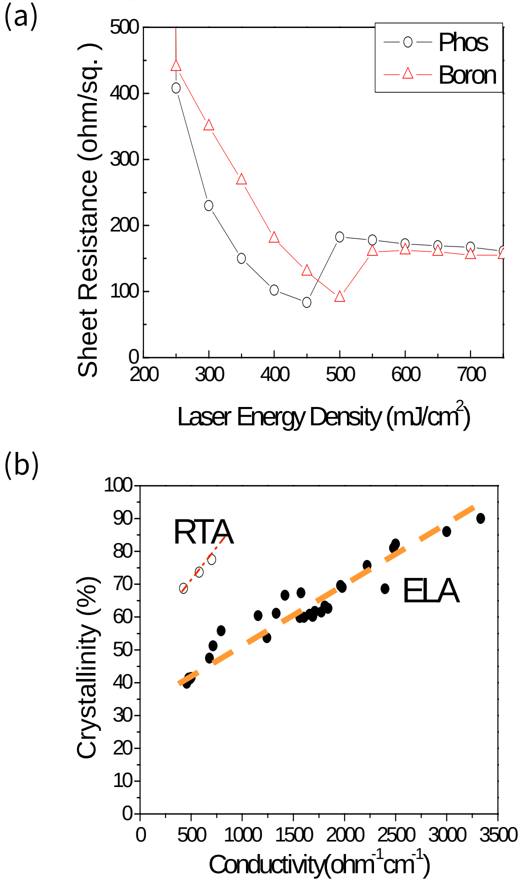

Figure 1. (a) Energy dependence of Rs and Crystallinity (circles for Phosphorus doping, triangles for Boron doping) (b) Crystallinity dependence of conductivity for phosphorus-doped sample (closed circles for ELA, open circles for RTA)

On the figure 1(a), the Rs didn't monotonously decrease as the energy increased, but at the energy densities over 450mJ/cm^2 slightly increased and then saturated. The reason on it can be explained in terms of the crystallinity dependence on the laser energy density.

$$\sigma = N_a \cdot q \cdot \mu \qquad (1)$$

The resistivity of the material is basically determined by the equation (1), in which σ is conductivity, N_a is average carrier concentration, q is electric charge, and μ is mobility. The mobility (μ) is largely decided by the degree of free carrier scattering at point or line defects such as vacancies, grain boundaries, or dislocations. Among these, it is well-known that the grain boundary is the most critical factor for the Rs value. [9] The crystallinity from UV reflectance analysis is physically related with density of dangling bonds including those in grain boundaries. In addition, we confirmed that the transition of grain size obtained by SEM for the change of ELA condition is identical to that of the crystralliny measured by UV reflectance analysis. For instance, at the ELA condition with the maximum grain size – for phosphorus-doped or boron-doped case, around 0.2 µm -, the UV crystallinity also showed the maximum value. Figure 1(b) is the graph showing the relation between the conductivity and the crystallinity for the phosphorus-doped sample activated at various energies with various shot numbers. On that graph

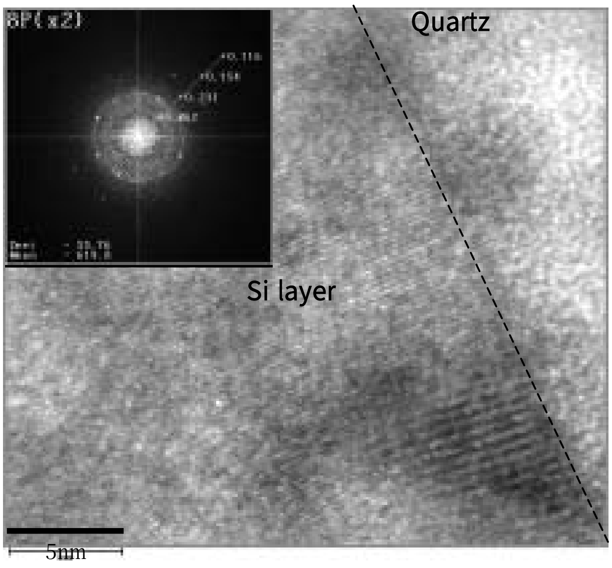

Figure 2. TEM image of the bottom region of doped silicon activated at 250mJ/cm^2. The inset is diffraction pattern in that region. (dashed line is boundary between Si and substrate)

we can confirm that the conductivity is almost proportional to crystallinity.

In terms of activated dopant density (N_a), we might think that N_a values would be different at each activation condition, because the depth of activated region from the Si film surface could be different, as the activation condition changed. This point was confirmed by figure 4 indirectly. However, in Figure 1(b), all the points are almost on the same straight line irrespective of the energy density and shot number, which can mean N_a values of samples activated under various laser energy conditions are nearly identical. Figure 2 shows a TEM image, including an inset diffraction pattern, of the lower region of phosphorus-doped silicon layer annealed at a laser energy density of 250 mJ/cm^2. We can see the crystalline lattice planes, and a diffraction pattern corresponding to poly-Si even at the minimum energy for crystallization. This means the whole depth of silicon film has undergone the crystallization. The full crystallization phenomena at higher energy densities were confirmed by additional TEM analysis. If the doped-Si undergoes crystallization, the layer can be easily activated. This means that the degree of activation and the N_a value at each performed activation condition become nearly identical. Conclusively, we speculate the reason of Rs behavior is due to the change of crystallinity according to the change of laser annealing condition. [10]

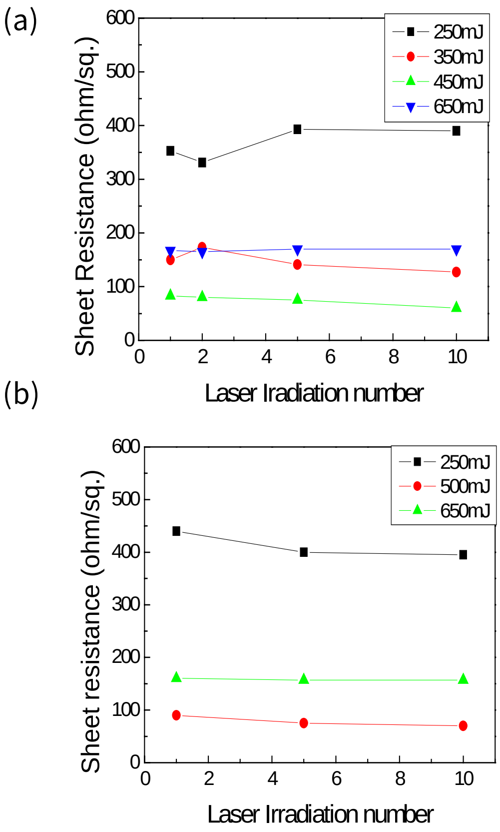

Figure 3. Effect of Multi-shot irradiation of on Rs (a) For phosphorus-doped Si film (b) For boron-doped Si film

Figure 3 shows the irradiation shot number effect on the Rs at fixed laser energy density. The minimum Rs values, 60 ohm/sq for phosphorus and 70ohm/sq for boron, were obtained, with 10-shot irradiation at each specific energy density. In the case of multi-shot irradiation, the Si film of rather higher the crystallinity shows lower Rs value. We speculate that, this is because the crystallinity was improved rather than N_a was increased, as the number of laser shot was increasing.

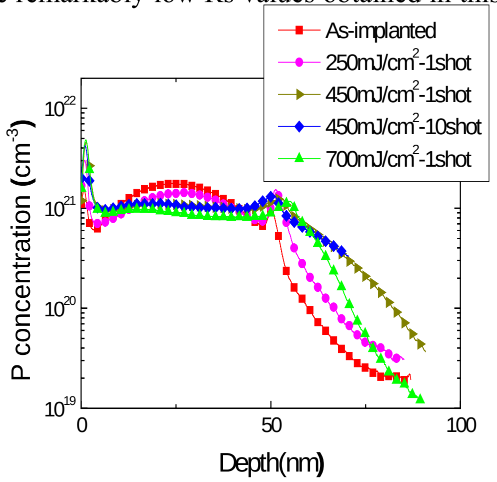

Figure 4. Result of SIMS analysis for phosphorus-doped sample : From 450mJ/cm^2-1shot the profile becomes flat

The remarkably low Rs values obtained in this study, which are comparable with that of single crystal Si doped with the same amount of dose [11], can be explained as follows. Generally, molten Si is saturated with dangling bonds of silicon atoms and the diffusivity of phosphorus atoms is faster than in solid by 10^8 times. [12] As a result, the probability of P atoms bonding with Si atoms in the liquid state is much higher than that in solid. In figure 1(b), we briefly compared the activation efficiency of ELA and that of RTA. The ELA method showed lower Rs values at the same crystallinity. In addition, we speculate that it was possible to obtain lower Rs values by realizing large grain size (~0.2μm), which is possible because of using the long laser pulse duration (160ns). The pulse duration is an important factor to control the thermal evolution and crystallization dynamics. [13-14]

From the SIMS result of phosphorus-doped sample (Figure 4), we can also expect a certain degree of lateral diffusion of dopants under complete melting conditions. We think the complete melting happened at the energy density over 450mJ/cm^2. Such lateral diffusion can result in a smoother dopant profile at the boundary between the channel and source of transistor, if we optimize the junction geometry. This is speculated to reduce leakage current in devices fabricated from these films.

4. Conclusion

Through this study, we have achieved a low Rs value of 60 ohm/sq. and 70 ohm/sq on phosphorus and boron-doped poly-Si film, respectively by realizing effective activation as well as large grain size using ELA. Laser activation of poly silicon can be effective in obtaining very low sheet resistances, and be a very promising way for ultra-low temperature TFT processes below 200°C, especially for newly emerging flexible displays using plastic substrates.

This study shows that the resistivity of the doped poly-Si films activated by laser annealing has a strong dependence on the crystallinity of the film, at a fixed dose of phosphorous and boron. The efficient dopant diffusion is observed from the near-complete-melting energy region during laser activation.

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