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Impact of a High Concentration Fluorine Layer on Carriers Transport at the Poly-Si/Si Interface

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A high concentration fluorine layer was found to grow at the poly-Si/Si interface for BF_2^+-implanted poly-Si/Si after annealing. Electrical measurements on poly-Si emitter contacted diodes showed that this layer result in a larger saturation current density J_o and a anomalous generation-recombination current of diodes. The results demonstrated that the recombination velocity of minority carrier at the poly-Si/Si interface is increased by this layer.

1. INTRODUCTION

It is well known that the poly-Si/Si interface plays an important role in the electrical properties of poly-Si emitter bipolar transistors.[1] A heavily doped p^+ poly-Si was used as emitter contacts and diffusion sources for pnp transistor. The heavily doped p^+ poly-Si films are often doped by BF_2^+ implantation. In our recent study, fluorine bubbles were found to grow at the poly-Si/Si interface in BF_2^+-implanted poly-Si/Si samples.[2] In this paper, we present results on a study of the effect of fluorine bubbles on the carrier transport at poly-Si/Si interface.

2. EXPERIMENTS

The poly-Si emitter contacted p^+-n diodes were fabricated on n-type, (100), Si wafer, with a resistivity of 0.5-2 Ω·cm. A 6300-Å field oxide was grown and patterned. Prior to poly-Si deposition, all wafers were dipped in a diluted HF solution to remove surface native oxide. Then, poly-Si films with a thickness 3500 Å were deposited in an LPCVD system at 625 °C. The poly-Si was implanted with BF_2^+, 80 Kev, 6×10^{15} cm^{-2} . The samples were annealed in the temperature range of 850-950 °C. Finally, aluminum film was evaporated and sintered at 400 °C for 30 min. in an N_2 ambient.

3. RESULTS AND DISCUSSIONS

Fig. 1 and Fig. 2 show SIMS boron and fluorine profiles in BF_2^+-implanted poly-Si/Si samples after annealing at 850-950 °C, respectively. A fluorine peak was found to develop at the poly-Si/Si interface after annealing. The fluorine peak at the poly-Si/Si interface is considered to be arised from the diffusion of fluorine atoms along poly-Si grain boundary and pile-up at poly-Si/Si interface during thermal annealing.

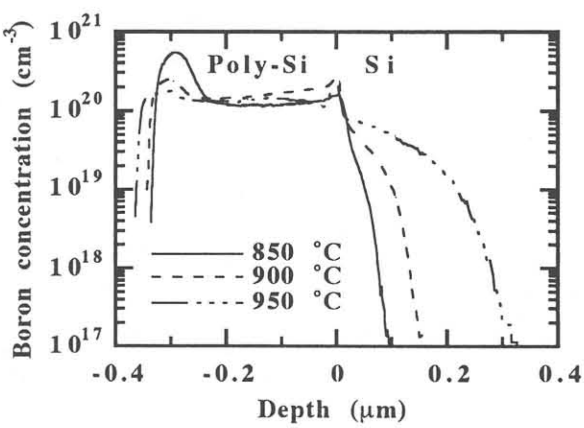

Fig. 1 SIMS boron profiles in the poly-Si/Si after annealing at 850, 900, and 950 °C for 30 min..

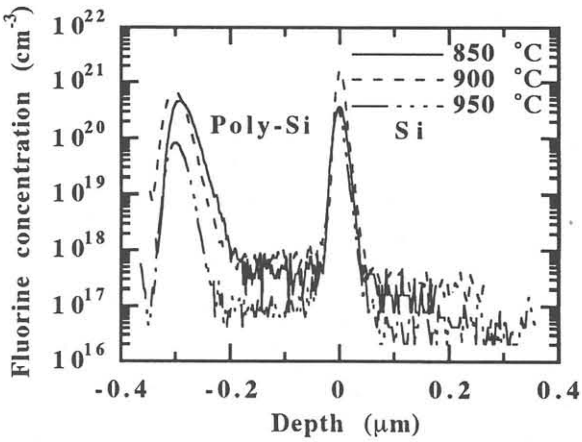

Fig. 2 SIMS fluorine profiles in the poly-Si/Si after annealing at 850, 900, and 950 °C for 30 min..

Figs. 3 (a) and (b) show XTEM micrographs of BF_2^+ as-implanted poly-Si/Si sample and sample after annealing at 850 °C, respectively. It can be seen that the poly-Si surface layer was completely amorphized by the BF_2^+-implantation to a depth of about 100 nm from the surface. The amorphous layer was recrystallized into poly-Si after annealing. The XTEM micrograph also reveals that a

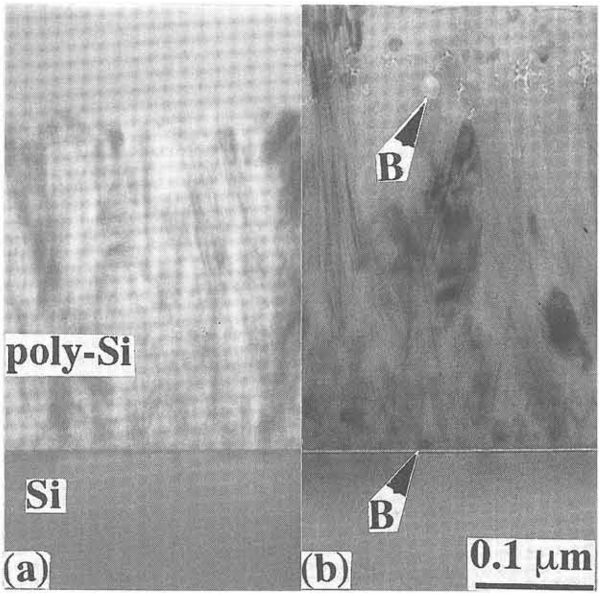

Fig. 3 XTEM micrographs of poly-Si/Si for (a) as-implanted sample (b) 850 °C, 50 min. annealed sample. B represents the bubbles and fluorine layer.

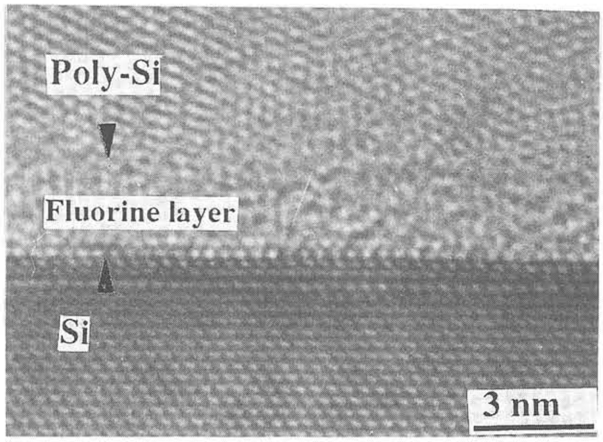

Fig.4 HRTEM micrograph of poly-Si/Si for 850 °C, 50 min. annealed sample.

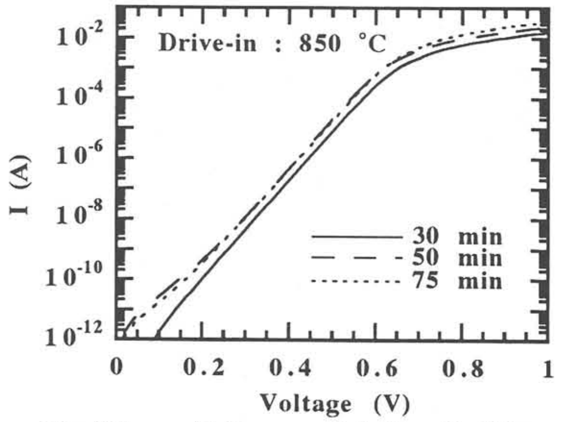

Fig. 5 Forward I-V curves of diodes with different annealing times.

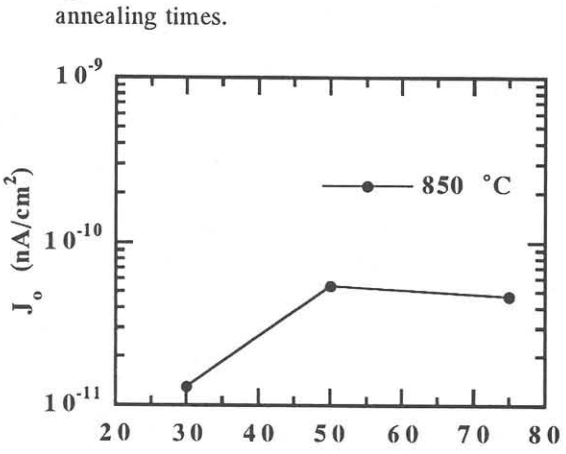

Fig. 6 J_o vs. annealing time for diodes drive-in at 850 °C

high density of bubbles was distributed in a depth range of 60-110 nm beneath the poly-Si surface. This is consistent with the SIMS fluorine profiles, as shown in Fig. 2, that a fluorine peak remains in the as-implanted fluorine peak regions after thermal annealing. The formation of fluorine bubbles is considered to be the accumulation of fluorine atoms and vacancies owing to the low solid solubility of fluorine atoms in the poly-Si.[2] It should be noted that a bright layer was found to grow at the poly-Si/Si interface after annealing. However, in our previous report, the bright layer was not present at the poly-Si/Si interface for Si-B layer as a diffusion source.[3)] Fig. 4 shows the HRTEM micrograph of this bright layer. A uniform layer with a thickness of 25 Å was present between poly-Si and Si. The thickness of this layer is dependent on the annealing temperature and time. As annealing temperature higher than 900 °C, the poly-Si films were epitaxially aligned with Si and the fluorine bubbles were formed at the poly-Si/Si interface.[2)] Moreover, the size of bubble was found to be increased with annealing temperature and time in the temperature range of 900-1000 °C. This indicated that the pile-up of fluorine atoms at the poly-Si/Si interface could break the Si-O bonds and then formation of fluorine bubbles. These results suggested that the bright layer may be a fluorine bubble layer or a high concentration fluorine layer.

Electrical measurements on poly-Si emitter contacted diodes have been performed to study the effects of this layer on the transport of minority carrier at the poly-Si/Si interface. Fig. 5 shows the forward I-V characteristics of diodes after drive-in at 850 °C with different annealing time. All diodes exhibits a forward ideality factor better than 1.02 over 4 decades. Fig. 6 shows the saturation current density J_o versus annealing times for 850 °C annealed sample. An anomalous increase of J_o with

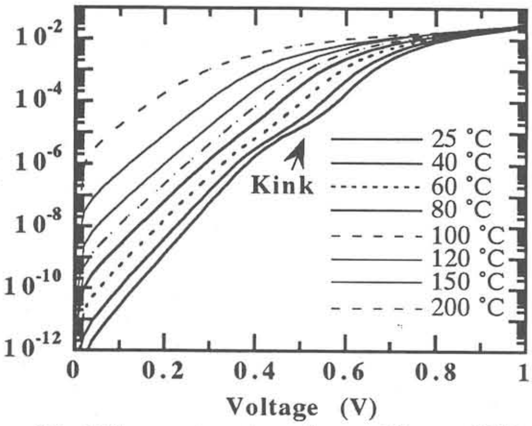

Fig. 7 Temperature dependence of forward I-V curves of diodes drive-in at 850 °C, 50 min..

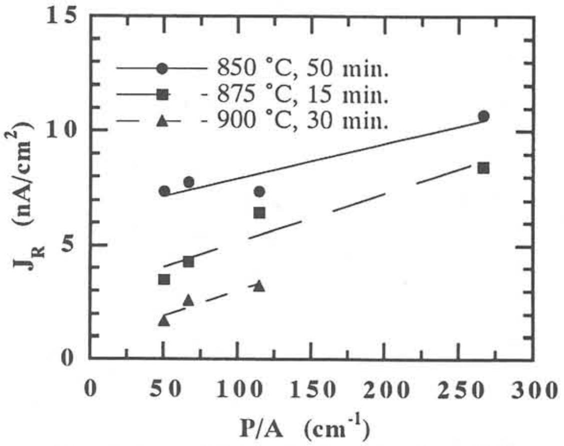

Fig. 8 J_R vs. P/A for diodes drive-in at 850, 875, and 900 °C.

annealing time was observed. In addition, as shown in Fig. 7, some diodes with drive-in temperature below 900 °C exhibit a kink in the forward I-V curves. The kink is disappeared as measurement temperature above 60 °C. It also found that the kink is caused by the increase of diffusion current in the lower forward-bias region (≤ 0.5 eV). These results indicated that a anomalous increase of J_o was present in BF_2^+ source diodes. In general, the values of J_o could be determined by several factors as follows : recombination in p^+ Si region, recombination at the poly-Si/Si interface, recombination in the poly-Si films, and recombination at the Al contact. Therefore, the increase of J_o value for BF_2^+ source diodes was considered to be caused by the increase of recombination velocity in the emitter regions. As shown in Fig. 4, a fluorine layer was present at the poly-Si/Si interface for BF_2^+-implanted poly-Si/Si after annealing. The presence of fluorine layer at the poly-Si/Si interface may lead to the increase of Si dangling bonds at the poly-Si/Si interface. Therefore, the recombination velocity of minority at the poly-Si/Si interface is increased by the presence of fluorine layer. Fig. 8 shows the reverse leakage current density J_R versus the perimeter to area ratio (P/A) for three samples, where J_R is the reverse current density of diodes measured at -5V. From the plots, the area component J_{RA} and the periphery component J_{RP} were determined. The periphery component J_{RP} of three samples are nearly the same. However, an anomalous J_{RA} component was found in diodes with annealing temperature below 900 °C. From the Arrhenius plots of Log (I_R/T^3) versus 1/T, the activation energy of reverse current at room temperature is estimated to be 0.55 eV. This indicated that the reverse leakage current is dominated by the generation-recombination current. On the other hand, an anomalous J_{RA} component in diodes with annealing temperature below 900 °C is caused by the generation-recombination current. As a thin oxide layer at the poly-Si/Si interface, it is expected that an extra voltage drop across the uniform bubble layer and band banding at its interface.[1] In addition, the surface states at the poly-Si/Si interface are increased by the presence of fluorine bubbles. On the other hand, a anomalous J_{RA} for samples A and B is considered to be caused by the generation-recombination current at the poly-Si/fluorine layer/Si interfaces. As the drive-in temperature higher than 900 °C, the generation-recombination current at the poly-Si/Si interface is reduced by the break-up of fluorine bubble layer and the epitaxial regrowth of poly-Si films.

4. CONCLUSIONS

In summary, a high concentration fluorine layer was found to grow at the poly-Si/Si interface for BF_2^+-implanted poly-Si/Si after thermal annealing. Electrical measurements of poly-Si emitter contacted diodes demonstrated that the layer play an important role for a large saturation current density and a anomalous generation-recombination current. The results demonstrated that the recombination velocity of minority carrier at the poly-Si/Si interface is increased by the fluorine layer.

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