

## The Effect of Ion Shower Doping Conditions on Electrical Properties of Amorphous Silicon and Thin Film Transistors

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In this paper, we examine the effect of ion doping conditions on electrical properties of amorphous silicon films. We relate these electrical properties to the amount of hydrogen incorporated during ion doping process by measuring the optical gaps of the films and by ion doping process simulation. By proper choice of ion doping conditions, a-Si films with conductivity as high as  $10^{-2}$  S/cm can be obtained. The effect of ion doping conditions on TFT characteristics is also examined.

### 1. INTRODUCTION

Recently there has been a lot of interest in ion doping (non-mass-separated implantation from dopant gas plasma) technique to dope source and drain regions of thin film transistors<sup>1)</sup>, since it offers several advantages over ion implantation technique such as simple machine system, high beam current, and large area implantation. One of the major disadvantages of ion doping technique is the lower conductivity obtained for the doped films compared to ion implantation. This is probably due to implantation of unwanted species such as hydrogen during ion doping, since no mass separation is employed in this case. In this paper, we present a systematic study of the effect of ion energy and ion dose on the conductivity of amorphous silicon films and relate it to the amount of hydrogen incorporated during ion doping process. We show that by minimizing hydrogen incorporation during ion doping, the amorphous silicon films with conductivity as high as that obtained by ion implantation can be produced. We also present the results of the effect of ion doping energy on TFT characteristics.

### 2. EXPERIMENTAL PROCEDURE

The amorphous silicon films used for conductivity study were deposited by PECVD technique on 7059 glass at 270°C. The film thicknesses were 500Å and 2000Å. The films were ion doped in the ion dose range  $10^{15}$  to  $10^{16}$  cm<sup>-2</sup> and at ion energies ranging from 10 KeV to 60 KeV. The conductivity was measured using carbon contacts which were painted after scribing the a-Si surface. Thus the conductivity results represent the bulk conductivity. The optical gaps of the films were determined using Tauc's plots<sup>2)</sup>. Ion doping process simulation was carried out using a computer program TRIM<sup>3)</sup>.

### 3. RESULTS AND DISCUSSION

Figure 1 shows the conductivity as a function of phosphorus ion dose for various ion energies for 500Å thick a-Si films. As can be seen from the figure, at 60 KeV ion energy, the conductivity increases with ion dose as expected, but at lower energies this trend does not follow. At 30 KeV, the conductivity increases upto a P dose of  $5 \times 10^{15}$  cm<sup>-2</sup>, and then it decreases. At even lower

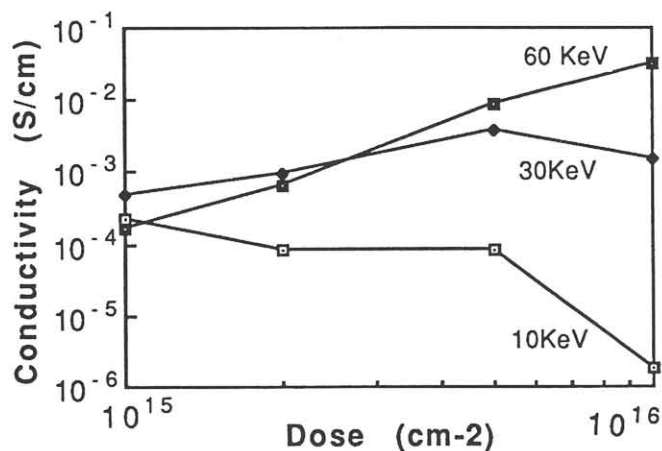


Fig.1. Amorphous silicon film conductivity as a function of P ion dose for various ion energies for 500Å thick films.

energy (10 KeV), the conductivity decreases as the dose is increased in the range of  $10^{15}$  to  $10^{16}$   $\text{cm}^{-2}$ . This can be explained as follows. In the ion-doping plasma, in addition to P ions, hydrogen ions are also present. Since hydrogen ions are lighter, their projected range is much higher than phosphorus ions. As estimated from implantation process simulation, at 60 KeV, the projected range of hydrogen, is much larger than a-Si film thickness and essentially all the hydrogen ions end up in the glass substrate. Thus the conductivity is not affected by the presence of hydrogen ions and we see an increase in conductivity value as the P dose is increased. As the implant energy is decreased, more of the hydrogen ions remains in the film. The increase in P concentration increases the conductivity, while increase in the hydrogen concentration decreases the conductivity. Because of these two competing processes, we see a conductivity maxima in case of 30 KeV implant. At 10 KeV, even higher concentration of hydrogen remains in the film and we see a continuous decrease in conductivity as the ion dose is increased. Probably the conductivity maxima lies below  $10^{15}$   $\text{cm}^{-2}$  ion dose in case of 10 KeV ion energy. To confirm the above model, the optical gaps of ion doped films were measured. The optical gap of pure amorphous silicon is 1.5 eV and it

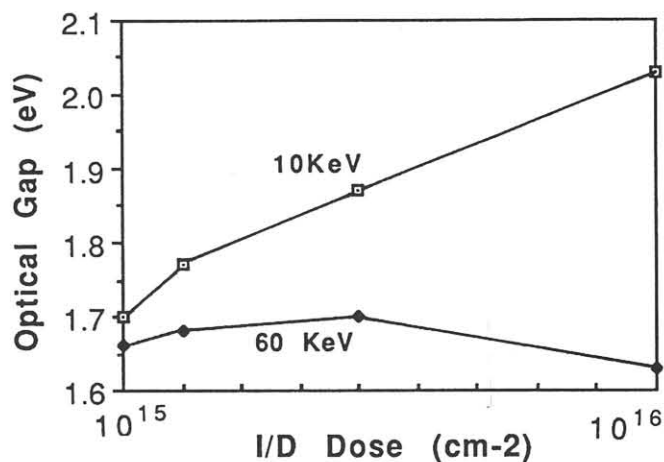


Fig. 2. Optical gap as a function of ion dose for 10 KeV and 60 KeV ion energies for 500Å thick films.

increases with increase in hydrogen concentration. Figure 2 plots the optical gap as a function of ion dose for 10 KeV and 60 KeV ion energies. At 10 KeV, the optical gap of the ion doped films increases with ion dose, indicating increase in hydrogen content, while at 60 KeV, the optical gap is nearly constant. Our model was further confirmed by the fact that at 60 KeV and  $10^{16}$   $\text{cm}^{-2}$  P dose, the conductivity values obtained by ion doping and ion implantation (no hydrogen present) are similar ( $\sim 10^{-2}$  S/cm), indicating that there is no effect of hydrogen implant for 60 KeV ion doping even at very high dose. We also note from figure 1, that inspite of same dose ( $10^{16}$   $\text{cm}^{-2}$ ), conductivity values differ by 4 orders of magnitude for 10 KeV implant (conductivity  $\sim 10^{-6}$  S/cm) and 60 KeV implant (conductivity  $\sim 10^{-2}$  S/cm), while corresponding optical gap value changed from 2.02 eV (10 KeV implant) to 1.62 eV (60 KeV implant). The similar trend in conductivity and optical gap as a function ion dose and ion energy is observed for 2000Å thick films also. The highest conductivity obtained in our ion doping experiment is comparable to the highest conductivity obtained in literature using ion implantation of PECVD a-Si films, and is atleast one order of magnitude higher than the results obtained in literature for ion doped PECVD films<sup>4,5</sup>).

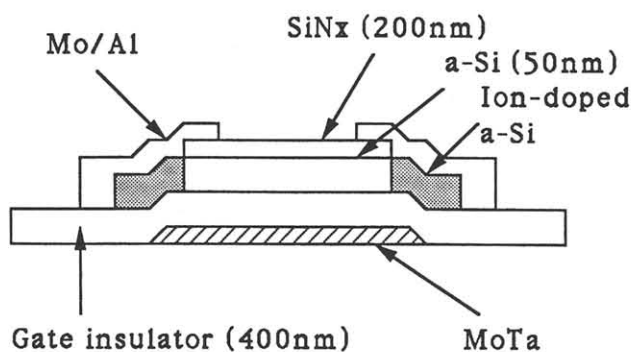


Fig. 3. Cross sectional schematic of an ion doped TFT.

Figure 3 shows cross sectional schematic of an ion doped TFT. For the ion doping P dose of  $2 \times 10^{15} \text{ cm}^{-2}$  at 10 KeV, a field effect mobility of  $0.6 \text{ cm}^2/\text{V-s}$  and  $V_{th}$  of 2.6 V were obtained. Increase in ion energy (30 KeV, 60 KeV) was found to reduce the field effect mobility as shown in figure 4, even though, as seen from figure 1, the conductivity at 30 and 60 KeV is higher than 10 KeV ion energy for  $2 \times 10^{15} \text{ cm}^{-2}$  P dose. This is probably due to incorporation of hydrogen into channel area and/or defects caused by high energy ions in top silicon nitride layer, channel area, gate insulator and source and drain regions, since as observed from our implantation process simulation, only at 10 KeV ion energy (the lowest energy used) the top nitride layer is able to completely stop the hydrogen penetration into underlying layers. Also, for high energy implants, the dopant peak lies deeper and phosphorus concentration at the surface is lower. This increases the series resistance near contacts, which also lowers the mobility. Figure 4 also shows the results of BTS studies ( $80^\circ\text{C}$ , 1800s,  $V_g = 15\text{V}$ ) for a ion doping dose of  $2 \times 10^{15} \text{ cm}^{-2}$ . The threshold voltage (before BTS) increases with increase in implant energy due to defects created by high energy ions. However, the threshold voltage shift due to BTS is reduced at higher energies because defects caused by BTS has relatively less effect since the amorphous silicon channel layer and gate insulator layer are already defective due to high energy implants. Thus threshold voltage after BTS is nearly independent of ion

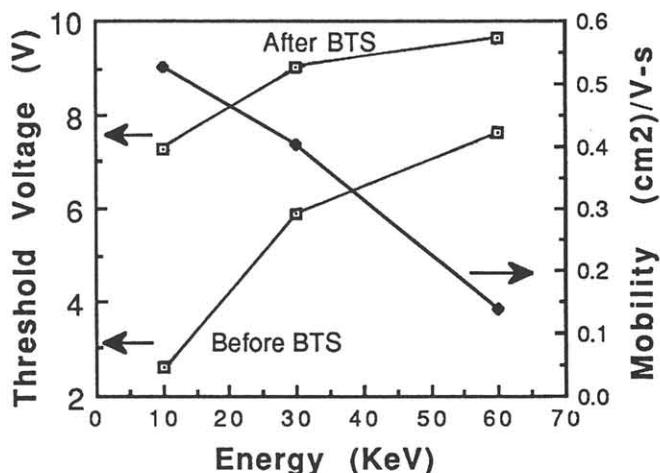


Fig. 4. Threshold voltage and mobility as a function of ion doping energy.

doping energy for higher energy implants.

#### 4. CONCLUSIONS

A wide variation in conductivity of ion doped a-Si films was observed for films subjected to various ion doping conditions. The conductivity variation is related to hydrogen incorporation into a-Si films during the ion doping process. The ion doped TFT characteristics degrade as the implant energy is increased.

#### 5. ACKNOWLEDGMENTS

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