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The Effect of Ion Doped Hydrogen on the Quality of Channel Region of a-Si TFTs

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In this paper, we examine the effect of hydrogen penetration through SiNx channel-masking layer on the quality of channel during phosphorus ion doping of source and drain regions of a-Si thin film transistors (TFTs). It was found that the quality of channel degraded at ion energies of 20 KeV or higher when 2000 Å thick SiNx was used as channel-masking layer, while no degradation of channel quality was observed up to 60 KeV when 4000 Å thick SiNx was used as channel-masking layer. These results are explained by hydrogen ion depth profiles at various ion doping energies. It was also found that H_2^+ and H_3^+ ions were responsible for channel degradation, while H^+ ions did not affect the channel quality.

1. INTRODUCTION

The ion doping technique is a non-mass separated implantation technique which implants dopant ions from a gas plasma into a substrate over a large area. Because of large area doping capability and much higher doping speed compared to ion implantation, the ion doping technique has recently attained considerable popularity in doping the source and drain regions of thin film transistors (TFTs) used in large area active matrix liquid crystal displays (AM-LCDs) [1-3]. During the doping of source and drain regions of a TFT, a deposited silicon nitride layer is used as a mask to prevent the implantation of ions into the channel region (figure 1).

During phosphorus doping of source and drain regions using the ion doping technique, the plasma is created by applying RF field to hydrogen diluted PH_3 gas, and hence the plasma contains high concentrations of hydrogen ions along with phosphorus ions. Incorporation of hydrogen ions into the source and drain regions affect the conductivity of these regions tremendously as was discussed in our earlier publications [1,4]. In addition, since the hydrogen ion are much lighter compared to phosphorus ions, they can penetrate the silicon nitride masking layer and can cause damage to the channel area of a-Si TFTs. The penetration of hydrogen ions will depend upon silicon nitride layer thickness, the implant energy, and type of dominant species such as H^+, H_2^+ or H_3^+ present in the plasma. In this paper, we examine the effect of various nitride film thickness and ion energies on the quality of channel region of an a-Si TFT subjected to an ion doping process.

2. EXPERIMENTAL PROCEDURE

Figure 2a shows the structure used for ion doping experiments. This structure is analogous to a cross section through the channel region of the TFT structure shown in figure 1. Two different thickness of silicon nitride layer, 2000 Å and 4000 Å, were used in

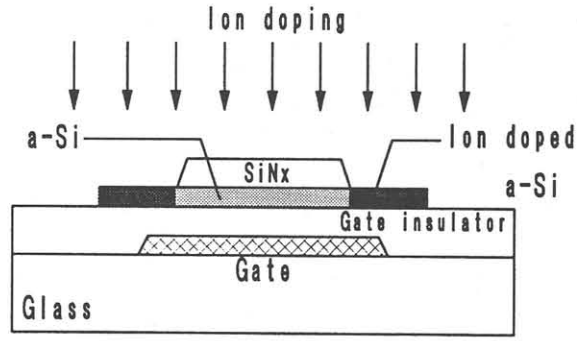

Figure 1. Typical TFT structure used for ion doping experiments

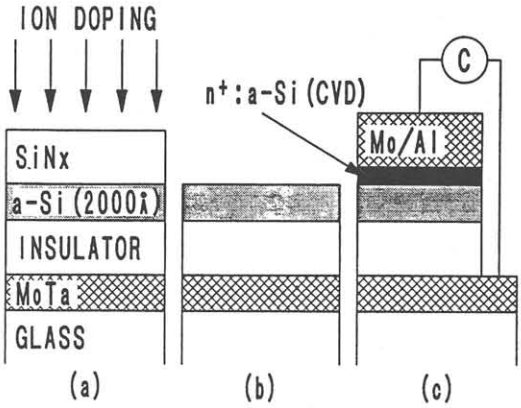

Figure 2. The process and structure of MIS samples

this study. The thickness of amorphous silicon layer (channel layer) was 2000 Å. The ion doping experiments were carried out in the range of 10 to 60 KeV ion energy at an phosphorus dose of $5x10^{15}$ cm^{-2}. After ion doping, the silicon nitride layer was removed as shown in figure 2b, and n^+ a-Si and metal electrode were deposited as contacts to the resulting MIS structure as shown in figure 2c. The capacitance-voltage experiments (100 KHz) were carried out for the structure shown in figure 2c.

3. RESULTS AND DISCUSSION

Figures 3a and 3b show the C-V characteristics for the MIS structure of figure 2c having 2000 and 4000 Å thick silicon nitride layers, respectively. As can be seen from figure 3a, for 2000 Å SiNx layer, the C-V characteristics deteriorate with increase in ion energy. At 4000 Å SiNx thickness, however, no deterioration of C-V characteristics is observed up to 60 KeV.

To explain these results, the hydrogen ion depth profiles were measured after ion doping. Figure 4 shows the depth profiles of H^+, H_2^+, and H_3^+ ions at various energies for the structure of figure 2a with 2000 Å SiNx layer. The depth profiles of figure 4 were obtained by fitting simulated depth profiles [5] for various hydrogen ions to total hydrogen concentration obtained by SIMS. Figure 5 shows the similar depth profiles when the SiNx thickness is 4000 Å. As can be seen from figure 4, at 10 KeV ion energy, most of the hydrogen is stopped by 2000 Å of SiNx. On increasing the ion energy to 20 KeV, high concentration of H_2^+ ions and some H^+ ions are incorporated into the

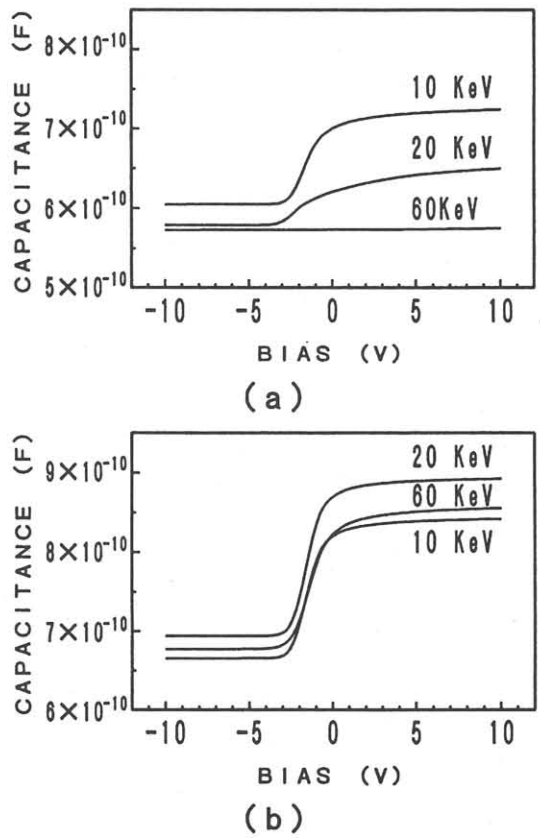

Figure 3. C-V characteristics of MIS samples for (a) 2000 Å SiNx and (b) 4000 Å SiNx

amorphous silicon layer. This results in deterioration of C-V characteristics as seen in figure 3a. We attribute the deterioration of C-V characteristics at 20 KeV to incorporation of H_2^+ ions rather than H^+ ions because H_2^+ ion concentration is higher and they are heavier compared to H^+ ions. At 60 KeV, high concentrations of H_2^+ and heavier H_3^+ ions are incorporated into a-Si. Moreover, H_2^+ ions also reach the a-Si/insulator interface. This results in flat C-V characteristics at 60 KeV as seen in figure 3a for 2000 Å SiNx layer.

When the SiNx film thickness is 4000 Å (figure 5), H_2^+ and H_3^+ are almost stopped by SiNx at all energies, while H^+ enter a-Si and reach a-Si/insulator interface only at 60 KeV. Since the C-V characteristics are not affected at 60 KeV (figure 3b), H^+ ions do not seem to contribute to damage to a-Si or a-Si/insulator interface. This is probably because of lower concentration as well as lower mass of H^+ ions.

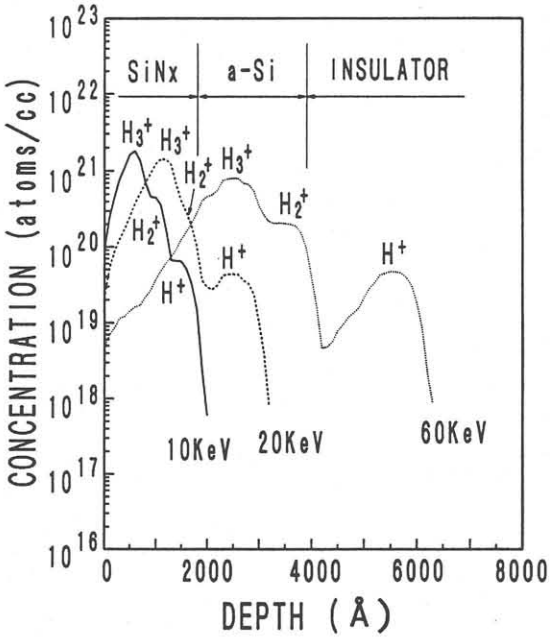

Figure 4. The depth profiles of H^+, H_2^+, and H_3^+ at various ion energies for 2000 Å SiNx

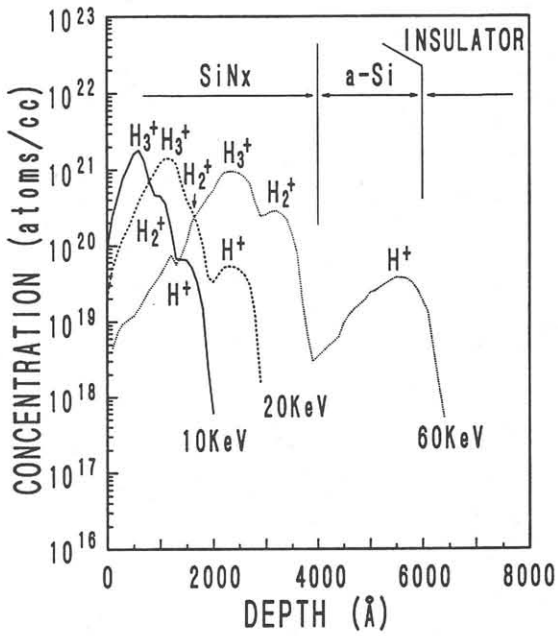

Figure 5. The depth profiles of H^+, H_2^+, and H_3^+ at various ion energies for 4000 Å SiNx

In addition, also note that even though the a-Si thickness is 2000 Å in this analysis, a quick examination of figures 3 and 4 will reveal that the above analysis is also valid for thinner a-Si films. Thus this analysis is applicable to a-Si TFTs having a channel layer thickness of 2000 Å or less.

4. CONCLUSIONS

In conclusion, we have shown that H_3^+ and H_2^+ are the main ions which affect the quality of channel region of a-Si TFTs during an ion doping process. The H^+ incorporation does not have any significant effect on the channel quality probably due to its lower concentration in ion doping plasma. Because of this, when 2000 Å thick SiNx is used as an implant mask, the channel region is damaged even at an ion energy as low as 20 KeV, whereas 4000 Å thick SiNx layer protects the channel region at an ion energy as high as 60 KeV.

5. ACKNOWLEDGMENTS

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