Dopant Activation in Ion-Shower-Doped Poly-Si

Jae-Sang Ro

Department of Materials Science and Engineering, Hongik University, Seoul, 121-791, Korea

Abstract— Abnormal behavior of dopant activation was observed in P+/B+ ion shower doped poly-Si upon post implant annealing. Phosphorous or boron was implanted by ion shower doping using a source gas mixture of PH3/H2 or B2H6/H2. Activation annealing was conducted using a tube furnace in the temperature ranges from 350°C to 650°C. Hall measurement revealed that reverse annealing occurred for poly-Si implanted with P and B, respectively. It was observed that reverse annealing starts at 550°C in P+ ion shower doped poly-Si, while at 350°C in the case of B-doping.

Keywords— Activation, Ion shower doping, LTPS, Reverse annealing, TFTs

I. INTRODUCTION

Non-mass analyzed ion shower doping (ISD) technique with a bucket-type ion source has been widely used for source/drain doping, for LDD (lightly-doped-drain) formation, and for channel doping in fabrication of low-temperature polycrystalline silicon (poly-Si) thin-film transistors [1,2,3]. Phosphorous or boron can be implanted using ion shower doping with a mixture gas of PH3 or B2H6, diluted with H2 [4]. Due to non-mass-separation nature of ISD, hydrogen atoms incorporated into poly-Si films after ion shower doping may play an important role in enhanced dopant activation and passivation of defects. Activation efficiency of dopant atoms in single crystalline or polycrystalline silicon is therefore higher for ISD than for mass-separatted ion implantation [3]. Greater electrical activation has been reported in the hydrogenated samples at lower temperatures below 600°C [5].

In the case of boron implantation, activation at lower temperatures is limited by the formation of boron-interstitial clusters easily formed at concentrations lower than solid solubility limit. The presence of mobile hydrogen atoms may assist in the breakup of boron-interstitial clusters and hydrogen effusion during annealing may create vacancies. Low energy H+ ion implantation following As implantation with low temperature annealing was reported to be effective for damage passivation and dopant activation [6]. Meanwhile, reverse annealing is well known phenomenon for B implantation into single crystalline silicon in the temperature ranges between 500°C and 600°C. We observed reverse annealing in P+/B+ ion shower doped poly-Si and report here on its behavior.

II. EXPERIMENTAL PROCEDURE

For the sample preparation SiO2 insulation layer with a thickness of 3000 Å was formed on a Corning 7059 glass substrate of 370 mm x 470 mm x 0.7 mm (length x width x thickness) by means of plasma enhanced chemical vapor deposition (PECVD). An a-Si thin film with a thickness of 500 Å was formed successively upon the insulation layer using PECVD. The substrates used were poly-Si produced by excimer laser crystallization on 500 Å-thick PECVD a-Si. The glass substrate was broken into pieces of 20 mm x 20 mm, thereby preparing a test piece. Phosphorous or boron was implanted by ion shower doping with a main ion source of P2H4 or B2H6 using a source gas mixture of PH3/H2 or B2H6/H2 as shown in Fig. 1. Activation annealing was performed in the temperature ranges from 350°C to 650°C for 30 min using a tube furnace in nitrogen ambient. Carrier concentration by dopant activation was determined by Hall measurement using a van der Paw method. A 4-point-probe was used to check the value of sheet resistance determined by Hall measurements. The as-implanted damage induced by ion shower doping and damage recovery following an activation annealing was assessed with transmission electron microscopy (TEM).

Fig. 1 Schematic diagram of ion-shower-doping system used in this work.

III. RESULTS AND DISCUSSION

Acceleration voltage was changed from 3 kV to 15 kV for P doping and from 2 kV to 6 kV for B doping. Doping time was kept constant as 1 min for all samples used in this study.
Figure 2 shows sheet resistance as a function of acceleration voltage after activation annealing. 30 min-isochronal annealing was conducted in the temperature ranges from 350°C to 650°C. As shown in Fig. 2-(a), for P-doped samples annealed at temperatures greater than 600°C the sheet resistance gradually decreases as acceleration voltage increases, while it initially decreases with acceleration voltage and increases again with acceleration voltage beyond a certain value for the samples annealed at temperatures lower than 500°C. A concentration profile of implanted atoms becomes broader and the peak concentration at the projected range gets lower as the acceleration voltage increases. An excess concentration of dopant atoms beyond solid solubility at a given annealing temperature thus becomes large as the acceleration voltage decreases. Activation efficiency is therefore higher as the acceleration voltage increases. This may explain the decrease of sheet resistance with acceleration voltage.

Meanwhile, for the samples implanted with higher acceleration voltage followed by low temperature annealing as-implanted damage by high mass ion such as P may not be sufficiently cured. This may explain the increase of sheet resistance with acceleration voltage. Figure 3 shows transmission electron microscopy (TEM) for the samples implanted with acceleration voltage of 15 kV for 1 min. Figure 3-(a) shows TEM micrographs for as-implanted sample, Fig. 3-(b) shows the one annealed at 550°C for 30 min, and Fig. 3-(c) shows the one annealed at 600°C for 30 min. TEM results indicate that implanted damage is not recovered sufficiently even for the sample annealed at 550°C.

In contrast to the case of P-doping the sheet resistance decreases as the acceleration voltage increases in B-doped sample except for the samples annealed at 650°C. Since boron is a light mass ion damage may not be generated to a significant amount. If we look at Fig. 2-(b) carefully the values of sheet resistance have an abnormal relationship with annealing temperatures. In the case of 6 kV-implanted samples the sheet resistance decreases as the annealing temperature increases.
It can thus be said that reverse annealing starts at 550°C in P⁺ ion shower doped poly-Si.

Reverse annealing is well known phenomenon for B-doped single crystalline silicon using a mass separated ion implanter. Seidel et al. reported that reverse annealing is observed in single crystalline silicon implanted with boron in the temperature ranges between 500°C and 600°C [7]. B-doped samples were observed to exhibit reverse annealing behavior as indicated in Fig. 5-(b). Reverse annealing, however, begins at lower temperatures in B-doped poly-Si samples compared to B-doped single crystalline silicon. Reverse annealing already starts from 350°C in B⁺ ion shower doped poly-Si.Unlike semiconductor processing, in which a bulk single crystalline silicon is used, LTPS-TFTs make use of a very thin poly-Si, which serves as an active layer on the top of a SiO₂ dielectric layer. Thus the structure of LTPS-TFTs is similar to silicon-on-insulator in that they both include a silicon/buffer oxide interface [8]. As the interface between the poly-Si and SiO₂ buffer layer on top of the glass substrate acts like a diffusion barrier for the Si self-interstitials, the self-interstitials generated by ion implantation tend to be supersaturated in a thin poly-Si layer. Such factors are bound to significantly affect the activation behavior of ion-implanted poly-Si. This may explain the reason why we observed reverse annealing at significantly lower temperatures in B-doped poly-Si samples. Reverse annealing seems to end at 600°C for the samples implanted with lower acceleration voltage.
As mentioned earlier reverse annealing is related to Si self-interstitials released from the ion induced damage-region [9-11]. As primary damage such as silicon self-interstitials generated by ion implantation is thermodynamically unstable, they may agglomerate themselves to form extended defects, or, they may migrate and bind with boron atoms to form boron-interstitial clusters. Once boron-interstitial clusters are produced, boron atoms become electrically inactive, thus resulting in the loss of charge carriers. As the diffusion of both boron atoms and silicon self-interstitials is required, the kinetics associated with the formation of boron-interstitial clusters would be a slow process. Based on this argument, damage recovery would be required in order to release self-interstitials for formation of boron-interstitial clusters resulting in reverse annealing. This would explain why activation efficiency becomes lower as the annealing temperature increase as demonstrated in Fig. 5-(b).
IV. Conclusions

The sheet resistance decreases as acceleration voltage increases since an excess concentration of dopant atoms beyond solid solubility at a given annealing temperature becomes small as the acceleration voltage increases with some exception for the P doped samples implanted with acceleration voltages exceeding a critical value. In this work reverse annealing was observed in P⁺/B⁺ ion shower doped poly-Si upon activation annealing. It was found that reverse annealing starts at 550°C in P⁺ ion shower doped poly-Si, while at 350°C in the case of B-doping. Compared to B-doped single crystalline silicon reverse annealing, however, begins at lower temperatures in B-doped poly-Si samples due to supersaturation of the self-interstitials since the interface between the poly-Si and SiO₂ buffer layer on top of the glass substrate acts like a diffusion barrier for the self-interstitials.

Acknowledgment

This work was partially supported by the IT R&D program of MOTIE/KEIT. [10043413, Development of Heat Treatment Processes for Fabrication of Next-Generation Flat Panel Displays and Semiconductor Devices Using Rapid Heating Methods] and by EnSilTech Corporation.

REFERENCES