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A—4—2 Effects of High Dose Rate Phosphorus Implantation into Silicon

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INTRODUCTION High current ion implantation techniques have been increasingly required in order to minimize the time spent in high dose ion implantation. When high current implantation is performed into substrates, anticipated problems such as the beam heating effect occur, that is, influence of substrate temperature rise on the activation of implanted impurities and the formation of lattice defects in both as-implanted and post-annealed samples. The present paper clarifies the effects of high current phosphorus ion implantation with varied dose rates with regard to phosphorus activation and residual damage to the silicon substrates.

EXPERIMENTS Phosphorus ions with doses above $1 \times 10^{16}/cm^2$ (typically at $3 \times 10^{16}/cm^2$) were implanted into (111), (100) and (110) CZ silicon wafers of p-type (boron-doped, 1 ohm·cm) at an energy of around 30 keV. Ion current density was varied between 10 and 500 $\mu A/cm^2$. The substrate temperature rise during implantation was measured by infra-red thermometer. The maximum temperature rise was observed when no thermal contact existed between wafer and holder. The samples used here were classified into 5 types as shown in Table 1, depending on temperature rises during implantation. In this table, A and A' samples were prepared in order to observe the effect of dose rate under the same temperature rise. After implantation, samples were annealed in dry N_2 between 400-1200°C. Hall effect and sheet resistivity measurements were carried out to obtain isothermal and isochronal annealing characteristics of carriers as well as to determine their depth distribution profiles. Transmission electron microscope (TEM) and reflection electron diffraction were used to observe residual damage in as-implanted and post-annealed samples.

RESULTS A typical example of carrier characteristics produced by a 30 min isochronal anneal measured as a function of the dose rate is shown in Fig. 1. In this figure, fraction activated of vertical axis means the ratio of the number of carriers at each temperature to that of 1200°C. Some features deduced from this figure are as follows: (1). For all the samples, the rapid increase of carriers is obvious at temperatures below 1000°C; they saturate above 1000°C. This phenomenon for annealing temperatures below 1000°C is attributed to the phosphorus atoms in the peak of implanted profiles exceeding the solid solubility. At 1100°C, complete activation was obtained at annealing times above 10 min for all the samples. (2). The fact that both A and A' samples show nearly the same annealing behavior suggests that dose rate has no effect when temperature rise is the same during implantation. (3). Annealing behavior of B and C exhibit reverse annealing stages between 500 and 700°C, in contrast to the result of monotonic recovery of A and A'. The phenomena of (1), (2) and (3) were equally observed in (100) and (110) wafers.

Next, residual defects and damage were investigated in these samples. The main results obtained were as follows: (1'). For samples A, A' and B, the as-implanted layers showed amorphous layer formation in contrast to the recovery result into single crystals of C and D samples. (2'). Although TEM observations showed apparently the same defect formation for all samples annealed below 1000°C, their depth distribution varied extremely between each samples.

Namely, two characteristic results of A, A', B and C after annealing at 800°C for 30 min and of as-implanted D sample were as follows: (2'-1). Only dislocations were observed in A, A' and B from surface to 1000 Å depth. Since there was little difference in the density and nature of defects between A and A', the effect of dose rate is not observed in this case contrary to the defect increase result reported by Crowder[1]. While, in addition to the dislocations, dislocation loops and rod-like defects remained in C and D. Those defects were distributed deeper than dislocations. The existence of deeper defect is consistent with recent backscattering data obtained in high dose implantation[2]. The deepest defect and the highest defect density were observed in D. (2'-2). The appearence of rod-like defects in C and D probably had a strong connection with the above mentioned reverse annealing phenomenon. The rod-like defect density was maximum in (110) samples, suggesting that they occur easily on (110) planes.

(3'). When annealing was carried out at temperatures higher than 1000°C, dislocation networks were formed as already reported in high dose phosphorus implanted samples[3]. The density of networks increased in the order of sample A' to sample D, as shown in Fig. 2, in accordance with the result of the order of secondary defect density of (2'-1). However, it has already been verified that these dislocation nets have no effect on junction characteristics[4], provided outside dislocations are not generated from implanted areas through wet O_2 annealing.

<u>CONCLUSION</u> The effect of high dose rate implantation on phosphorus activation and residual damage was observed in connection with temperature rise. Our results show that dose rate, by itself, is not responsible for increase in defect density caused by temperature rise during implantation.

<u>REFERENCES</u> 1). B. L. Crowder: Proc. US-Japan Seminor on Ion Impl. in Semicond. ed. by S. Namba, 1971, p.63. 2). L. Csepregi et al.: Appl. Phys. Lett. 29, 645 (1976). 3). T. Ikeda et al.: Proc. 6th Conf. SSD, Tokyo, 1975, p.311. 4). T. Tokuyama et al. : J. Japan Soc. Appl. Phys. 44, 596 (1975).

Table 1. Sample classification

Sample	Dose rate ($\mu A/cm^2$)	Temp. rise during implantation (°C)
A	10	r.t. - 150
*A'	150	
B	50	250 - 350
C	130	500
D	500	800

*A' was implanted intermittently with a duty cycle of 1/40.

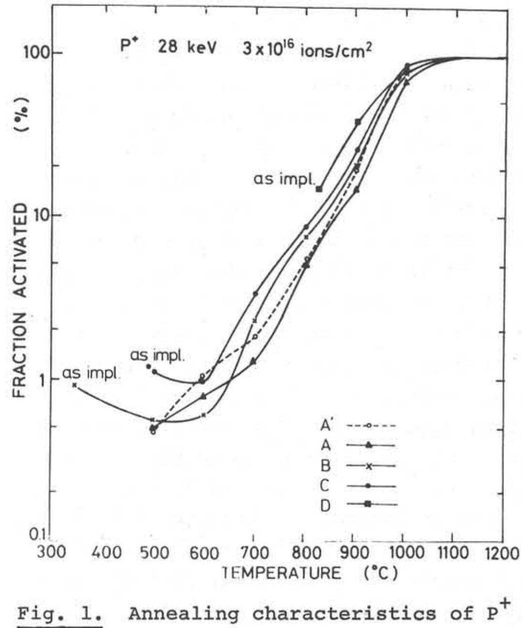

Fig. 1. Annealing characteristics of P^+ implanted Si as a function of dose rate.

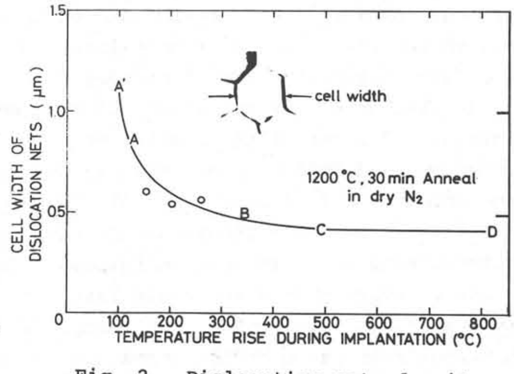

Fig. 2. Dislocation nets density as a function of dose rate.