Study on the Influence of Implant Dose Rate and Amorphization for Advanced Device Characterization

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ABSTRACT

Different dose rates of implant can lead to different amorphous layer thicknesses for amorphizing implants and may influence device performance. In addition, it has to be noticed that the batch type spot-beam was proved as divergent beam with large angle divergence which is different from single wafer spot beam and also takes into consideration by both bare wafer and also real device leanings. In the present study, the interaction between ion beam parameters related to beam scanning architectures (single-wafer spot and ribbon beams) and process results dependent on dose rate and amorphization effect will be evaluated for the effect on thickness of amorphous layer, damage, and electrical properties for advanced device.

Keywords: Dose Rate, Amorphization

INTRODUCTION

The variation of wafer scan mechanisms and shapes could contribute to measurable variation on process and device performance through affecting amorphous layer formation, defect generation and active dopant distribution [1,2]. One-dimensional (1D) mechanical scan coupled with ribbon beam and two-dimensional (2D) scan coupled with spot beam are two primary scan mechanisms utilized for high-current implanter for advanced semiconductor technology development. A ribbon beam is typically taller than wafer diameter and features a high aspect ratio (height vs width) of 4:1 or more; spot beam, differently, is shorter than wafer diameter and has an aspect ratio about 2:1. For a 1D scan, the wafer sweeps through the stationary ribbon beam horizontally back and forth until a desired and uniform dose is reached; for a 2D scan, in additional to sweeping the wafer across the stationery spot beam horizontally back and forth, the wafer also translates in vertical direction after each horizontal scan is completed. The different characteristics of 1D and 2D scan pose the risk of the variations on process through affecting dose rate, dwell time and angle uniformity. Ribbon beam has smaller ion flux density than spot beam at same beam current due to its larger effective implantation area, which affects dose rate. For a same dose, 1D scan has lower scan speed/frequency than 2D scan, which affects both dwell time and dose rate. Tall ribbon beam could have higher divergence angle than spot beam because of beam tuning, which affects angle uniformity. The mentioned variables contribute to the disparity of device performance and should be well controlled in process matching. Previous literatures of dose rate effects have shown dependencies on various implant parameters such as beam current [3] and differences between spot beam and ribbon beam implanters due to different dose rates and self-annealing effect [2,4]. Different dose rates of implant can lead to different amorphous layer thicknesses for amorphizing implants [5] and may influence device performance. In addition, it has to be noticed that the batch type spot-beam was proved as divergent beam with large angle divergence which is different from single wafer spot beam and also takes into consideration by both bare wafer and also real device leanings in the present study.

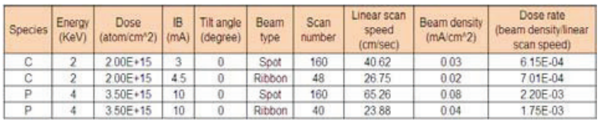
EXPERIMENTAL

Both bare and structure wafers were implanted on a single-wafer, high-current implanter which was designed to be operated interchangeably with 1D mechanical scan with ribbon beam and 2D mechanical scan with spot beam for advanced devices. The generated ribbon beams feature a near-rectangular projected shape towards wafers surface with a height slightly more than 300 mm and a width about 80 mm; the spot beam has a near-elliptical projected shape with major axis length about 150 mm and 80 mm. The normal vacuum level of implantation process is under 1E-5 torr. The implantation condition performed in the present study are carbon 2keV 2E15 at/cm2 with 0^o tilt angle and phosphorus 4keV 3.5E15 at/cm2 with 0^o tilt angle. For bare wafers, transmission electron microscopy (TEM) was also used to check the thickness of amorphous layer after implantation. For structure wafers, an advanced mass production process flow was used for NFET SRAM device performance check with the above implant conditions processed in S/D area. The detail ion beam condition and the influences on electrical properties are both discussed in the present study.

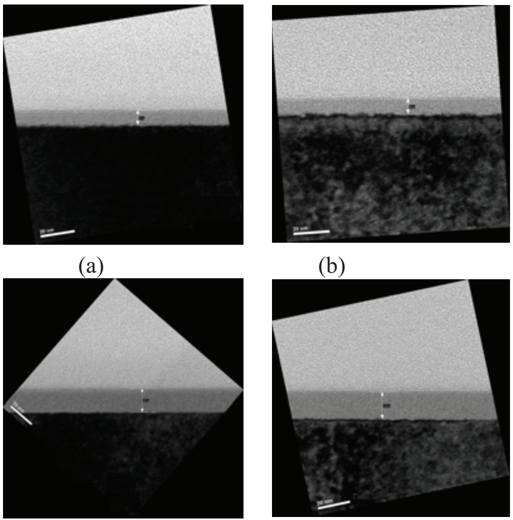
RESULTS AND DISCUSSION

Table 1 compares the parameter of 1D and 2D scan and profile information of C-2K2E15 and P-4K3.5E15 beams which are used in the present study. Instantaneous dose rate and average dose rate should be taken into consideration when referring to the influence on electrical device performance by damage accumulation and relaxation during an implant process. For carbon specie, the instantaneous dose rate of 1D-ribbon beam is slightly higher than 2D-spot beam (<20% difference). For phosphorous specie, the instantaneous dose rate of 1D-ribbon beam is slightly lower than 2D-spot beam (<15% difference). Previous study revealed that the key differences between the spot and ribbon beam single-wafer implants are the beam density and fast-scan duty cycle [2]. The former-designed spot beam system factor of ~15 to 20 times higher ion flux than ribbon beam system due to the size of the spot beam is much smaller than the spot beam used in the present study. On the other hand, the fast-scan duty cycle was significantly smaller for the former-designed spot beam than ribbon beam systems. In the present study, the same instantaneous and average dose rates for 1D and 2D implants are due to the sum of beam areas, beam current densities, and duty cycles are close. Fig. 1(a) and Fig. 1(b) show the TEM micrographs of blanket wafer C2K spot and ribbon beams. The same amorphization thickness (87 Å) was obtained. Fig. 1(c) and Fig. 1(d) show the TEM micrographs of blanket wafer P4K spot and ribbon beams. The same amorphization thickness (162 Å) was also obtained. From the above TEM results, similar ion-cascade, damage accumulation properties, and self-annealing effects can be predicted and should be taken into consideration when applying different usages on electrical devices.

Table 1: Implant beam condition comparison for C2K and P4K



Species	Energy (KeV)	Dose (atom/cm^2)	IB (mA)	Tilt angle (degree)	Beam type	Scan number	Linear scan speed (cm/sec)	Beam density (mA/cm^2)	Dose rate (beam density/linear scan speed)
C	2	2.00E+15	3	0	Spot	160	40.62	0.03	6.15E-04
C	2	2.00E+15	4.5	0	Ribbon	48	26.75	0.02	7.01E-04
P	4	3.50E+15	10	0	Spot	160	65.26	0.08	2.20E-03
P	4	3.50E+15	10	0	Ribbon	40	23.88	0.04	1.75E-03

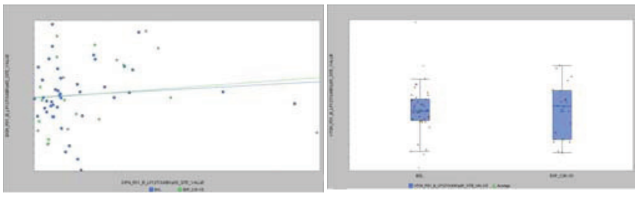


(a) (b)

(c) (d)

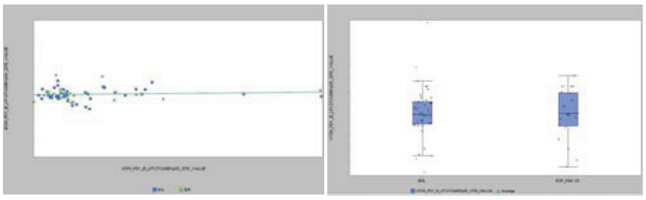
Fig. 1: TEM images of as-implanted spot and ribbon beams for (a) C2K-spot, (b) C2K-ribbon, (c) P4K-spot and (d) P4K-ribbon

Fig. 2 represents the device performance comparison for C2K spot and ribbon beams. Fig. 2(a) shows the Ion/Ioff universal curve and the trend is comparable. Fig. 2(b) also shows the comparable threshold voltage for both spot and ribbon beams. Fig. 3 represents the device performance comparison for P4K spot and ribbon beams. Fig. 3(a) shows the Ion/Ioff universal curve and the trend is comparable. Fig. 3(b) also shows the comparable threshold voltage for both spot and ribbon beams. Previous study indicates the amorphization threshold is technically defined as the dose "when the number of displaced atoms in a unit volume reaches the atomic concentration (i.e. all atoms are removed). As a rule of thumb, for medium-to-heavy implants in silicon, this dose is a few times E14 ions/cm^2." [6]. In the present study, the dosage of both C2K and P4K implants are above amorphization threshold (E15 level) and therefore the amorphization effect for both spot and ribbon beams are the same to device performance. This phenomenon can also be proved from the TEM results in Fig. 1. To be concluded, both the over-amorphization threshold spot and ribbon beams can be applied into the advanced device application with the same electrical performance due to the same instantaneous and average dose rates for 1D and 2D implants with the same sum of beam areas, beam current densities, and duty cycles.



(a) (b)

Fig. 2: Electrical device performance after C2K spot/ribbon beam implantations. (a) Ion/Ioff and (b) Threshold voltage.



(a) (b)

Fig. 3: Electrical device performance after P2K spot/ribbon beam implantations. (a) Ion/Ioff and (b) Threshold voltage.

CONCLUSIONS

Different ion beams combined with scanning architecture will impact the process performance of high-current implants, where the diffusion and activation of dopants are directly dependent on the as-implanted conditions. The as-implanted amorphization quality will directly influence the device performance after annealing process due to the difference of activation and implantation damage recovery. The present study provides a manageable way to match single-wafer spot and ribbon ion implantation beams with similar damage accumulation and final amorphous layer thickness for over-amorphization threshold implants. The comparable electrical device performances can be thus obtained.

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