Implant Damage Studies with Different Implant Temperature by Spot and Ribbon Beam

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Abstract. Wafer temperature during implant has a dominate effect on the amorphous layer thickness and post anneal residual defects which can result in difference in device performance and difficulties in tool matching between different implant systems, namely batch type vs. single wafer implanter and spot beam vs. ribbon beam system. Although the implant temperature set point can be well defined and controlled, the instantaneous temperature on wafer during implant is quite complicated interactions among beam shape, dose rate, duty cycle and cooling system to the behavior of defect generation and dynamic annealing. A batch system, iStar, and a single wafer system, iPulsar, which delivers both spot beam and ribbon beam with cold implant capability were used to study the effect of implant temperature to the post anneal residual defects by BF2 15keV $3x10^{15}$ cm^{-2} implant after 850°C/ 30s anneal. Measurements from Rs, SIMS, plane view TEM are compared and analyzed. The results by ribbon beam and spot beam are also compared.

Keywords: cold implant, dislocation loops, dose rate, spot beam, ribbon beam, BF2 Implant, EOR, 2^{nd} Fluorine Peak.
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INTRODUCTION

Ion implantation technology has been used in semiconductor device fabrication for many years. Device sensitivity and difficulty for process match between different implanters system, especially between spot beam and ribbon beam systems have been reported [1]. Understanding such sensitivity is critical to maintain device performance when different type implanters are used. Device matching at different system requires careful consideration in many areas like implant angle, energy contamination level, dose rate, and wafer temperature effects. Recently, a lot of attention has been put on sub-zero implant as additional knob for process control in meeting advance device stringent requirement on leakage currents and other device parameters affected by the damage formation and subsequent annealing. This study concentrates in comparing blanket wafer implant damaging between spot beam and ribbon under different implant temperature with BF2 15keV $3x10^{15}$ cm^{-2}, followed by 850°C, 30s anneal. Rs, SIMS, X-S & P-V TEM are analyzed to study the dopant distribution & defect formation.

EXPERIMENTAL

Wafers were implanted on iStar (batch type) at room temperature and iPulsar, a spot and ribbon beam two-in–one single wafer system, at temperature from room temperature down to -50°C as shown in Table_1. All the samples were implanted at same beam current, scan speed and beam size except those specified otherwise. The annealed condition are fixed at 850°C for 30sec in N_2 ambient.

Results & Discussion

All annealed samples were sent to SIMS and TEM as shown in FIGURE-1 after Rs were measured. From SIMS analysis, 2^{nd} peak of boron and fluorine were found in those higher implant temperature cases at depth around 300Å and gets deeper as the 2^{nd} peak concentration (boron or fluorine) decrease depending on the thickness of the amorphous layer as reported by M. Ameen et al. from dose rate study [2]. Interestingly, the Rs, as summarized in TABLE-1, were increased initially as the 2^{nd} fluorine peak decreased by changing the chiller temperatures and implanted with spot beam or ribbon beam. These tests also demonstrated that active cooling is critical in controlling the wafer temperature. Those cases without using backside gas to conduct heat showed a high level of dislocation loops from plane-view TEM (a) (b) in Figure_1. As the 2nd fluorine peak lowed to a level, the density of dislocation loops dramatically reduced, to a point, the Rs trend reversed and started to decrease as the implant temperature further decreased. Another interesting finding is the 2nd boron peak which was also reported other reports [1, 11]. These 2nd boron peaks, as shown in Figure_1-d, were found at a/c interface and slightly deeper than 2nd fluorine peaks. This 2nd boron could still be observed in the case at the lowest implant temperature tested where no 2nd fluorine peak was observed. This suggests that this 2nd boron peak should not be from F-B chemical interaction [5].

Notatation & Split	System	ESC BSG	Chiller Temp.	Beam Size	Scan Speed	Rs Mean
Spot NBG 20C	iPulsar B	off	20°C	X 1	X 1	428.45
Spot NBG -20C	iPulsar B	off	-20°C	X 1	X 1	442.51
Spot 5C	iPulsar B	On	5°C	X 1	X 1	464.76
Spot -10C	iPulsar B	On	-10°C	X 1	X 1	450.74
Spot -20C	iPulsar B	On	-20°C	X 1	X 1	443.02
Spot HDA -20C	iPulsar A	On	-20°C	X 1/2	X 1	442.87
Spot HD -20C	iPulsar B	On	-20°C	X 1/2	X 1	440.82
Spot HDA80 -20C	iPulsar A	On	-20°C	X 1/2	X 1/2	434.36
Spot HDA -40C	iPulsar A	On	-40°C	X 1/2	X 1	428.74
Spot HDA -50C	iPulsar A	On	-50°C	X 1/2	X 1	427.61
Ribbon NBG 20C	iPulsar B	off	20°C	X 1	X 1	422.92
Ribbon NBG -20C	iPulsar B	off	-20°C	X 1	X 1	431.14
Ribbon -10C	iPulsar B	On	-10°C	X 1	X 1	474.89
Ribbon -20C	iPulsar B	On	-20°C	X 1	X 1	463.67
iStar Spot RT	iStar (Batch)	n/a	20°C	X 1	X 1	460.72

TABLE 1. Notation & Rs results: Split conditions, notation used in the following figure and Rs results are summarized.

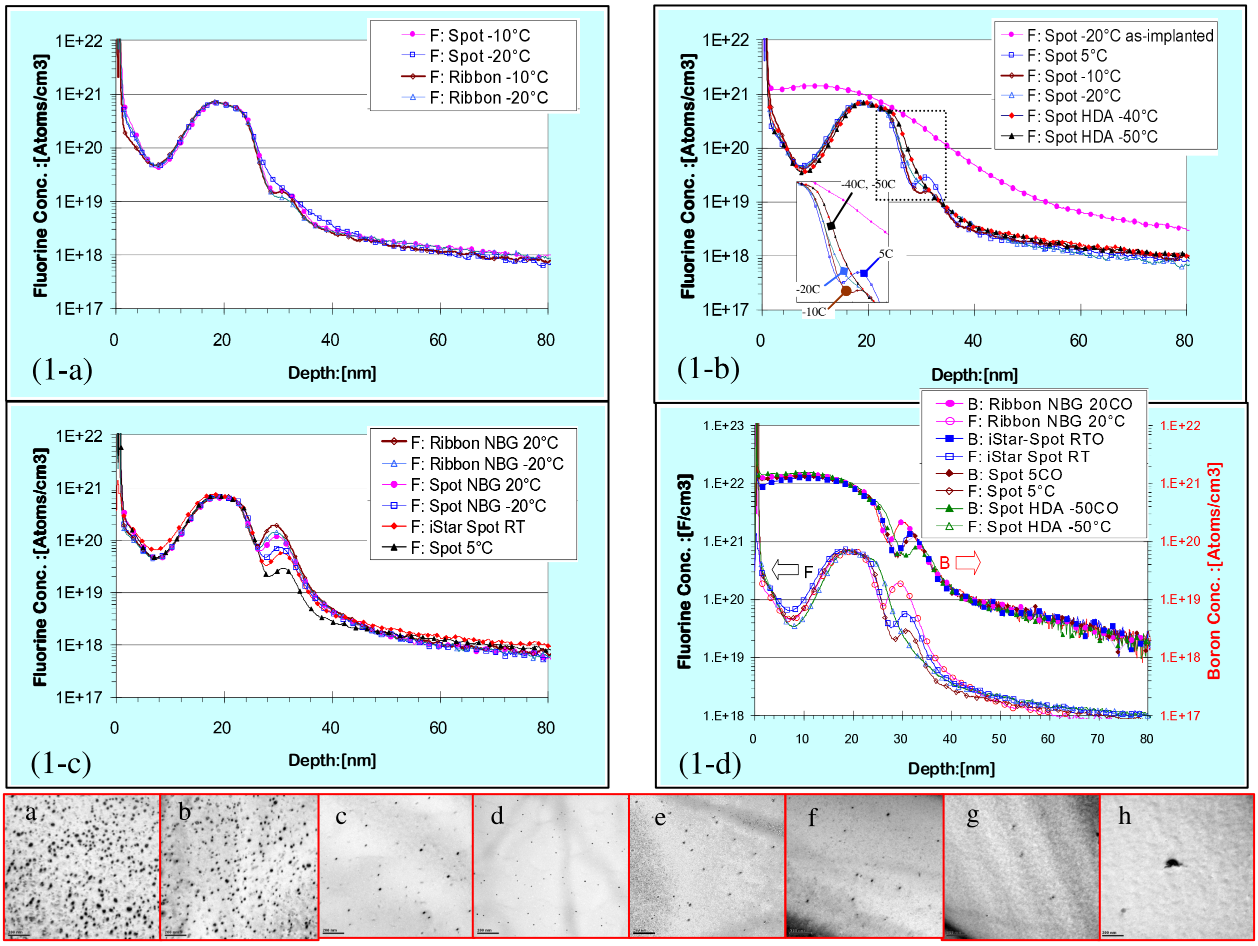

FIGURE 1. Annealed SIMS profiles of boron & fluorine from BF_2 at various implant temperatures, by spot or ribbon beam, are plotted. (1-a): Compared the fluorine profile by spot beam and ribbon beam at -10° and -20°C. (1-b): Fluorine profiles by spot beam implant from 5°C down to -50°C. One as-implanted fluorine profile is also plotted as reference. (1-c): This plot showed 2nd fluorine peaks from high to low cases. (1-d): This plot shows 2nd boron profiles along with the 2nd fluorine profiles. All the fluorine profiles are potted against left Y-axis and boron profiles against the right Y-axis to make 2nd boron peaks more visible. P-V TEM: (a) ribbon NBG 20°C (b) Spot NBG 20°C (c) ribbon -10°C (d) Spot -10°C (e) ribbon -20°C (f)Spot -20°C (g) Spot HD -40°C (h) Spot HD -50°C

Spot Beam vs. Ribbon Beam:

The first set of data was comparing the differences between spot beam and ribbon beam at different chiller temperature but without back side gas (BSG) running. The 2nd fluorine peaks were significant higher implanted by ribbon beam as compared to that of spot beam as shown in Figure_1-a. These results showed that the 2nd fluorine peak by ribbon beam at -20°C even higher than that of implant by spot beam at room temperature. With BSG at -10°C, the 2nd fluorine peak from ribbon beam implant was about the same height as that of from spot beam (Figure_1-a) but the Rs from ribbon beam is significant higher (474.89 Ohm/sq vs. 450.74 Ohm/sq). At -20°C, there was still a small 2nd fluorine peak by ribbon beam but not on spot beam. However, the main fluorine profile shifted deeper in the depth near the a/c interface and the concentration surpassed that of the 2nd fluorine peak from ribbon beam at same depth (Figure_1-c) while Rs was significantly lower than that that from ribbon beam (463.67 vs. 443.02 Ohm/sq). The difference in Rs translated into temperature based of the slope of Rs vs. implant temperature, as shown by inserted plot in FIG-2, is about 20~30°C. This Rs difference by spot beam and ribbon beam at low implant temperature could be related to the formation of fluorine-vacancy cluster which created an undersaturation of the interstitial concentration in the vicinity of boron profile, [6, 7] judging from the shift in fluorine profile.

Sheet Resistance:

It is interestingly noted that with all the tested conditions by varying the implant temperature and switching between spot beam and ribbon beam, we were able to generate wide range of amorphous layer thickness as indicated by the depth of 2nd fluorine peak or 2nd boron peak [2]. While amorphous layer thickness increased, the Rs trends appeared to be covered by two different dopant activation regimes, de-activation and re-activation regime, similar to the behavior of increasing the annealing temperature around 800 ° C in Solid-Phase Epitaxial Regrowth (SPER). In the de-activation regime, the Rs increased as the 2nd fluorine peak concentration decreased or peak depth got deeper. In the reactivation regime, the Rs trend reversed and decreases as the 2nd fluorine peak further decreased, starting from spot beam at 5°C. This trend down continued and extended to those cases where no 2nd fluorine peak was observed, starting from spot beam at -20°C and flatted out between -40°C and -50°C as shown in FIGURE_2. In the deactivation regime, the mechanism of deactivation is likely to be driven by interstitials emerging from the end-of-range defect region [8, 9, 10]. The presence of fluorine at the a/c interface might increase the stability of EOR defects. Lowering the 2nd fluorine peak by lowering the implant temperature might increase the availability of silicon self-interstitial to deactivate boron in Rp region [10] and resulted in higher Rs. As the 2nd fluorine peak lowered to a level, the Rs trend reversed and entered a re-activation regime. We propose a hypothesis that the amount of interstitials beyond EOR reduced due to thicker amorphous layer formed during implant surpass the lowering in blocking effect as the 2nd fluorine peak was lowered. As the implant temperature for spot beam at -20°C or below, the main fluorine peak drift deeper toward the a/c interface as the implant temperature further lowered. This drift might indicate that more fluorine-vacancy clusters formed in the region between main fluorine peak and a/c interface [3, 4] as compared to implant at higher temperature. These fluorine-vacancy clusters created an under-saturation of the interstitial concentration in the vicinity of boron profile [5, 6, 7] and as driver to increase the re-activation when implant temperature further decreased to -40 ° C. With the implant temperature decreased from -40°C to -50°C, the Rs trend down almost flatten out which suggests that very limited interstitials were available to deactivation the boron in Rp region. This is supported by very few dislocation loops were observed from plane-view TEM at these low implant temperatures, as shown by plane view TEM in FIGURE_1 .

Scan Speed and Beam Size Effect:

Scan speed effect and beam size effect were tested at -20°C by split condition using half of the beam size or half of the scan speed. Rs, SIMS and TEM results were compared as shown in FIGURE_3 & 4.

For scan speed, reducing the scan speed to half did not show a clear difference in plane-view TEM. For SIMS profile, the fluorine profiles are almost on top of each other. The Rs, however, changed from 442.87 Ohm/sq to 434.36 Ohm/sq which is almost 4X delta Rs as compared to that by changing the beam size. For beam density effect, reduce beam size by a factor of 2 did not show a clear difference in plane-view TEM. For SIMS, fluorine profile shifted deeper about 5Å (could also be SIMS measurement error) with reducing the beam size. Rs were reduced from 443.02 Ohm/sq to 440.82 Ohm/sq. Overall, reducing the scam speed or beam size has similar effects as lowering the implant temperature but more noticeable with scan speed.

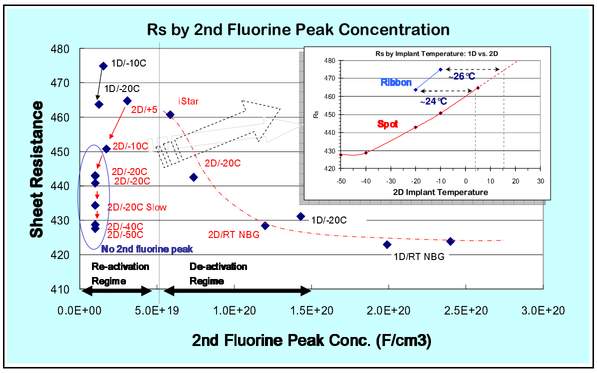

FIGURE 2: Rs results from 850C/30sec in N2 ambient were plotted against the 2nd peak fluorine concentration. It appeared to have two different stages, deactivation regime then, the re-activation regime as implant temperature lowed. The top-right plot shows the re-activation regime where Rs decreased as the implant temperature was lowered.

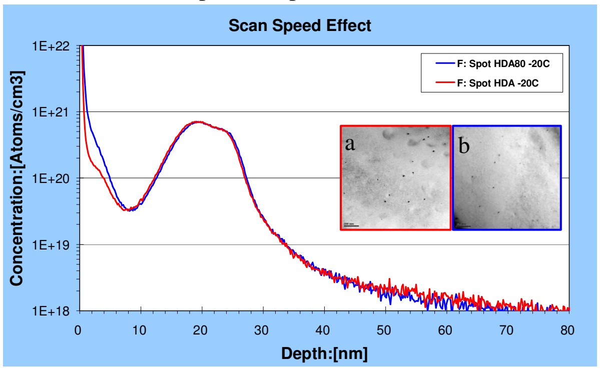

FIGURE 3: scan speed effect test @ -20C by reducing speed to half of other split conditions. PV TEM (15KX) & Rs: (a) HD Spot -20°C, Rs= 442.87 Ω/cm^2 (b) HD80 Spot -20°C, Rs=434.36 Ω/cm^2.

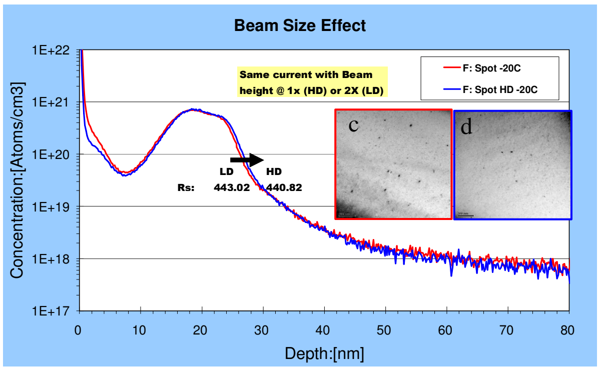

FIGURE 4: **B**eam size effect test @ -20C by reducing speed to half (HD) of other split conditions. PV TEM (15KX) & Rs: (c) Spot -20C Rs=443.02 Ω/cm2 (d) HD Spot -20C, Rs=440.82 Ω/cm2.

Conclusion

Implant temperature has shown a strong effect in EOR defect control. The amorphous layer grows thicker as decreasing the implant temperature indicated by the depth of 2nd fluorine and 2nd boron peaks. From the Rs trend in this study, there appeared to cover two distinct stages, deactivation regime and reactivation regime, by decreasing the implant temperature. In the first stage, the Rs trends up as decreasing the implant temperature. This seems to happen when there is still high level of defects at EOR as observed by SIMS and TEM in this study. In the 2nd stage, the Rs trend went down monotonically with further decreasing the implant temperature until it reaches a limit where Rs does not decrease further. The results between spot beam and ribbon beam were also compared. From these results, there were noticeable difference in defect formation at higher temperature to difference in dopant activation at low implant temperature, estimated equivalent to delta 20~30°C from the studied in -10°C~ -20°C cases.

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