The Influence of Dose Rate on Ultra Shallow Surface Dopant Profile

Shao-Yu Hu, Ger-Pin Lin, Ching-I Li, Hong Lu, Zhimin Wan
Advanced Ion Beam Technology, Inc.
Tainan City, Taiwan

Abstract— **Dose rates were widely studied in ion implanter history due to the influence on semiconductor device performance. Several major parameters can be adjusted by dose rate, including implant damage, doping profile distribution, and doping activation. As devices shrink, ultra shallow surface doping becomes more significant on device performance. In this study, a special phenomenon of Boron distribution was investigated. Some parameters for dose rate tuning were also used to adjust the surface profile, which were potentially knobs for tuning device performance improvement.**

Keywords—Dose rate; activation; ion implant; SIMS

I. INTRODUCTION

As the semiconductor device keeps scaling down, the implant process is more sensitive to beam line optics. The influence of implant dose rate became a popular study in the past ten years for device performance adjustment or because of tool machine issues [1-4]. The influence of dose rate studies were usually incocorporated three respects: implant damage, dose profile, and resistance. Implant damage is the major root cause. Implantation with high dose generates more interstitial–vacancy pairs (I-V pair), which makes the Si substrate more amorphous after implant. Fig.1 shows the amorphous layer thickness variation when dose rate is changed [1]. The amorphous layer increases the activation rate of solid-phase epitaxial regrowth (SPER) during annealing. However, the high dose rate may also increase the density of clusters during implant, which will lead to dopant deactivation behavior. Considering these two phenomena, dose rate can increase or decrease sheet resistance, depending on the implant conditions and what kind of species [2]. The amorphous layer also reduces the tunneling effect of implant ions. The junction depth of high dose rate implantation is usually shallower than that of low dose implantation. Fig. 2 shows an As case for example [3].

Scaling device dimensions for sub-20nm applications require considering interface phenomenon more. For implantation technology, except for junction depth, the dosage in ultra shallow surface becomes a significant factor in the integrated process [5-8]. In this paper, the influences of dose rate on surface doping profile were investigated. Traditionally, high dose makes the junction profile shallower. However, for ultra-shallow surface profile has not been studied yet. Characterization of these implantation requires accurate profile shape and within the upper several nanometer of the wafer surface. Point by Point Correction secondary ion mass spectrometry (PCOR SIMS) of EAGLABS® was employed to characterize the doping profile. We used 0.5keV O_2 bombardment and applied PCOR-SIMS protocol to minimize matrix effects on B quantification and sputter rate due to surface oxide. This method avoids near-surface profile distortions introduced by the older oxygen flooding and normal incidence techniques and yields the most accurate junction depth measurements due to precise measurement of surface oxide thickness. Damage and amorphous layer characterization was performed by Transmission Electron Microscopy (TEM) analysis.

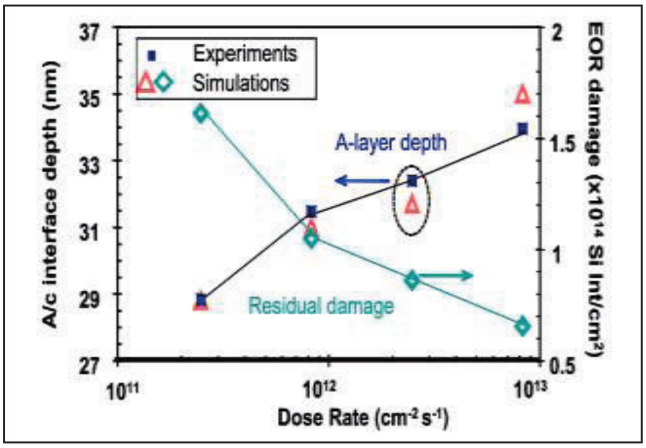


Fig. 1. The relationship between amorphous layer and dose rate [1].

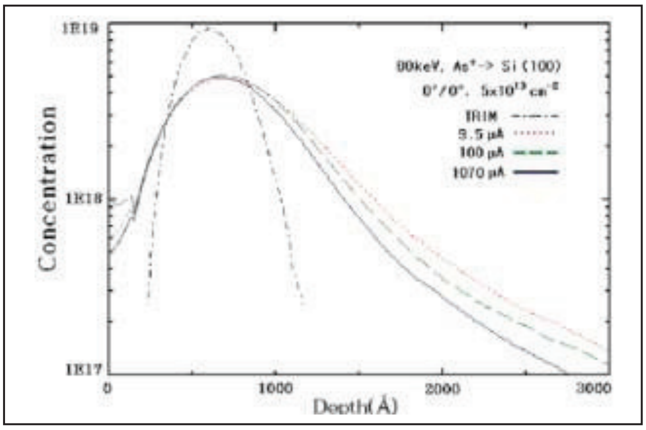


Fig. 2. SIMS profile of various beam current [3].

II. EXPERIMENT

The experiment was accomplished by AIBT *iPulsar Plus* with low energy <5 keV boron implant, and a high dose range 2-5×10^{15} at/cm^2 condition. The tilt angle is 0°. The implant temperature is 15°C. For Ribbon beam implant, a continual rotation FlexScan was employed, and conventional quad-mode was used for spot beam condition. The conventional quad-mode is the method which implant with 4 rotations at 90 degrees each. The FlexScan mode is a continuous rotated mode. It completes 360 degree rotation within one recipe.

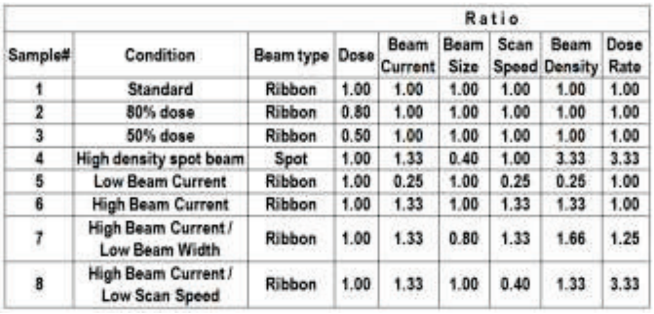
The split conditions are listed in Table 1. The items of dose rate and beam density are defined as below.

Dose Rate = Beam Current / (Beam Size*Scan Speed)

Beam Density = Beam Current / Beam Size

All samples were characterized by PCOR SIMS. The amorphous layer was checked by cross section TEM of sample#1.

Table 1. Implant condition split table.



			Ratio					
Sample#	Condition	Beam type	Dose	Beam Current	Beam Size	Scan Speed	Beam Density	Dose Rate
1	Standard	Ribbon	1.00	1.00	1.00	1.00	1.00	1.00
2	80% dose	Ribbon	0.80	1.00	1.00	1.00	1.00	1.00
3	50% dose	Ribbon	0.50	1.00	1.00	1.00	1.00	1.00
4	High density spot beam	Spot	1.00	1.33	0.40	1.00	3.33	3.33
5	Low Beam Current	Ribbon	1.00	0.25	1.00	0.25	0.25	1.00
6	High Beam Current	Ribbon	1.00	1.33	1.00	1.33	1.33	1.00
7	High Beam Current / Low Beam Width	Ribbon	1.00	1.33	0.80	1.33	1.66	1.25
8	High Beam Current / Low Scan Speed	Ribbon	1.00	1.33	1.00	0.40	1.33	3.33

III. RESULTS AND DISCUSION

Fig. 3(a) shows the SIMS profile of sample#1 standard beam condition. A special phenomenon was found. In such a low energy and high dose condition, the profile is not an ideal Gaussian shape but two peaks profile. We define the peak near the surface as peak-1 and the deeper peak as peak-2 in this paper. It was speculated that one of the peaks might relate to surface damage from ion implant because peak-1 position is very shallow. Fig. 4 shows the cross section TEM of standard condition sample#1. A thin amorphous layer was formed in such a low energy but high dose implant condition. Fig. 3 (b) shows surface SIMS profile of different dose (sample#1~#3). It was found that peak-1 was not very obvious if the dose is decreased to 50%. Peak-1 increased when dose increases. For normal boron implant case, amorphous layer would not be formed if the dose is not high enough. However, in the TEM image, the amorphous layer was found after implant. It was also found that the peak-1 position was within the range of the A/C interface. The phenomenon of peak-1 increase can be correlated to amorphous layer formation.

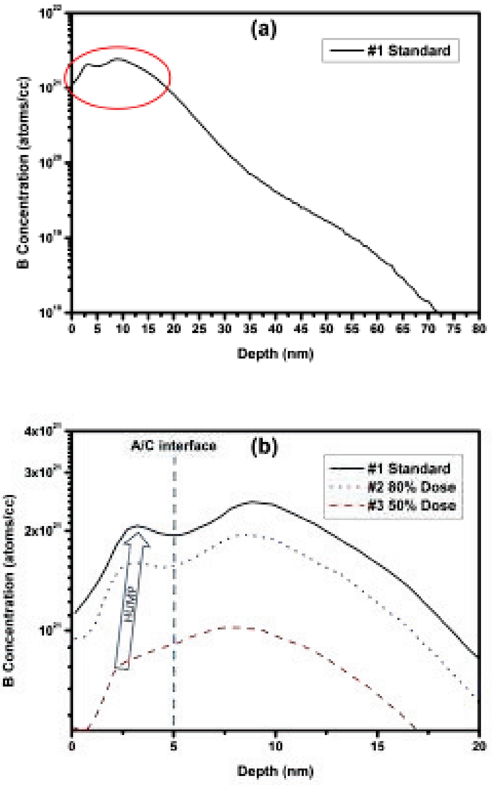


Fig. 3. (a) SIMS profile of sample#1 standard beam condition. (b) Surface SIMS profile of different implant dose.

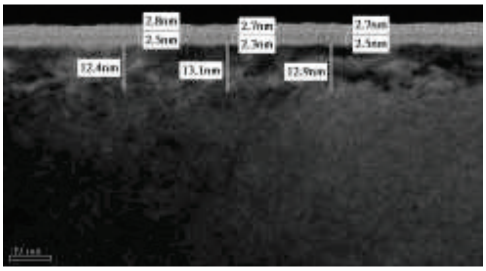


Fig. 4. Cross section TEM of sample#1 standard implant condition.

Since the peak-1 formation is related to implant damage, it should be also related to implant dose rate. For AIBT *iPulsar Plus*, both ribbon beam and spot beam shape can be tuned up for implant by different scan mode. The dose rate of spot beam is much higher than that of ribbon beam because the beam size is much smaller. Fig. 5 shows the surface SIMS profile of ribbon beam and spot beam comparison. Sample#1 was standard condition and its dose rate ratio was defined as 1. Sample#4 was spot beam with a calculated dose rate ratio of 3.33. For peak-2 and tail region, the profile of high dose rate spot beam is shallower. This result was consistent with a previous dose rate study [3]. However, for peak-1, high dose rate shows higher and deeper profile than low dose rate.

Sample#8 was another high dose rate condition. It achieved a similar dose rate as sample#4 by adjustment of the scan speed. However, we found that the shift of peak-1 had the same trend but the change was smaller than sample#4. Although beam density and scan speed were both factors of dose rate, some studies considered that beam density is the major factor which dominates the implant damage [4]. Fig. 6 shows the surface SIMS of different beam current (sample #1, #5, #6). The beam densities were changed with beam current, but the dose rates were kept the same by adjustment of the scan speeds. It was found that the tail was shallower in the high beam current profile. For peak-1, high beam current shows a deeper and higher hump. These trends were consistent with the result of the ribbon/spot beam split. According to this result, beam density should be the major factor in dose rate influence for this case.

Fig. 7 shows a supposed mechanism of peak-1 shift in such an implant condition. When the implanted ion strike the substrate, the collision with Si lattice will scatter the implanted ion in a random direction. The deeper Peak-2 is the original projected range including the channeling effect. Part of the scattering ions will reflect to the surface. If an amorphous layer exists under the surface, the reflected ion will be decelerated and trap in this layer. If the dose is not high enough, no amorphous layer is formed. The trapping phenomenon is not very intense. As the dose increases, more ions were stopped in amorphous layer. The peak-1 increases. In the introduction section, we referred to a previous investigation that showed high dose implant induces a deeper A/C interface. The deeper A/C interface will stop the reflected ions in a deeper position. That can explain why higher dose would lead deeper and higher peak-1.

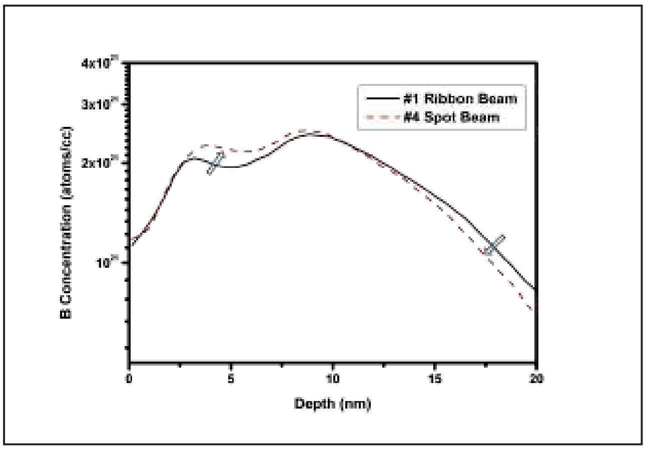


Fig. 5. Surface SIMS profile of ribbon beam (low dose rate) and spot beam (high dose rate).

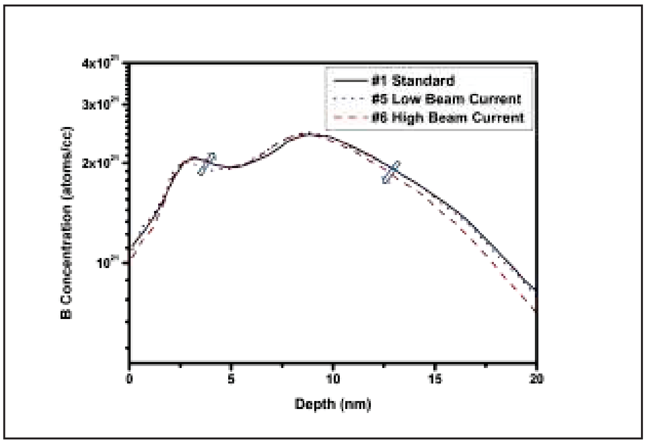


Fig. 6. Surface SIMS profile of different beam current

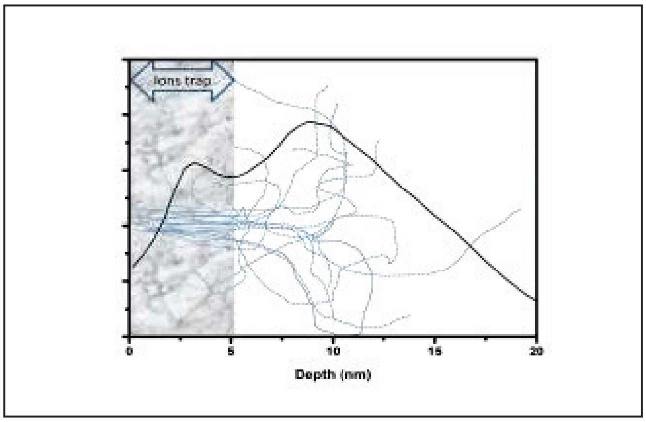


Fig. 7. Schematic diagram of the mechanism of peak-1 formation.

IV. CONCLUSION

The influences of surface concentration become more significant in ion implant technology because the surface condition is an important factor for sub-20nm scale semiconductor devices. In this paper, surface doping distribution was found to be related to implant damage. Furthermore, the surface doping profile can be manipulated by a dose rate effect. The surface peak position and concentration can be change by beam shape tuning or beam current. That gives potential implant parameters to modulate advanced device performance.

REFERENCE

[1] L. Pelaz, L. A. Marqués, P. López, I. Santos and M. Aboy, “Modeling of defect generation and dissolution in ion implanted semiconductors,” Ion Implantation technology 2010 , p. 176, 2010.

[2] G. Fuse, M. Sano, H. Murooka, T. Yagita, M. Kabasawa, T. Siraishi, Y. Fujino, N. Suetsugu, H. Kariya, H. Izutani, M. Sugitani, “Electrical characteristics due to differences in crystal damage induced by various implant conditions,” Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 237(1), 77-82, 2005.

[3] I. B. Sung, J. K. Kim, Y. S. Yoo, B. Y. Jeong, and S. T. Kang, “Depth Profile of an Ion-Implanted Sample for Various Dose Rates,” J. Korean Phys.Soc. 46, pp.478-481, 2010.

[4] M. S. Ameen, M. A. Harris, C. Huynh, and R. N. Reece, “Dose Rate Effects: the Impact of Beam Dynamics on Materials Issues and Device Performance,” Ion Implantation technology 2008 , p. 30, 2008.

[5] A. Y. C. Yu, "Electron tunneling and contact resistance of metal-silicon contact barriers." *Solid-State Electronics* 13.2 , 239-247, 1970.

[6] R. aboudian, K. Pond, V. Bressler-Hill, M. Wassermeier, P. M. Petroff, G. A. D. Briggs, and W. H. Weinberg, "Tunneling spectroscopy on the GaAs (110) surface: effect of dopant concentration." *Surface science* 275.1, L662-L668, 1992.

[7] F. A. Faria, J. Guo, P. Zhao, G. Li, P. K. Kandaswamy, M. Wistey, and D. Jena, ”Ultra-low resistance ohmic contacts to GaN with high Si doping concentrations grown by molecular beam epitaxy,” *Applied Physics Letters*, *101*(3), 032109, 2012.

[8] K. Takei, R. Kapadia, Y. Li, E. Plis, S. Krishna, and A. Javey, “Surface Charge Transfer Doping of III–V Nanostructures,” *The Journal of Physical Chemistry C*, *117*(34), 17845-17849, 2013.