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Ion Beam Control and Transistor Characteristics for 45nm Source-Drain Extension Formation

K. Okabe, M. Nishikawa, K. Ikeda[1], H. Kurata[1], T. Mori, S. Satoh[1], and M. Kase

Device Development Division Fujitsu Microelectronics Ltd., [1]Fujitsu Laboratories Ltd.,:1500, Mizono, Tado, Kuwana, Mie 511-0192, Japan,

Abstract. The beam trajectory and divergence angle is systematically examined with ion source parts degradation and focusing condition. We clarified that the variation and drive current of NMOSFET transistor characteristics are related the beam angle conditions, using our advanced logic transistor of 45 nm low stand-by power and high performance device technology. We can propose the practical condition to become insensitive to ion beam angle degradation and some gain of drive current of MOSFET is achieved.

Keywords: Ion beam, angle, Trajectory, divergence, 45nm, lens
PACS: 61.72.Uj

INTRODUCTION

The ion beam angle effect is quite important for stable manufacturing of advanced logic and memory devices. In the past conferences, the trajectory and divergence of the ion beam were highlighted. They discussed the influences to MOSFET characteristics such as the asymmetry of drive current and gate overlap variation [1-6]. We examined the beam trajectory and divergence in detail using single high current implanter and its influences on the characteristics of MOSFET using our advanced 45 nm logic transistor including the gate length of less than 35 nm.

MAIN CAUSE OF TRAJECTORY AND DIVERGENCE

We find that the change of ion source electrode shape and change of focus lens has strong impact on such beam properties. Such as the arc chamber, suppression and ground electrodes, the ion source part shape is varied depending on the running timing. The condition of lens part is changed depending on each beam setup. As a result, trajectory and divergence of ion beam is usually changed.

Figure 1 shows the change of ion source electrode shape after the running time of 120 and 200 hours. The opening slit on the electrode is becoming wider as the source running timing is progressed due to sputtering effect. After 200 hours of operation, we find the position five is particularly becoming wider. This situation is dependent on the type of implanter, ion source itself and the ion source operation condition. This degradation of source parts is influenced by the density of extracted beam and some of focusing lens parameters enhance this phenomenon strongly.

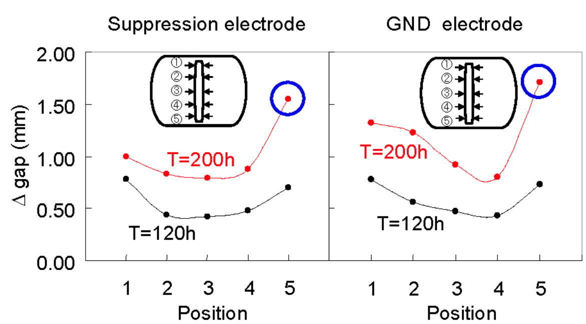

FIGURE 1. The change of ion source electrode shape after the running time of 120 and 200 hours.

INFLUENCE OF TRAJECTORY AND DIVERGENCE

The important properties of ion beam angle are its direction and spreading. To identify these, we examine the trajectory and divergency of beam using 2 dimentional profiler of the ion beam. The beam size and center of gravity are measured at the point of wafer plane and the point behind a distance *L* from wafer plane. The trajectory and divergence angle are

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calculated from equation (1) and (2) respectivily using the beam center of gravity (*CofG*) and the difference of beam width (*W*) at the wafer plane (front) and the point behind a distance *L* (back). The beam size is defined at the point of the beam intensity of 98 %.

$$Trajectory(\text{deg}) = \tan^{-1}\left\{\frac{CofG(\text{back}) - CofG(\text{front})}{L}\right\} \quad (1)$$

$$Divergence(\text{deg}) = \tan^{-1}\left\{\frac{W(\text{back}) - W(\text{front})}{2L}\right\} \quad (2)$$

Figure 2 shows the beam profiles and angle data of ultra low energy As ion beam as function on the ion source running time. A deceleration mode is used and focus condition is fixed. For 120 hours of operation, the left figure shows the practical beam divergence and same center of gravity between the front and back position, and it has a good beam trajectory. The right figure shows the different profile of front and back, so that the ion beam has shifted beam axis and its divergence becomes wider after the running time of 200 hours. Even if the ion source setting is the same, the parts degradation causes this beam angle degradation.

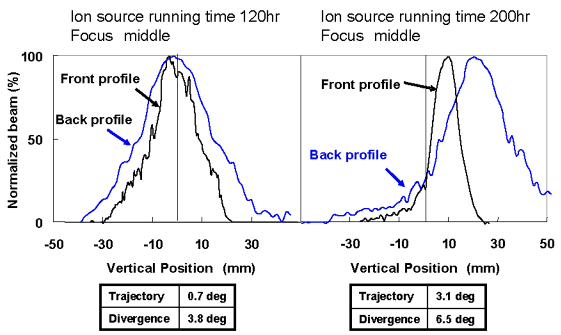

FIGURE 2. Beam profiles and angle data of ultra low energy Arsenic ion beam as function on the ion source running time.

Figures 3 shows the forward and reverse transistor Ion-Ioff characteristics on the low stand-by power type NMOS FET of 45 nm device generation, which is adopted the ultra low energy As implant for the extension formation after the ion source running time is 200 hours. To clarify the beam angle influence, the tilt angle of 0° and 1 direction implant are used. The difference between forward and reverse drive current is quite large, so it is 9% of Ion. The advanced logic transistor would be designed to be a small overlap between the gate and extension, so the angle variation makes a strong impact to the MOSFET characteristics.

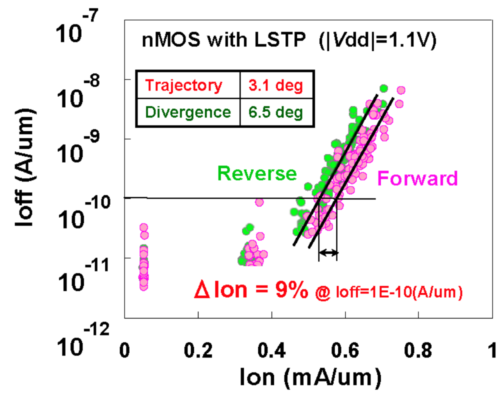

FIGURE 3. Forward and Reverse transistor *I*on-*I*off characteristics.

To clarify the influence of divergence angle, we make the beam which has a large divergence angle by tuning the focus lens condition. The beam profile results are shown in Figure 4. A new ion source is used. We success to make that the trajectory angle is 0 ° and the divergence angle is 4.1 and 6.9°.

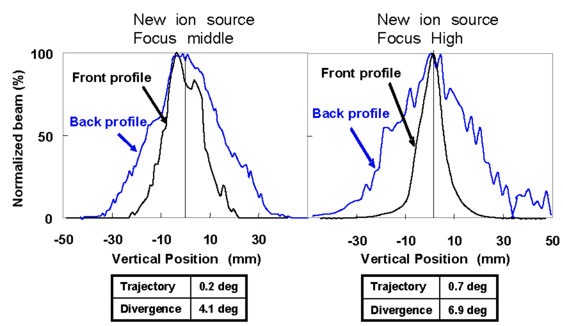

FIGURE 4. Change of divergence angle by tuning the focus lens condition.

Figure 5 shows the difference between forward and reverse drive current as function on the implant tilt angle. To clarify the beam divergence influence, the 1 direction implants are used, again. The result shows that the asymmetry of drive current is twice higher in case of 4.1° divergence. The low divergence beam makes shape lateral profile, so it makes large dependence on tilt angle. In the case of broaden beam, the dose loss may be occurred. It makes transistor performance lower. As a result, to minimize the variation of transistor characteristics, Tilt angle should be controlled preciously in mechanical and beam trajectory and divergence should be stable and repeatable.

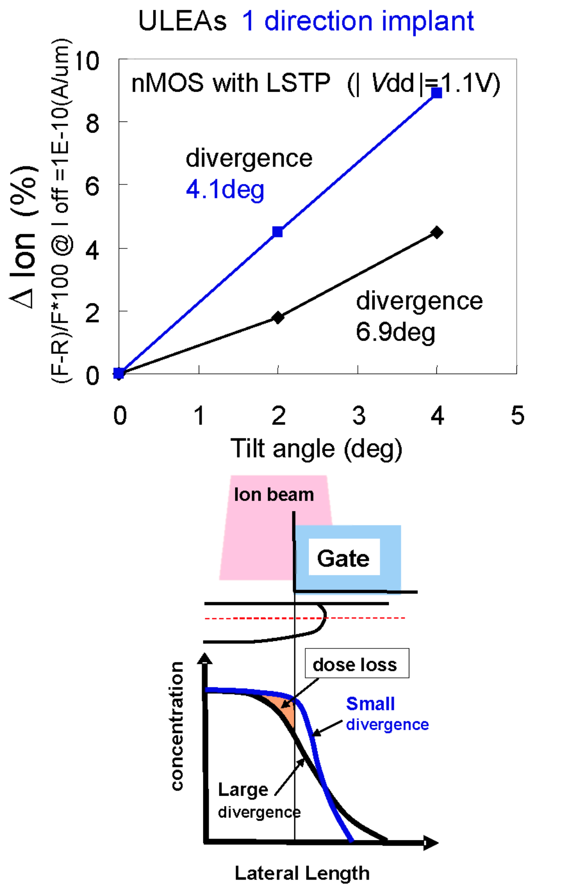

FIGURE 5. Difference between forward and reverse drive current as function on the implant tilt angle and schematic view of gate overlap of lateral profile

Figures 6 shows the *L*min-*I*on characteristics of transistor when the quad implant is adopted. *L*min is the minimum gate length of roll-off characteristics at the threshold voltage of 0 V, and *I*on is the transistor drive current. The transistor is high performance type NMOS FET of 45 nm device generation. The quad implant is used to form the extension implant. The tilted angle of wafer is 0° and 5°. The divergence angle is 4 and 7°. The trajectory angle is 0.3°. In the case of 0° tilt implant, the *I*on and *L*min is strongly depended on the beam divergence, however in the 5° tilted implant case, the dependence to the beam divergence is much small. This means that there is good balance of overlap of gate and extension, and parasitic resistance, and we can achieve small variation of transistor performance with small degradation of drive current. This result of tilted angle and implanted dose might be depended on the process flow such as side wall design, pocket hallow implant and thermal budget.

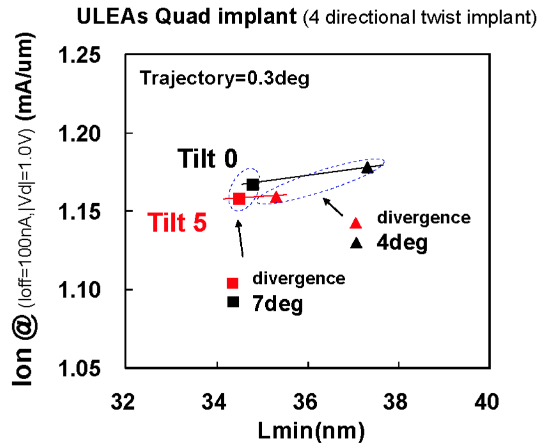

FIGURE 6. *L*min-*I*on characteristics of high performance type NMOSFET when the quad implant.

Figure 7 shows the case of PMOSFET. The result shows less dependence on the beam angle of tilt and divergence. The B profile of PMOSFET extension is different from the As profile of NMOSFET like as lower abruptness or smoother shape. Based on the mechanism described on Figure 7, we adopt the fine tuning to the implant parameters, as a results we can get 8% gain on *I*on using tilt implant at 10°. The reason why of gaining the drive current, is the B part of implanted B area does not overlap with the gate electrode. And the B part dose are more than the A part dose. Therefore the parasitic resistance is lower and the Vth roll-off does not changed. By the tilted angled and quad implant a advantage on higher *I*on and low variation are achieved.

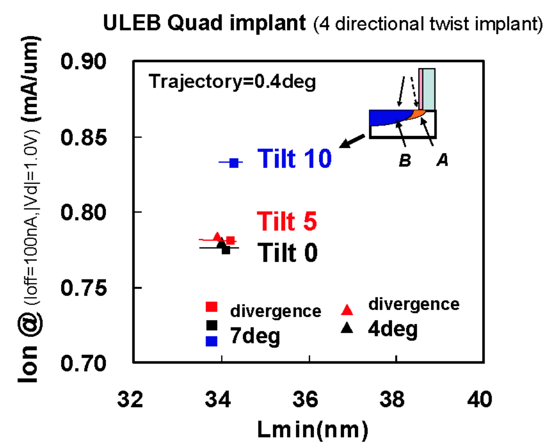

FIGURE 7. *L*min-*I*on characteristics of high performance type PMOSFET when the quad implant.

WHAT IS THE BEST TUNING OF IMPLANTER TO MINIMIZE THE VARIATION?

The thermal budget of next generation transistor fabrication flow is minimized due to the requirement of shallow junction and extension layer is formed using diffusion less annealing technique. By such the extension formation, a variation of as-implanted profile should influence the transistor characteristics. The beam tuning of implanter is directly reflected the dopant profile, so it becomes increasingly important to stabilize the transistor performance at the mass production. Figure 8 shows that the beam size and its trajectory angle depends on the focus voltage after ion source running time of 200 hours. We can see to minimize the beam size on the focus voltage of just focus value, but the trajectory angle is maximized. This is caused from bad condition of ion source. When the implantation is performed on such condition with the focus point, large trajectory angle could be degraded the transistor asymmetry. Even if quad implant is used, the variation is not suppressed enough in this case. To decrease the trajectory angle, we can choose either lower or higher voltage. Higher voltage has a possibility of glitch issue, so we choose the lower voltage area. We must decrease a beam current about 10%. Figure 9 is the divergence angle as function on the focus voltage. In the low focus voltage area the divergence angle is small. The divergence will be decided with balance of space charge effect of beam density and convergence of focus lens. As a result, we use low focus voltage and quad implant, so we can achieve stable device fabrication process condition.

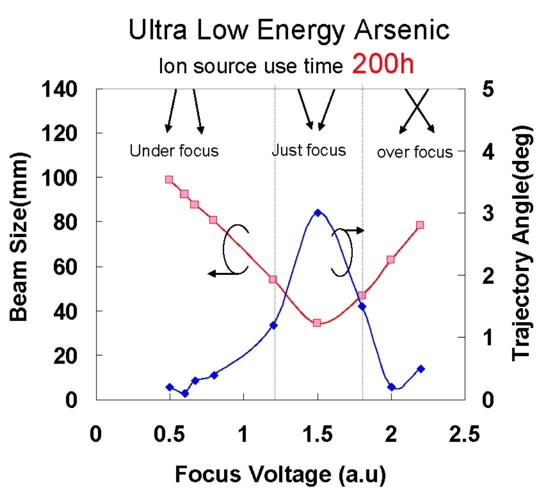

FIGURE 8. Lmin-Ion characteristics of high performance type PMOSFET with the quad implant

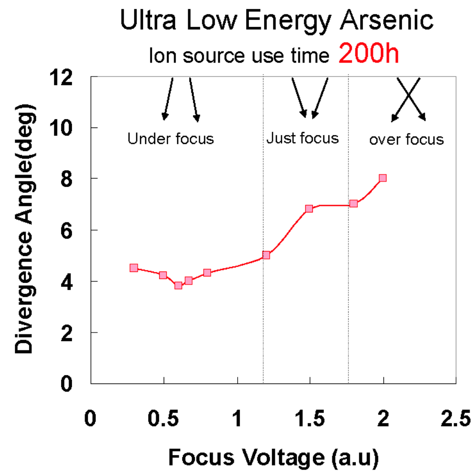

FIGURE 9. Lmin-Ion characteristics of high performance type PMOSFET with the quad implant.

SUMMARY

The beam trajectory and divergence angle is systematically examined with ion source parts degradation and focusing condition. We clarified that the variation and drive current of NMOSFET transistor characteristics are related the beam angle conditions, using our advanced logic transistor of 45 nm low stand-by power and high performance device technology. We can propose the practical condition to become insensitive to ion beam angle degradation and some gain of drive current of MOSFET is achieved. Finally, it is strongly required that the implanter can manage and stabilize automatically the beam angle parameters such as trajectory and divergence.

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