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The Improvement of LDD MOSFET's Characteristics by the Oblique-Rotating Ion Implantation

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The dependence of LDD MOSFET's characteristics on an incident angle by the oblique-rotating ion implantation has been studied. It was found not only that the asymmetrical characteristics of the substrate and the drain current were dissolved by our new implantation method, but also that the decrease of hot carrier generation was brought by the lowering effect of the oblique-rotating ion implantation. Moreover it was suggested that the optimized angle and impurity dose must be determined after total consideration of the symmetrical effect and the lowering dose effect.

1. Introduction

Recently asymmetrical characteristics of short channel MOSFET's especially employing lightly doped drain (LDD) structure[1)-5)] have been investigated from the point of the shadowing effect of the conventional inclined ion implantation and the gate bird's beak[6),7)]. This asymmetry has been reported to degrade the sensitivity of a DRAM sense amplifier composed of LDD transistors and futhermore to affect the hot carrier degradation and its reliability[8),9)].

In this paper we described the experimental results about the improvement of the substrate and the drain currents' asymmetry and the β degradation[10)] by the oblique ion implantation with rotating the wafers(oblique-rotating ion implantation) compared to the 0° fixed ion implantation after the discussion of the impurity dose profiles and the specific effects by the oblique-rotating ion implantation.

2. Characteristics of oblique-rotating ion implantation

Figure 1 shows the system diagram and the schematic diagram of the oblique-rotating ion implantation. Ions are implanted to a wafer which is tilted with an angle θ and rotating with an angular velocity ω. Then ions are screened by the gate electrode at some rotated positions.

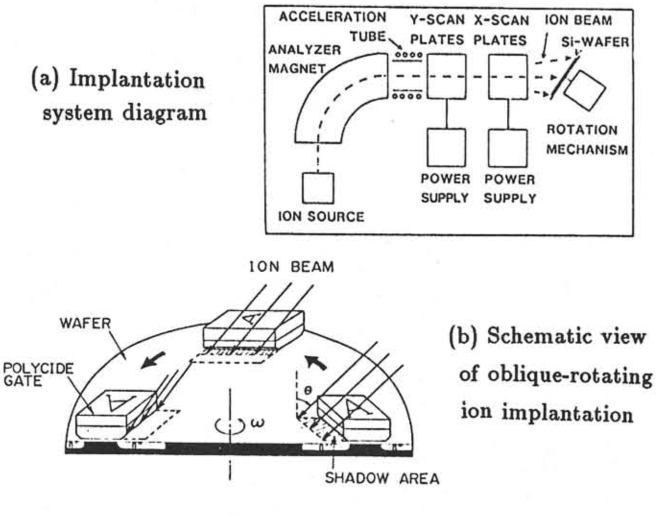


Fig.1. Diagrams of the oblique-rotating ion implantation

In order to estimate the effective dose profiles, a oblique-rotating implantation model is considered as shown in Figure 2. Here a fixed coordinate system located on the gate is introduced and it is assumed that ions are implanted at a x-point in a conic shape and screened by the gate edge between the time t_1 and t_2. The screening time interval is found to increase at closer points to the gate.

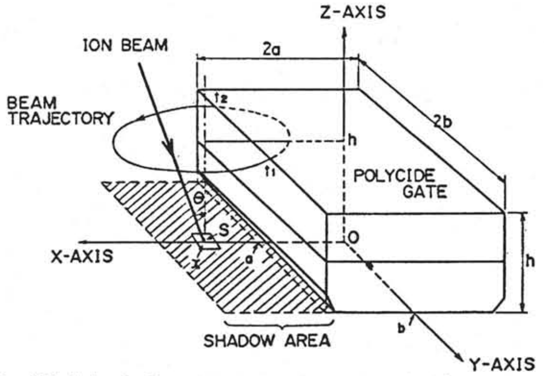


Fig.2. Model of the oblique-ratoting ion implantation with an incident angle θ at a x-point in the shadow area

The effective implanted dose $i(\theta, \Delta t)$ perpendiculer to the area S per duration time Δt with an incident angle θ is given by

$$i(\theta, \Delta t) = \Delta t \mathbf{N} \cdot \mathbf{S}, \qquad -(1)$$

where $\mathbf{N}$ designated the ion beam intensity vector which has a dose $N\,[atom/cm^2 \cdot sec]$ and a proceeding direction of incident atoms, and $\mathbf{S}$ designates the area vector which has an area $S[cm^2]$ and a direction perpendiculer to the surface S. In our model three dimensional representations of the oblique-rotating ion beam vector $\mathbf{N}$ and the implanted area vector $\mathbf{S}$ can be written by

$$\mathbf{N} = (N \sin\theta \cos\omega t, N \sin\theta \sin\omega t, -N\cos\theta)$$

$$\mathbf{S} = (0, 0, -S)$$

where ω is the rotating beam anguler velocity in our coordinates system.(Actually a wafer is rotated with an anguler velocity ω.) The effective dose during a cycle time T is as follows.

$$\begin{aligned} I(\theta) &= \int_0^{t_1} \mathbf{N} \cdot \mathbf{S} dt + \int_{t_1}^{t_2} 0 \cdot dt + \int_{t_2}^{T} \mathbf{N} \cdot \mathbf{S} dt \\ &= NS\cos\theta \cdot [T - (t_2 - t_1)] \qquad -(2) \end{aligned}$$

On the other hand there is the relation between the time interval $t_2 - t_1$ and the distance from the gate edge $x - a$. It is given by

$$\cos\frac{1}{2}\omega(t_2 - t_1) = \frac{x-a}{h\tan\theta}, \qquad -(3)$$

where h is the height of the gate and a is the point of the gate edge. Therefore the effective implanted dose per unit time and unit area $\tilde{I}(\theta)$ is obtained by

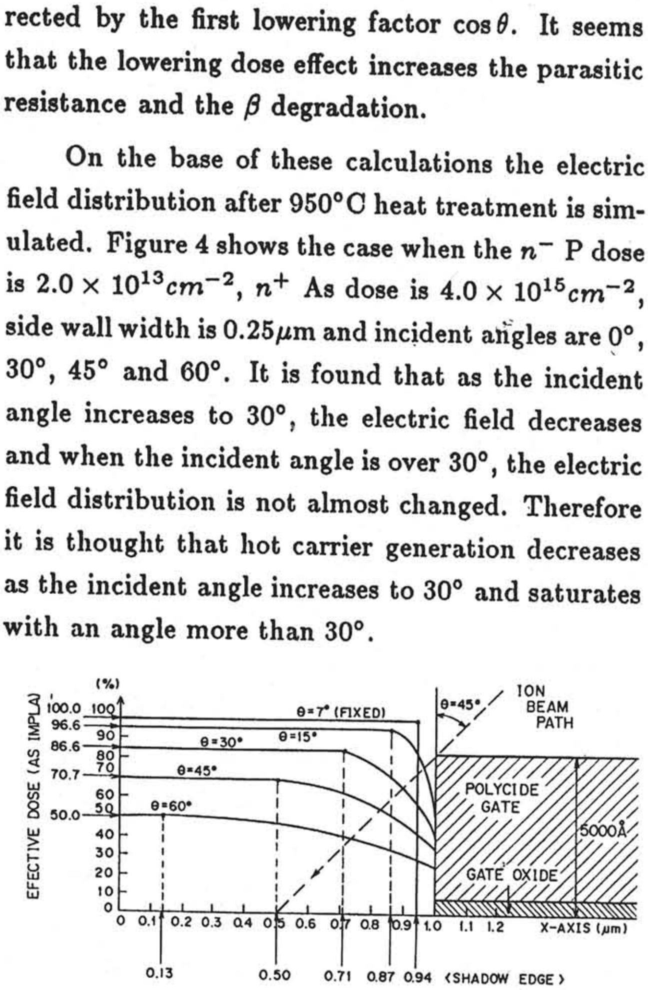
$$\tilde{I}(\theta) = N\cos\theta\Big[1 - \frac{1}{\pi}\cos^{-1}\Big(\frac{x-a}{h\tan\theta}\Big)\Big]. \qquad -(4)$$

Figure 3(A) shows the effective dose profile calcurated with this model. The total lowering rate is

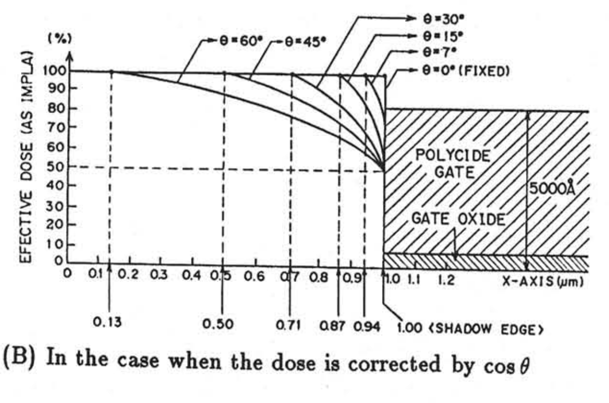
$$\cos\theta\Big[1 - \frac{1}{\pi}\cos^{-1}\Big(\frac{x-a}{h\tan\theta}\Big)\Big]. \qquad -(5)$$

The term $\cos\theta$ is the first lowering factor by the incident angle of the oblique implantation and the other term is the second lowering factor by the shadowing of the rotating implantation. Figure 3(B) shows the profile when the ion dose is corrected by the first lowering factor $\cos\theta$. It seems that the lowering dose effect increases the parasitic resistance and the β degradation.

On the base of these calculations the electric field distribution after 950°C heat treatment is simulated. Figure 4 shows the case when the n^- P dose is $2.0 \times 10^{13} cm^{-2}$, n^+ As dose is $4.0 \times 10^{15} cm^{-2}$, side wall width is 0.25μm and incident angles are 0°, 30°, 45° and 60°. It is found that as the incident angle increases to 30°, the electric field decreases and when the incident angle is over 30°, the electric field distribution is not almost changed. Therefore it is thought that hot carrier generation decreases as the incident angle increases to 30° and saturates with an angle more than 30°.

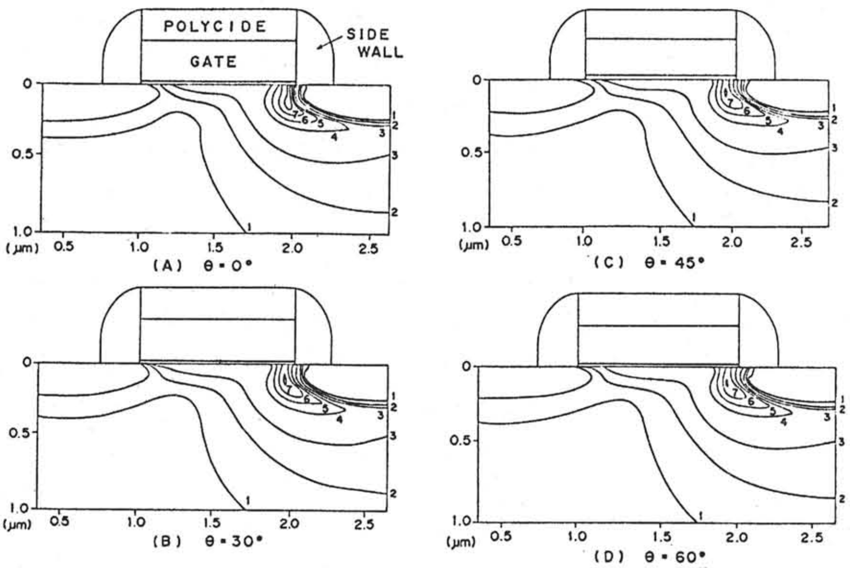


(A) In the case when the dose is not corrected by $\cos\theta$



(B) In the case when the dose is corrected by $\cos\theta$

Fig.3. Effective dose profile



n^-	P: 2.0×10^{13}
n^+	As: 4.0×10^{13}

NO	E(V/cm)
7	1.6×10^5
6	1.4×10^5
5	1.2×10^5
4	1.0×10^5
3	6.0×10^4
2	4.0×10^4
1	2.0×10^4

Fig.4. Simulations of the electric field for LDD MOSFET using the oblique-rotating ion implantation

From these results it should be noticed that the incident angle and impurity dose must be optimized in consideration of the lowering dose effect which brings the β degradation and the relaxation of electric field, as well as the symmetric effect.

3. Experiment and results

N-channel LDD MOSFET's with 1.2μm gate length were fabricated. A 10Ωcm p-type substrete, 0.25μm CVD side wall, 250Å thick gate oxide and 5000Å thick $MoSi_2$ polycide gate were used. The n^- P and n^+ As dose were $2.0\times10^{13}cm^{-2}$ and $4.0\times10^{15}cm^{-2}$ respectively and the incident angle was varied with fixed 0°, conventional fixed 7°, rotating 7°, 15°, 30°, 45° and 60°.

Figure 5 shows the substrate and the drain current characteristics for the conventional 7° fixed implantation. Both currents have an asymmetry: the substrate current has a long tail in the reverse bias condition and the drain current asymmetry is small in linear region, but prominent in saturation region. When the oblique-rotating implantation was adopted, it was found that the asymmetry was improved at incident angles over 15°. Figure 6 shows the sample that the 15° oblique-rotating ion implantation almost dissolved the asymmetry of electric characteristics.

Figure 7 shows the dependence of the maximum substrate current on the incident angle. When the dose of implantation was not corrected by the first lowering factor $\cos\theta$, the maximum substrate current decreases with increase of the incident angle(closed circles). While the implantation was performed at the corrected dose by the first lowering factor, the maximum substrate current still remained decreasing; drastically decreasing at angles from 0° to 30°, and gradually decreasing at angles more than 30°(open circles). This result with the correction shows that the electric field is also relaxed by the second lowering factor.

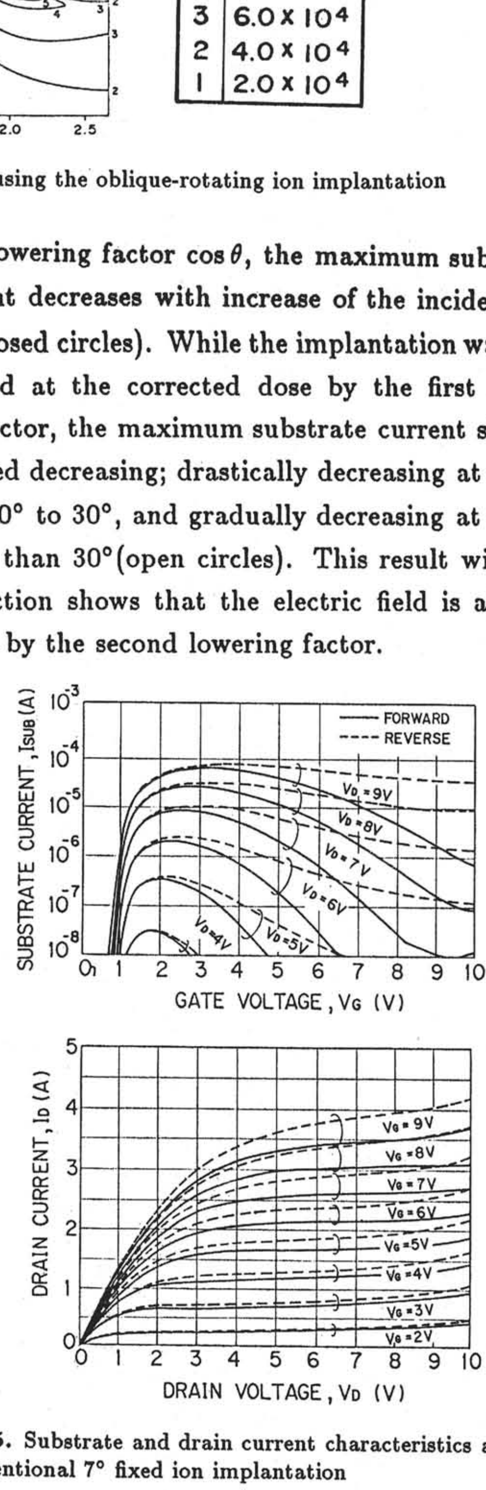


Fig.5. Substrate and drain current characteristics at the conventional 7° fixed ion implantation

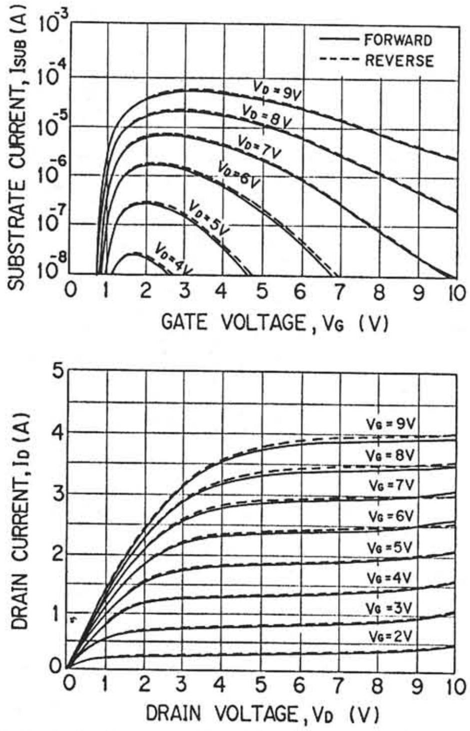


Fig.6. Substrate current and drain current characteristics at the 15° oblique-rotating ion implantation

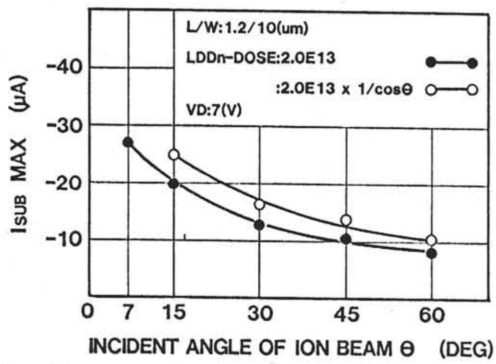


Fig.7. Dependence of maximum substrate current on an incident angle of the oblique-rotating ion implantation

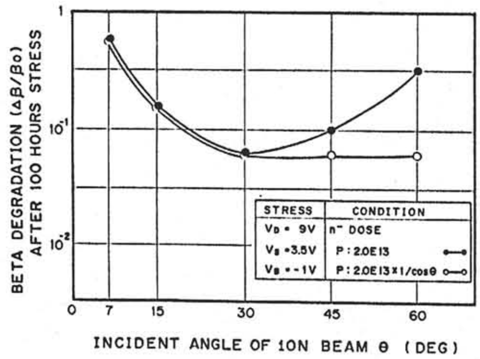


Fig.8. Dependence of β degradation on an incident angle of the oblique-rotating ion implantation after 100 hours' stress

The β degradation after 100 hours' stress of these samples were measured as shown in Figure 8. It is found that in a case without correction an amount of the β degradation decreases and reaches the minimum at 30° and increases again at angles more than 30°. On the other hand in a case with correction the degradation decreases from 0° to 30° in the same manner, and keep the minimum at angles more than 30°. The result from 0° to 30° indicates that β degradation is also improved only by the second lowering effect. From the result at angles more than 30° it is supposed that in a case without correction β degrades owing to the lowering of the surface impurity concentration by the first lowering factor ,but in a case with correction this lowering is negligible.

4. Summary

We obtained the results that the oblique-rotating ion implantation improved not only asymmetric characteristics but also hot carrier effect of LDD MOSFET's. In accordance with hot carrier effect the lowering dose effect by the oblique ion implantation relaxes the electric field, however increases the parasitic sheet resistance. Therefore It is suggested that the optimized angle and impurity dose of the new implantation method must be determined after total consideration of the electric field relaxation and the lowring effect of the surface impurity concentration, as well as the symmetric effect.

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