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Extraction of Depth-Dependent Lateral Standard Deviation from One-Dimensional Tilted Implantation Profiles

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Introduction

Ion implantation is commonly employed in VLSI technology. As MOS device scaling continues, it is expected that the lateral distribution of impurity profiles strongly affects the device characteristics. The key parameter to determine the lateral extension is lateral standard deviation ΔR_{pt} (Fig. 1).

Up to now, there have been many theoretical estimates but less experimental data for ΔR_{pt} [1–3] due to the lack of accurate 2-D profiling technique [4, 5]. In this paper, we propose a simple method which enables us to extract ΔR_{pt} including its depth dependence only from 1-D (vertical) SIMS profiles with various tilts.

Model for tilted implantation profile

We denote the 2-D impurity profile in a-Si as $N(x, y)$, with x as the vertical coordinate and y as the lateral one.

When the tilt angle is 0 ° (Fig. 2(a)), $N(x, y)$ is expressed as

$$N(x, y) = \Phi h(x) \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi}\Delta R_{pt}(x)} \exp\left[-\frac{(y-y_i)^2}{2\Delta R_{pt}^2(x)}\right] dy_i = \Phi h(x) \quad (1)$$

follows, by assuming a Gaussian lateral distribution function, where Φ is the dose, $h(x)$ is the vertical profile which is independent of y, $\Delta R_{pt}(x)$ is the depth dependent ΔR_{pt}, and y_i is the incident beam location, respectively.

For a tilt angle α ($\neq 0$) (Fig. 2(b)), on the other hand, we assume that the profile along the incident beam direction only depends on the depth from the surface. By integrating impurity concentration parallel to the y axis, followed by changing the (x, y) coordinate to the wafer one (s, t) as shown in Fig. 2(b), we obtain

$$N(s, t) = \Phi \int_{-t\frac{\cos\alpha}{\tan\alpha}}^{\infty} h(t\cos\alpha + k\tan\alpha) \times \frac{1}{\sqrt{2\pi}\Delta R_{pt}(t\cos\alpha + k\tan\alpha)} \exp\left[-\frac{(t\sin\alpha - k)^2}{2\Delta R_{pt}^2(t\cos\alpha + k\tan\alpha)}\right] dk \quad (2)$$

Equation (2) indicates that the tilted implantation profile becomes a function of both lateral standard deviation and tilt angle. That is, lateral standard deviation can be extracted from the tilted implantation profile in theory.

For detailed understanding of ΔR_{pt} dependence of tilted implantation profile, we consider an example of special case by using a simple Gaussian $h(x)$ and a constant ΔR_{pt}. In this case, Eq. (2) reduces to also Gaussian function and the following relationships for Gaussian parameters are obtained.

$$R_{p\alpha} = R_{p0} \cos\alpha \quad (3)$$

$$\Delta R_{p\alpha}^2 = \Delta R_{pt}^2 \sin^2\alpha + \Delta R_{p0}^2 \cos^2\alpha \ , \quad (4)$$

where R_p and ΔR_p are the projected range and its standard deviation, respectively, and the suffix indicates the tilt angle. According to Eq. (4), it is clear that the contribution of ΔR_{pt} to $\Delta R_{p\alpha}$ becomes larger as the tilt angle increases. And we can extract ΔR_{pt} by evaluating both $\Delta R_{p\alpha}$ and ΔR_{p0}.

Extraction of depth-dependent ΔR_{pt}

Based on the theory in previous section, we tried to extract ΔR_{pt} for various ions experimentally.

As, P, Sb, and B ions were implanted at various tilt angles and energies with a fixed dose of 1×10^{14} cm^{-2} into CVD a-Si films deposited on (100) Si substrates. We describe $h(x)$ through joined half Gaussian distribution for As, Sb, and P, and Pearson IV distribution for B.

Figure 3 compares SIMS profiles with analytical ones at an energy of 40 keV. The dashed lines in the figure show analytical curves fitted by using a constant ΔR_{pt}. An joined half Gaussian and a Pearson IV function well express the SIMS profiles in the peak region.

As the tilt angle increases, however, the deviation of the analytical curve from the SIMS profile becomes larger especially in the tail region. This indicates that the lateral standard deviation depends on the depth [2].

We, therefore, introduce a depth dependent ΔR_{pt} by where m is the proportionality coefficient assumed to be inde-

$$\Delta R_{pt}(x) = m(x - x_0) + \Delta X \ , \quad (5)$$

pendent of implantation energy, x_0 is the location where the main function $h(x)$ has a peak value, and ΔX gives the value of lateral standard deviation at x_0, respectively.

Overall SIMS profiles are well expressed by using Eq. (5) as shown in Fig. 3 (solid lines). The parameter m for each ions is also shown in Fig. 3. Since m's are not equal to 0, the lateral standard deviation depends for all ions on the depth, and it increases with depth for As, P, and Sb, but it decreases with depth for B.

By comparing ΔR_{pt} depth dependence for As between experiments and Monte Carlo simulations [2], our extracted data showed a very similar depth dependence to the calculated one, so Eq. (5) seems to be a good approximation.

Table I summarizes the experimentally extracted ΔX together with the parameters of an joined half Gaussian or a Pearson IV distribution against ion implantation energy. The reported average ΔR_{pt}'s [1] based on theory are also shown in the table. For As and Sb, ΔX is close to the standard deviation of the front part of the Gaussian ΔR_{p1}. For P, on the other hand, ΔX agrees well with that of the back part of the Gaussian ΔR_{p2}. As for B, ΔX resulted in almost the same of the second moment of Pearson IV distribution ΔR_p. Totally, our extracted values agree well with the theoretical ones verifying the validity of our model.

Conclusion

We proposed an extraction method for evaluating the lateral standard deviation. This method successfully permits us to evaluate the depth-dependent lateral standard deviation experimentally for various ions in a-Si from tilt angle dependent depth profiles.

References

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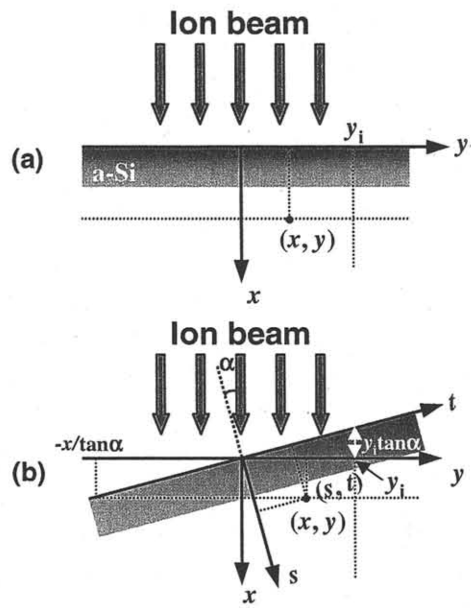

Fig. 2 Coordinate system used in this study in the case of (a)tilt = 0 ° and (b)tilt = α (≠ 0 °).

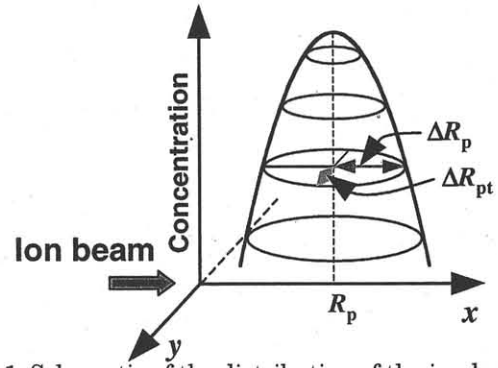

Fig. 1 Schematic of the distribution of the implanted ions. There are both lateral and vertical straggle which are characterized by ΔR_{pt} and ΔR_p, respectively.

Table I Extracted distribution parameters (nm)

Energy (keV)		20	40	80	160
As	R_p	15.7	25.2	46.6	90.2
	$\Delta R_{p1}/\Delta R_{p2}$	5.5 / 12.4	8.1 / 17.1	14.4 / 27.8	27.4 / 44.2
	ΔX	6.0	8.0	15.0	25.0
	ΔR_{pt}[1]	4.1	6.9	12.1	22.0
P	R_p	20.1	47.7	106.8	223.1
	$\Delta R_{p1}/\Delta R_{p2}$	8.2 / 16.7	22.5 / 25.0	44.3 / 39.6	79.2 / 53.4
	ΔX	10.1	17.8	30.0	54.4
	ΔR_{pt}[1]	9.4	17.5	32.3	59.6
Sb	R_p	13.7	22.3	37.6	66.0
	$\Delta R_{p1}/\Delta R_{p2}$	3.5 / 7.5	5.5 / 12.0	9.1 / 19.7	15.7 / 34.3
	ΔX	4.0	6.0	9.9	17.0
	ΔR_{pt}[1]	3.0	4.9	8.2	13.9
B	R_p	65.8	134.0	260.3	455.6
	ΔR_p	45.7	60.7	75.1	98.4
	ΔX	34.1	51.5	77.4	96.1
	ΔR_{pt}[1]	29.0	48.3	76.1	108.3

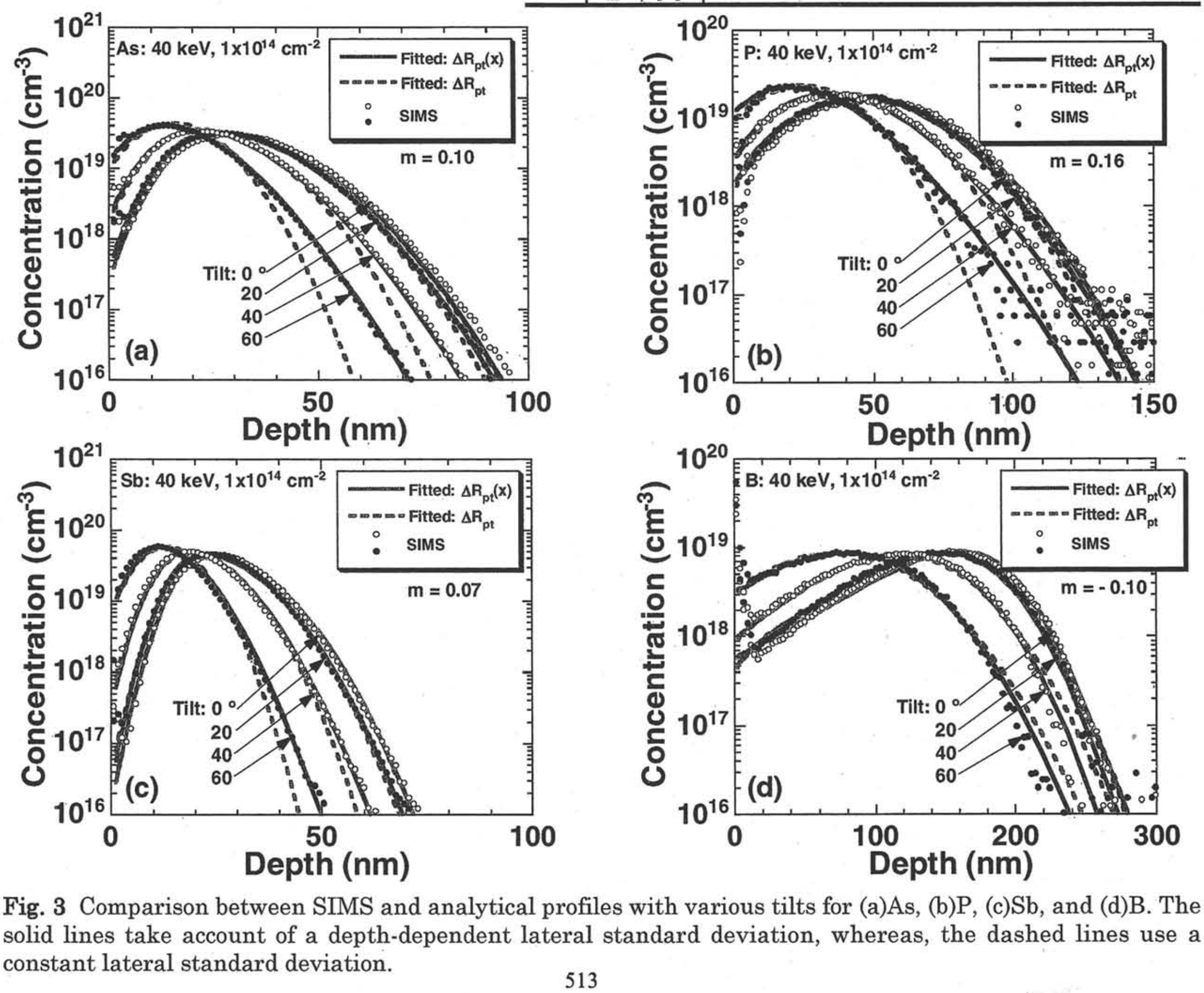

Fig. 3 Comparison between SIMS and analytical profiles with various tilts for (a)As, (b)P, (c)Sb, and (d)B. The solid lines take account of a depth-dependent lateral standard deviation, whereas, the dashed lines use a constant lateral standard deviation.