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Investigation of the Transverse Spread of Erbium Ions Implanted in SOI

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***Abstract*—The Er (erbium) ions at energies of 200 - 500 keV and dose of 2×10^{15} ions/cm^2 were implanted into the optical waveguide material SOI (Silicon - on - insulator) at room temperature (RT) under the angles of 0°, 45° and 60°, respectively. The range distribution of 200 - 500 keV, 2×10^{15} ions/cm^2 Er ions implanted in SOI samples were measured by Rutherford backscattering (RBS) technique. The transverse distribution of 200 - 500 keV Er ions in SOI samples were calculated according to the experimental principle proposed by Seijiro Furukawa et al. The measured results are compared with Monte Carlo code, SRIM (Stopping and Range of Ions in Matter) predictions. It is found that the measured experimental values are in good agreement with the SRIM 2012 theoretical simulation results.**

Keywords—electro-optical materials; transverse distribution; Rutherford backscattering technique; ion implantation

I. INTRODUCTION

Ion implantation is one of the important production process of semiconductor integrated circuit, optoelectronic devices and integrated optics. It has been widely used in integrated optics, magnetic materials, surface physics, chemistry, medicine, metallurgy and other fields, as well as the manufacturing process of various devices. Er's characteristic emission at 1.54 μm, a standard telecommunication wave length, has important significance for optical interconnection and optoelectronic integrated application of optical fiber communication. Photoluminescence (PL) and range profiles of Er doped semiconductors has widely been studied [1–9], ever since Ennen and Schneider [1] first reported on the observation of 1.54 μm PL due to Er in GaAs and Si. With the continuous development of integrated circuit, integrated optics and optoelectronic devices, the traditional Si materials showed some limitations in these areas because of its performance defects. SOI material has good resistance to high temperature, low power consumption, high speed, low voltage and other advantages. It is a key technology that can break through the limitation of bulk silicon material and silicon integrated circuit, and solve the power crisis of VLSI. SOI:Er is one of the prospective materials for light sources emitting at 1.54 μm at RT. In recent years, some works have been done on the projected range distribution, annealing behavior and photoluminescence of Er ions implanted into SOI material[10-11]. But the transverse distribution of Er ions implanted into SOI has not attracted sufficient attention. As far as we know, there has been no report on the research of the lateral spreads of keV Er ions implanted in SOI.

In this paper, the 200 - 500 keV, 2×10^{15} ions/cm^2 Er ions were implanted into SOI samples with different angles. The depth distributions and the transverse spreads of implanted Er ions at the energy of 200 - 500 keV in SOI were obtained by RBS technique. The measured transverse spreads are compared with those obtained by SRIM2012 (Stopping and Range of Ions in Matter, the predictions from Monte Carlo code) [12].

II. EXPERIMENT

The SOI Smart Cut® UNI-BOND wafers used in the work consisted of a 300 nm thick crystalline Si cap layer, on a 500 nm thick buried SiO_2 layer, and a 720 μm thick Si substrate. The implantation is performed on the 500 keV ion implanter at the Institute of Semiconductors, Chinese Academy of Sciences. The SOI samples were cleaned by the standard procedure before implantation. Er ions with energies of 200-500 keV at the dose of 2×10^{15} ions/cm^2 were implanted into the SOI samples at RT at the angles of 0°, 45° and 60° . The voltage (it decided the energy of the implanted ions) of the implanter was calibrated by high-tension voltmeter. To avoid excessive heating of the samples, the incident current density was less than 1 μA/cm^2.

The RBS experiments were performed at 1.7 MV tandem accelerator of the Shandong University. The depth range of Er ions implanted in SOI was measured by the RBS technique. The RBS spectrometry was carried out using 2.1 MeV He^{2+} ion beam produced by a 1.7 MV tandem accelerator with a ion beam current about 10 nA. The SOI samples were fixed on a three axis goniometer actuated by pulse motor in a vacuum chamber. All the measurements were carried out in a vacuum of 2.66×10^{-4} Pa. The backscattering spectra were performed by a multi-channel analyzer.

III. RESULTS AND DISCUSSION

The projection range distribution of Er ions with low energy implanted in SOI was nearly Gaussian, so the deepness profile could be depicted by the projected range and the range straggling, the standard deviation of the Gaussian distribution in deepness. The range straggling has been calculated from the surveyed full width at half maximum (FWHM)[13].

According to the composition by Furukawa and Matsumura[14], the transverse spread of an deposited ion in SOI can be put into the depth range straggling of a target under canted implantation. If the spatiality probability distribution of the implanted ions is a three-dimensional Gaussian, the deepness distribution for a target tilted at an angle to the

incident ion beam also becomes a Gaussian with standard straggling ΔD . The transverse spread and range straggling (longitudinal straggling) were denoted by ΔX_{L} and ΔR_{p} , respectively. Then the transverse distribution could be obtained by using Furukawa's formula[14]:

$$(\Delta D)^2 = (\Delta R_{\mathrm{p}})^2 \cos^2\theta + (\Delta X_{\mathrm{L}})^2 \sin^2\theta \qquad (1)$$

The transverse spread ΔX_{L} can be calculated from two measurements of ΔD for two different tilted implantation angles θ. Generally speaking, the deepness distributions of the implanted ions are not Gaussian absolutely; only in a small incident energy range of the implanted ion is distributed close to a Gaussian. Hence, Furukawa and Matsumura's method can only be approximately correct.

Figure 1 shows the RBS spectrum of 400 keV, 2×10^{15} ions/cm^2 Er ions implanted in SOI sample at an angle of 45° at RT. The energy of the He ion is 2.1 MeV, and the backscattering angle is 165°.

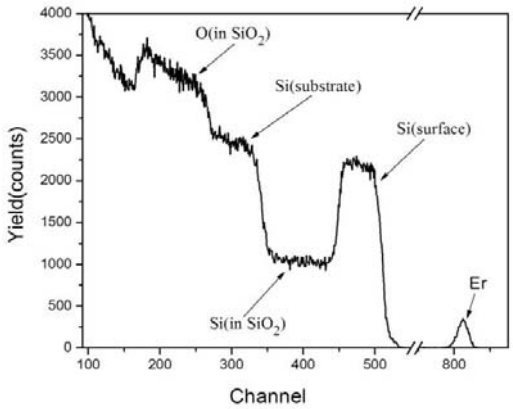

FIGURE I. RBS SPECTRUM OF 400 keV, 2×10^{15} ions/cm^2 Er IONS IMPLANTED IN SOI SAMPLE AT 45°

For the convenience of measurement, calculation, the depth distributions of RBS spectra of 400 keV, 2×10^{15} ions/cm^2 Er ions implanted in SOI samples at 0° and 45° are presented in Figure 2. The distribution shapes denoted by circles and triangles correspond to the samples were performed at 0° and 45° incident angles of the implanted ion beam, respectively. The Gaussian fit curve is represented by the solid line. It is evident that both distribution shapes show nearly Gaussian profiles for the incident ions. The values of the range straggling ΔR_{p} (0°) and ΔD_1 (45°) can be derived from the measured FWHM after taking into account the energy resolution of the measuring system and the energy straggling of He ions in the target. It is seen that the peak position of the distribution of implanted ions shifts toward the surface with an increasing angle θ. The profile shapes closely resemble each other except for a difference in FWHM. The FWHM becomes narrower with increasing the tilted angle. The main step in data analysis is the conversion of the RBS energy spectra to depth profiles. This work was done by using the theory of Chu, Mayer, and Nicolet [13]. The values of ΔR_{p} and ΔD_1 are 39.8 nm, 33.1 nm, respectively. Using Furukawa's formula (1) we get the lateral spread ΔX_{L} of 400 keV Er ions implanted in SOI sample, ΔX_{L1} =24.5 nm.

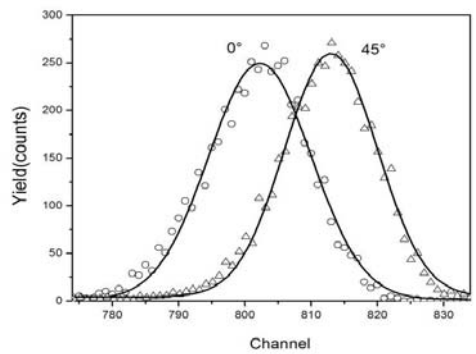

FIGURE II. DEPTH DISTRIBUTIONS OF RBS SPECTRA OF 400 keV, 2×1015 ions/cm2 Er IONS IMPLANTED IN SOI SAMPLE AT 0°AND 45°AND SOLID LINE REPRESENTS THE GAUSSIAN FIT

Figure 3 represents the RBS spectrum of 400 keV, 2×10^{15} ions/cm^2 Er ions implanted in SOI sample at 60°. The energy of the He ion is 2.1 MeV, and the backscattering angle is 165°.

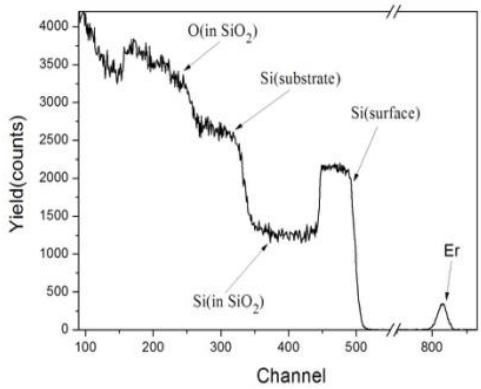

FIGURE III. RBS SPECTRUM OF 400 keV, 2×1015 ions/cm2 Er IONS IMPLANTED IN SOI SAMPLE AT 60°

Figure 4 shows the depth distributions of RBS spectra of 400 keV, 2×10^{15} ions/cm^2 Er ions implanted in SOI sample at 0° (circles) and 60° (triangles). It also gives the Gaussian fit curves (solid lines). It can be seen that the distribution shape shows nearly Gaussian profiles for the 60° implanted Er ions. Same, using the surface energy approximation [13], the range straggling ΔD of the 60° implanted Er ions is calculated, ΔD_2 =33.4 nm. Then another value of the transverse spread ΔX_{L} of 400 keV Er ions implanted in SOI sample was calculated by using formula (1), ΔX_{L2} =25.3 nm.

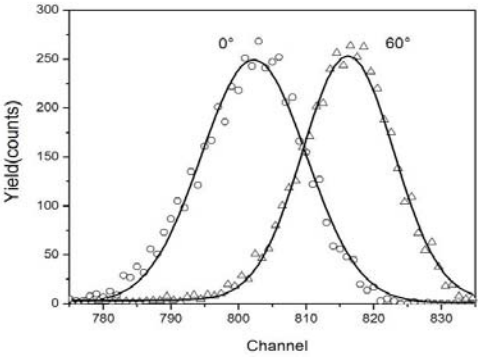

FIGURE IV. DEPTH DISTRIBUTIONS OF RBS SPECTRA OF 400 keV, 2×10^{15} ions/cm^2 Er IONS IMPLANTED IN SOI SAMPLE AT 0°AND 60°AND SOLID LINE REPRESENTS THE GAUSSIAN FIT

The mean experimental value of the transverse spread ΔX_L of 400 keV, 2×10^{15} ions/cm^2 Er ions implanted in SOI samples is calculated from the data of ΔX_{L1} and ΔX_{L2}, ΔX_L =24.9 nm.

One of the primary aim of this work is to compare the experimental transverse spread with its theoretic value. The lateral spread ΔX_L have been calculated by using SRIM2012 code. The value of the lateral straggling of 400 keV Er ions implanted in SOI calculated by SRIM2012 is 23.6 nm. Compare the theoretical simulation value with the experimental data, it can be seen that the experimental value of the transverse spread of 400 keV Er ions implanted in SOI is a bit of larger than the theoretical simulation data. The difference between the theoretical value of SRIM2012 and the experimental result is about 5.2%, which is a good agreement.

A summary of our experimentally determined values of ΔX_{LE} for all implant energies (200 keV, 300 keV, 400 keV and 500 keV) is shown in Table 1, together with values ΔX_{LS} obtained from SRIM2012. As seen in Table 1, the maximum difference between the experimental results and that of SRIM2010 is 7.8%.

TABLE I. SUMMARY OF THE MEASURED VALUES ΔX_{LE} AND THE CALCULATED VALUES ΔX_{LS} OF ΔX_L

E/keV	ΔX_{LE}/nm	ΔX_{LS}/nm	*D*
200	15.3	14.1	7.8%
300	20.2	18.9	6.4%
400	24.9	23.6	5.2%
500	28.3	26.7	5.7%

IV. SUMMARY

200-500 keV, 2×10^{15} ions/cm^2 Er ions were implanted in different SOI samples at room temperature at the angles of 0°, 45° and 60°, respectively. The distribution and the transverse distribution of Er ions implanted in SOI were measured by RBS technique. All deepness distributions of the 200-500 keV Er ions implanted in SOI samples at 0°, 30° and 45° are approximately Gaussian. The transverse spreads ΔX_L of 200-500 keV Er ions implanted in SOI sample were calculated using Furukawa's formula (1) and the data of Chu, Mayer and Nicolet. The experimental values of the transverse spread of the 200-500 keV Er ions implanted in SOI sample are compared with its data of SRIM2012 prediction. It is shown that the experimental transverse spreads agree well with the theoretical values.

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