

Investigation of the Transverse Spread of Neodymium Ions Implanted in SOI

X F Qin*, L Chen and F Y Xu

College of Science, Shandong Jianzhu University, Jinan 250101, China

Email:xfqin@sdjzu.edu.cn

Abstract. It is very important to consider the range distribution and transverse distribution of ions implanted into semiconductor materials in design and fabrication of semiconductor integration devices by ion implantation. The Nd (neodymium) ions with energy of 400 keV and dose of 2×10^{15} ions/cm² were implanted into SOI (Silicon-on-insulator) samples at room temperature under the angles of 0°, 30° and 45°, respectively. The transverse distribution of 400 keV Nd ions implanted in SOI samples were measured by Rutherford backscattering technique. The measured results are compared with Monte Carlo code SRIM2012 predictions. It can be found that the experiment values were in good agreement with the prediction of SRIM2012 code.

1. Introduction

SOI planar waveguide is promising for future low-cost photonic integrated circuits because of its excellent electronic and optical properties and compatibility with mature Si CMOS integrated circuit technology. The rare-earth (RE) particles doping of Si-related materials in the last years has been extensively investigated [1-7] for the development of light-emitting devices in the Si-based optoelectronics. As for RE doped materials, because Er's characteristic emission at 1.54 μm is occurring in the minimum absorption of optical fibers, people have paid much attention to the Er doped Si-related semiconductors [8-13]. Few reports can be found on Nd doped Si-related materials. Nevertheless, it is significant meaningful to investigate the luminescence in Nd³⁺ doped Si-related semiconductors owing to the excitation of strongly quenched high energy levels [14, 15], because not only infrared (IR) emission is produced from the ⁴F_{3/2} level, but also UV and visible luminescence from upper levels, such as ⁴D_{3/2}. And Nd ion is the popular RE element used for solid state lasers as active medium. It is Essential to study the transverse spread of Nd ions implanted in semiconductors, especially for today's deep-submicrometer devices. For all we know, there has been no report on the research of the transverse spreads of implanted keV Nd ions in SOI.

In this work, the 400 keV, 2×10^{15} ions/cm² Nd ions were implanted into SOI samples at the angles of 45°, 30° and 0°, respectively. The depth distributions and the transverse spreads of implanted Nd ions at the energy of 400 keV in SOI were obtained by Rutherford backscattering (RBS) technique. The measured transverse spreads were compared with those obtained by SRIM2012 (Stopping and Range of Ions in Matter, the predictions from Monte Carlo code) [16].



2. Experiment

The implantation was performed on the 500 keV ion implanter at the Institute of Semiconductors, Chinese Academy of Sciences. 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 SiO₂ layer, and a 720 μm thick Si substrate. The SOI samples were cleaned by the standard procedure before the implantation. All the SOI samples were implanted at room temperature (RT) with energy of 400 keV Nd ions at the dose of 2×10^{15} ions/cm². Sample I was implanted with Nd ion beams vertically (In fact, ion implantation has been performed at tilted 7° off the normal plane of the sample surface to avoid the channeling effect, which would result in an error less than 1%). To measure the transverse distributions, tilted angle implantations have been Carried out at 30° and 45° for samples II and III. 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/cm².

The RBS experiments were performed at 1.7 MV tandem accelerator of the Shandong University. The depth range of Nd ions implanted in SOI was measured by the RBS technique. The RBS spectrometry was carried out using 2.1 MeV He²⁺ 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.

3. Results and discussion

The depth distribution of Nd ions implanted in SOI is nearly Gaussian, so the deepness profile could be depicted by the range straggling and the projected range, the standard deviation of the Gaussian distribution in deepness. The range straggling can be calculated from the surveyed full width at half maximum (FWHM)[17].

In term of the composition by Furukawa and Matsumura[18], 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) are denoted by ΔX_L and ΔR_p , respectively. Then the transverse distribution could be obtained by using Furukawa's formula[18]:

$$(\Delta D)^2 = (\Delta R_p)^2 \cos^2 \theta + (\Delta X_L)^2 \sin^2 \theta. \quad (1)$$

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.

The backscattering spectra of Nd ions implanted in SOI show a nearly Gaussian distribution. To get the numerical values of the peak position and FWHM of longitudinal distribution of implanted Nd ions, these spectra were fitted by a computer program. These are relevant to the range straggling and projected range of Nd ions, respectively.

Figure 1 shows a typical RBS spectrum of the 400 keV, 2×10^{15} ions/cm² Nd ions perpendicularly implanted in SOI sample I at RT. The average projected range R_p and the range straggling ΔR_p of the implanted Nd ions in SOI can be calculated from the spectrum by the surface energy approximation[17].

In figure 2 the deepness distribution of 400 keV Nd ions perpendicularly implanted in SOI sample I by normal RBS spectrum of 2.1 MeV He ions is presented. The distribution shape denoted by triangles. The Gaussian fit curve is represented by the solid line. It is evident that the distribution shape shows nearly Gaussian for the incident ions. It is interesting that there is no obvious channeling tail in the spectrum of Nd ions perpendicularly implanted in SOI sample in Fig. 2, which manifests that the channeling effect in the surfase of SOI sample was nearly avoided by ion implantation performed at an

tilted of 7° . The value of the range straggling ΔR_p can be obtained from the measured FWHM after thinking about the energy resolution of the measuring system and the energy straggling of He ions in the target. The key step in data analysis is the transform of the RBS energy spectra to deepness profiles. The work was done by the theory of Chu, Mayer, and Nicolet [17]. The ΔR_p value is 44.1 nm.

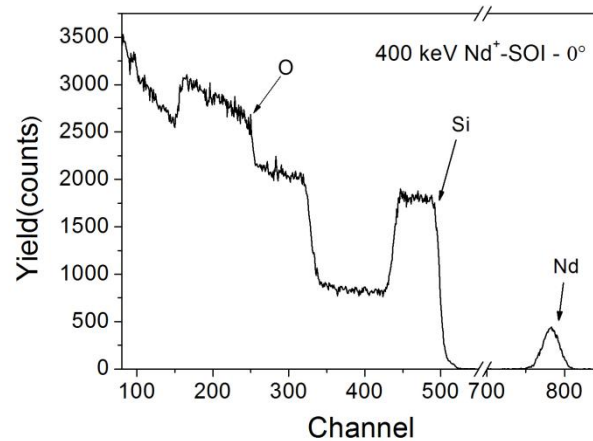


Figure 1. Typical RBS spectrum of the 400 keV, 2×10^{15} ions/cm² Nd ions vertically implanted in SOI sample I

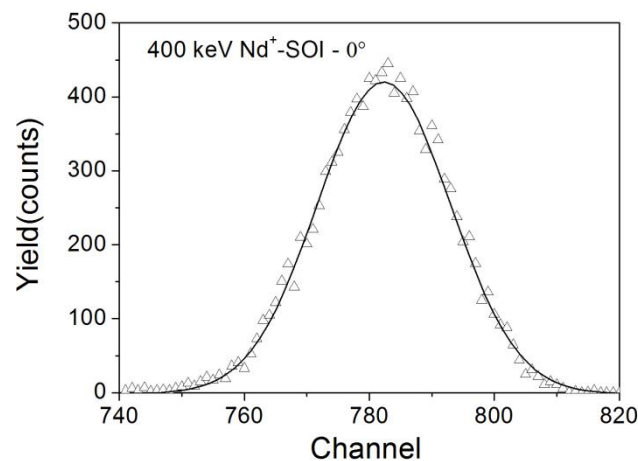


Figure 2. Normal RBS spectra of the deepness distribution of 400 keV Nd ions vertically implanted in SOI sample I. The data of the ions implanted at 0° and the Gaussian fit is represented by the triangles and solid line, respectively.

Figure 3 represents the RBS spectrum of the deepness distribution of 400 keV, 2×10^{15} ions/cm² Nd ions implanted in SOI at angle 30° (sample II). The distribution shape denoted by squares. The Gaussian fit curve is represented by solid line. It can be seen the distribution shape of the implanted ions shows nearly Gaussian profile. The standard deviation ΔD_1 of Nd ions implanted in SOI sample

II at 30° is obtained by the surface energy approximation^[17]. The ΔD_1 value of is 40.6 nm. The lateral spread ΔX_L of 400 keV Nd ions implanted in SOI sample II at angle 30° was calculated by using Furukawa's formula (1), $\Delta X_{L1}=27.6$ nm.

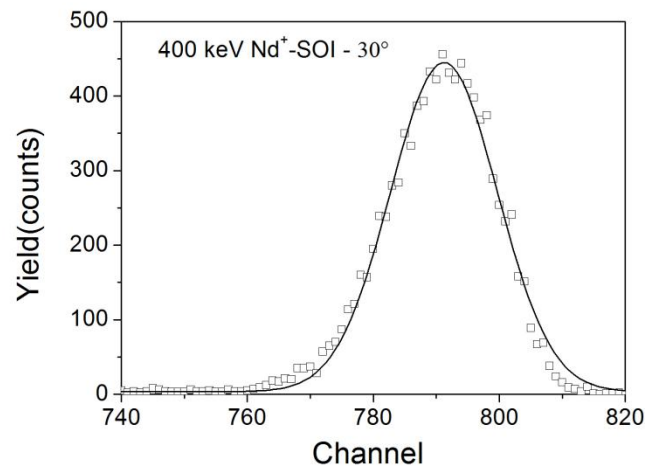


Figure 3. Normal RBS spectra of the deepness distribution of 400 keV Nd ions implanted in SOI sample II at 30° . The data of the ions implanted at 30° and the Gaussian fit are represented by the squares and solid line, respectively.

Figure 4 gives normal spectrum RBS of the deepness distribution (circles) of 400 keV, 2×10^{15} ions/cm² Nd ions implanted in SOI at 45° (sample III). The Gaussian fit curves (solid lines) was given too. It is obvious that the distribution shape shows nearly Gaussian profile for the 45° implanted Nd ions. Same, using the surface energy approximation^[17], the range straggling ΔD of the 45° implanted Nd ions is calculated, $\Delta D_2=37.2$ nm. Then another value of the transverse spread ΔX_L of 400 keV Nd ions implanted in SOI sample III was calculated by using formula (1), $\Delta X_{L2}=28.7$ nm.

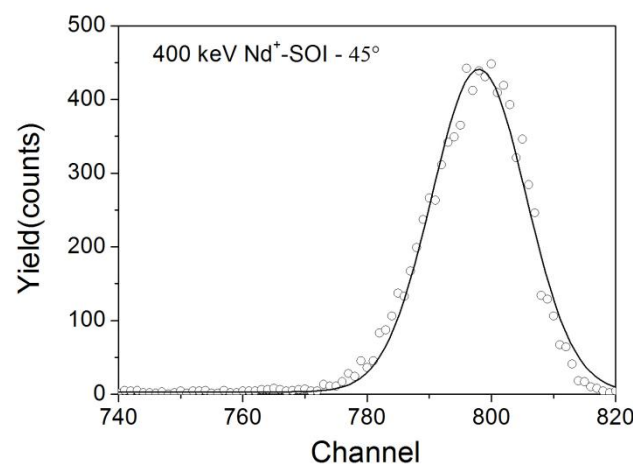


Figure 4. Normal RBS spectra of the deepness distribution of 400 keV Nd ions implanted in SOI sample III at 45° . The data of the ions implanted at 45° and the Gaussian fit are represented by the circles and solid line, respectively.

The mean experimental value of the transverse spread ΔX_L of 400 keV, 2×10^{15} ions/cm² Nd ions

implanted in SOI samples was calculated from the data of ΔX_{L1} and ΔX_{L2} , $\Delta X_L = 28.15$ 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 had been calculated by using SRIM2012 code. The value of the lateral straggling of 400 keV Nd ions implanted in SOI calculated by SRIM2012 is 26.6 nm. Compared the theoretical simulation value with the experimental data, it can be seen that the experimental value of the transverse spread of 400 keV Nd ions implanted in SOI is a bit of larger than the theoretical simulation data. The difference between the theoretic value of SRIM2012 and the experimental result is about 5.5%, which is a good agreement.

4. Summary

400 keV, 2×10^{15} ions/cm² Nd ions were implanted in different SOI samples at room temperature at the angles of 0°, 30° and 45°, respectively. The range distribution and the transverse distribution of Nd ions implanted in SOI were measured by RBS technique. All deepness distributions of the 400 keV, 2×10^{15} ions/cm² Nd ions implanted in SOI samples at 0°, 30° and 45° are approximately Gaussian. The transverse spread ΔX_L of 400 keV Nd ions implanted in SOI sample was calculated using Furukawa's formula (1) and the data of Chu, Mayer and Nicolet. The experimental value of the transverse spreads the 400 keV Nd ions implanted in SOI sample were compared with its data of SRIM2012 prediction. It is shown that the experimental transverse spread agrees well with the theoretic value.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (Grant No. 11205096), the Natural Science Foundation of Shandong Province, China (Grant No. ZR2015AM021), the Shandong Jianzhu University Doctoral Foundation, China (Grant No. XNBS1341), the Science and Technology Plan Project of Jinan City, China (Grant No. 201202092).

References

- [1] Chen C Y, Chen W D, Wang Y Q, Song S F and Xu Z J 2003 *Acta Phys. Sin.* **52** 736
- [2] Wang J Z, Shi Z Q, Lou H N, Zhang X L, Zuo Z W, Pu L, Ma E, Zhang R, Zheng Y L, Lu F and Shi Y 2009 *Acta Phys. Sin.* **58** 4243
- [3] Ennen H, Schneider J, Pomrenke G and Axmann A 1983 *Appl. Phys. Lett.* **43**(10) 943
- [4] Liang J J, Chen W D, Wang Y Q, Chang Y and Wang Z G 2000 *Chinese Phys. B* **9** 783
- [5] Ding W C, Liu Y, Zhang Y, Guo J C, Zuo Y H, Cheng B W, Yu J Z and Wang Q M 2009 *Chinese Phys. B* **18** 3044
- [6] Hansson G V, Du W X, Elfving A and Duteil F 2001 *Appl. Phys. Lett.* **78** 2104
- [7] Lei H B, Yang Q Q and Wang Q M 1998 *Acta Phys. Sin.* **47** 1201
- [8] Fu Y C, Li B S, Yang Y T, Zhang C H, Zhang H H and Zhou L H 2009 *Acta Phys. Sin.* **58** 3302
- [9] Qin X F, Chen M, Wang X L, Liang Y and Zhang S M 2010 *Chinese Phys. B* **19** 113403
- [10] Wang K M, Shi B R, Guo H Y, Wang W and Ding P J 1996 *Mater. Sci. Eng., B* **39** 133
- [11] Biersack J P 1982 *Z. Phys. A* **305** 95
- [12] Qin X F, Wang F X, Liang Y, Fu G, Zhao Y M 2010 *Acta Phys. Sin.* **59** 6382
- [13] Tan N and Zhang Q Y 2006 *Chin. Phys.* **15** 2165
- [14] Lenth W and Macfarlane R M 1990 *J. Lumin.* **45** 346
- [15] Macfarlane R M, Tong F, Silversmith A J and Lenth W 1988 *Appl. Phys. Lett.* **52** 1130
- [16] Ziegler J F <http://www.srim.org>
- [17] Chu W K, Mayer J W, Nicolet M A 1978 *Backscattering Spectrometry* (New York: Academic) chap 5, p137
- [18] Furukawa S and Matsumura H 1973 *Appl. Phys.* **22** 97