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Range and thermal behaviour studies of Tm^+, Er^+ and Yb^+ implanted into $LiNbO_3$ and quartz crystal

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Abstract

Tm^+, Er^+ and Yb^+ have been implanted into $LiNbO_3$ and quartz crystal (SiO_2) in the energy range 100–400 keV. The profile of implanted ions was measured by Rutherford backscattering of MeV He ions. The mean projected range and range straggling obtained were compared with TRIM code. The result shows that (1) The mean projected range and range straggling are in well agreement with TRIM prediction except for 100 keV for $LiNbO_3$ (2) The mean projected range is in good agreement with TRIM prediction within 8%, but the experimental range straggling is higher than the calculated value by TRIM code for quartz crystal. After 800°C annealing for 30 min, it is found that there is no obvious diffusion for the case of 300 keV Er^+, but for the case of 300 keV Yb^+ the diffusion occurs and the diffusion coefficient D estimated is 2.77×10^{-15} cm^2 s^{-1}. © 1997 Elsevier Science S.A.

Keywords: Ion implantation; $LiNbO_3$; Quartz crystal; Integrated optics

1. Introduction

Ion implantation is a promising tool for integrated optics. It is potential to use this technique either for building a waveguide by light ion implantation or for implanting active species such as rare earth ions [1]. The use of ion implantation to change the optical quality of optoelectronic materials has become increasing interest because it is possible to produce integrated optical devices such as waveguide, waveguide laser, and also more complex structures such as double waveguide. $LiNbO_3$ and quartz crystal (SiO_2) are important optoelectronic material. They have been used to form waveguide [2], second-harmonic generation [3]. It is typical for ion implantation that the greatest modification of the index occurs at the end of range of the projectiles [4]. Therefore, the precise knowledge of range profiles of implanted ions into solids is important [5].

Rare earth doped materials have recently achieved great importance for application in optical communication devices. For example, the Er ion shows an optical (intra-4f) transition around 1.5 μm which coincides with the low-loss window of standard optical telecommunication fibres [6]. Thermal stability is an essential aspect of viable waveguide laser. If a waveguide laser is to be successfully produced, for example by implanting rare earth ions, the barrier must be able to withstand the annealing. Waveguides of poor thermal stability have no chance of producing good laser waveguides [7]. The present study is useful in fabrication of the waveguide laser by rare earth ion implantation.

Grande et al have reported the measurement of range profile of As^+, Cs^+, Xe^+, Eu^+ and Yb^+ implanted into SiO_2 in a typically 10–200 keV energy range [8]. They found that the experimental projected ranges are in good agreement with theoretical values predicted by TRIM code [9], but there are significant deviations for range straggling. The objectives of the present work are three-folds. First, to give the measurement of parameter of range profile of Tm^+, Er^+ and Yb^+ implanted into $LiNbO_3$ and quartz crystal. Second, to compare the measured values with TRIM prediction. Third, to study their diffusion behaviour of Er^+ and Yb^+ into quartz crystal.

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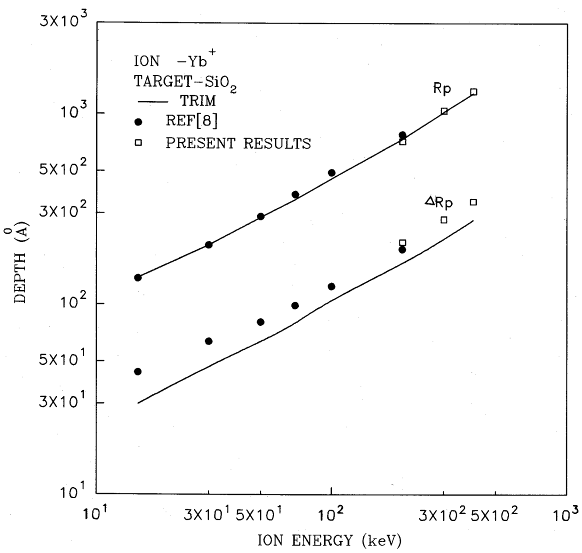

Fig. 6. The experimental mean projected range (R_p) and range straggling (ΔR_p) as compared with TRIM prediction for Yb^+ implanted into SiO_2. Square represents present measurement. Circle data are from [8].

suggested that the experimental value is in good agreement with the TRIM prediction for the mean projected range within 15–400 keV, but the experimental value of the range straggling is higher than the theoretical prediction. Tables 1 and 2 list the comparison of experimental data with calculated values by TRIM code for Tm^+, Er^+ and Yb^+ implanted into $LiNbO_3$ and quartz crystal (SiO_2), respectively. In the present work, the experimental mean projected ranges R_p are in good agreement with the TRIM prediction. This means that the universal potential and the ZBL (Ziegler, Biersack and Littmark) electronic stopping power used in TRIM code are successful for predicting the R_p in the case of $LiNbO_3$ and quartz crystal implanted by Tm^+, Er^+ and Yb^+ in the energy range of 100–400 keV.

Table 1
Comparison of experimental and calculated values on the mean projected range (R_p) and range straggling (ΔR_p) for Tm^+ implanted into $LiNbO_3$

Energy (keV)	Experimental values		Trim prediction	
	R_p (Å)	ΔR_p (Å)	R_p (Å)	ΔR_p (Å)
100	346	150	286	90
200	514	136	470	149
300	682	247	642	203
400	816	311	817	246

The calculated values are obtained based on the TRIM'91 code.

4. Summary

Tm^+, Er^+ and Yb^+ have been implanted into $LiNbO_3$ and SiO_2 with the energy of 100–400 keV. The depth distribution of implanted Tm^+, Er^+ and Yb^+ has been measured by Rutherford backscattering of MeV He ions. The shape of implanted Er^+ and Yb^+ distribution is compared with TRIM'91 simulation. For comparison, Gaussian fit is included. The R_p and ΔR_p obtained are compared with TRIM'91 code. The results show that (1) The measured R_p and ΔR_p are in good agreement with the TRIM prediction except for the case of 100 keV Tm^+ implanted into $LiNbO_3$; (2) The experimental R_p is in good agreement with theoretical value by TRIM code within less than 8%, but experimental ΔR_p is higher than theoretical value by TRIM code. The maximum difference between experimental and calculated values is about 36% for both Er^+ and Yb^+ implanted into quartz crystal. After 800°C annealing for 30 min, no obvious diffusion of 300 keV Er^+ implanted in quartz has been observed. But for the case of 300 keV Yb^+, the diffusion occurs. The diffusion coefficient obtained is 2.77×10^{-15} cm^2 s^{-1}.

Table 2
Comparison of experimental and theoretical values on mean projected range (R_p) and range straggling (ΔR_p) for both Er^+ and Yb^+ implanted into SiO_2

Ion	Energy (keV)	Experimental values		TRIM prediction	
		R_p (Å)	ΔR_p (Å)	R_p (Å)	ΔR_p (Å)
Er	200	705	148	653	142
Er	300	964	222	891	191
Er	400	1186	328	1124	240
Yb	200	622	183	648	145
Yb	300	907	242	893	196
Yb	400	1146	301	1116	241

The theoretical values are obtained by the TRIM'91 code. $D = 2.649$ g cm^{-3}.

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