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Defect Profiling with Low Energy Positrons of Nitrogen Implanted Silicon

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Abstract The vacancy profile in Czochralski silicon (111) implanted with 50 keV nitrogen ions has been determined using positron annihilation spectroscopy. The nitrogen distribution has been measured using secondary ion mass spectroscopy. The fitted defect distribution compares well with the results of TRIM calculations.

Introduction

Ion implantation beneath solid surfaces is widely used for sample preparation and modification in science and technology. The understanding of implanted nitrogen donor impurity is especially important since the nitrogen doping of float zone silicon is used to prevent thermal slip and warpage of wafers subjected to high temperature processing [1,2]. Nitrogen implantation of silicon usually leads to a layer with a very high concentration of defects beneath the surface. Various techniques have been used to investigate the damage created during implantation and the subsequent annealing behaviour in silicon. Of these, positron annihilation spectroscopy (PAS) has been applied successfully to study implantation with hydrogen, boron, arsenic, phosphor, oxygen, helium and fluorine [3-8]. This study extends the use of positrons to study implantation with nitrogen.

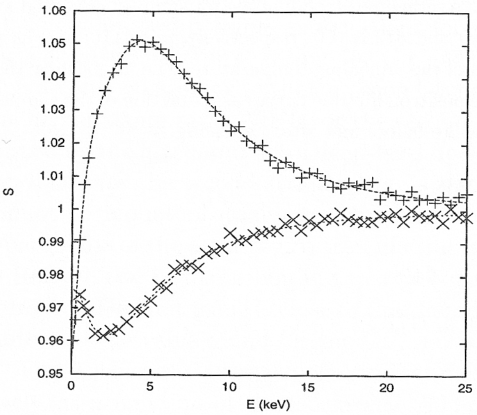

Figure 1. *The Doppler parameter S plotted as a function of positron impact energy for an unimplanted silicon wafer (crosses) and for silicon implanted with 3.5×10^{16} ions/cm^2 at 50 keV (plusses). The lines are the result of fitting the diffusion model to each set of data using ROYDEPPROF program.*

Experimental

Czochralski (111) Si wafers were implanted with 50 keV nitrogen ions at room temperature with a Kuffman ion beam. The beam consisted of 10% N_2^+ and 90% N^+. At the surface the N_2^+ ions immediately break into N^+ and N^o which share the incident energy. First, one sample was implanted with a dose of 3.5×10^{16} ions/cm^2. Subsequently, the profiles of defects beneath the surface of the samples were studied with a variable low energy positron beam (TACITUS). Then, the nitrogen profile of the sample was determined using Secondary Ion Mass

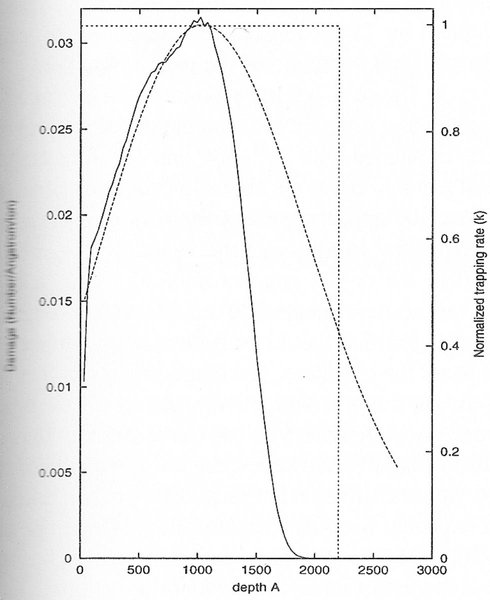

Figure 2. *The defect distribution as calculated using TRIM (solid line), the fitted truncated Gaussian trapping rate (broken line) and the fitted square defect distribution.*

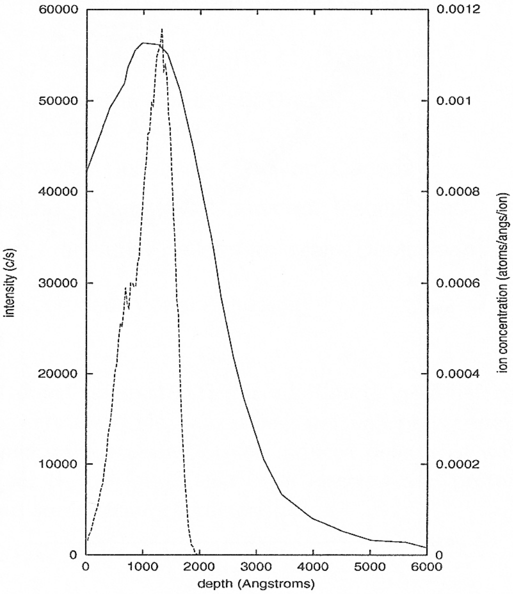

Figure 3. *The SIMS depth profile of ions for the 3.5×10^{16} ions/cm^2 implanted silicon sample (solid line) and the profile as calculated using TRIM (broken line).*

Spectroscopy (SIMS) [9]. The vacancy and nitrogen distributions for 50 keV nitrogen ions in silicon was also calculated using the Monte Carlo ion implantation program TRIM-95 [10]. Afterwards three silicon samples were implanted with doses of 10^{14}, 10^{15}, 10^{16} ions/cm^2, respectively, and studied using TACITUS.

Results and discussion

Figure 1 shows the measured S parameter as a function of incident positron energy for silicon implanted with 3.5×10^{16} ions/cm^2 and for an unimplanted specimen of the same wafer. In silicon, at room temperature single vacancies are believed to disappear resulting in divacancies and for these a specific positron trapping rate σ of 2×10^{-8} cm^3/sec has been reported [11]. We fitted defect distributions to the S curve using our own positron diffusion model program ROYDEPPROF which may accommodate any distribution of defects. The analysis of the unimplanted sample resulted in a diffusion length of 2200 Å which is in accordance with the value of 2150 Å reported by Schultz et al. [12]. Using a square defect distribution we find a defect region of 2200 Å depth and a defect concentration $C_v = 8\times10^{-5}$ defects per atom. Using a combination of two truncated Gaussians the maximum defect concentration yields the same value. One observes for TRIM that the majority of the vacancies produced lies in a region of 2000 Å wide with a maximum at 1000 Å. This is in poor agreement with either the square distribution or the truncated Gaussian. Previously, comparisons between TRIM and positron annihilation spectroscopy [13-15] showed that TRIM underestimates the range of the defect to a greater degree, except for phosphorus implanted into silicon in which compensation may be achieved by adding an electric field [16].

The nitrogen contents for the same sample were measured using Secondary Ion Mass Spectroscopy. The results are shown in figure 3, together with TRIM results for the for 50 keV nitrogen ions implanted into silicon. Figure 3 shows that the measured peak of the nitrogen profile is at about 1100 Å and it falls to zero at about 4000 Å. The figure also shows the nitrogen ion range estimated with

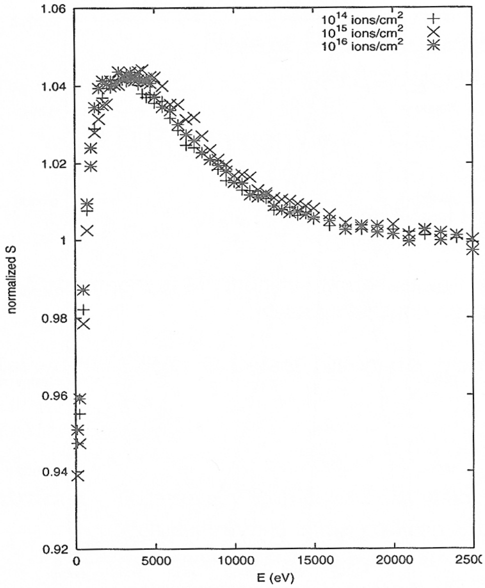

Figure 4. *The Doppler parameter S plotted as a function of positron impact energy for three silicon implanted with 50 keV N_2 ions with different dose.*

TRIM at 50 keV. It turns out that the peak position as calculated by TRIM reproduces the measured value fairly well, but the width of the peak is smaller.

In figure 4 we have plotted the measured S parameter as a function of incident positron energy for silicon implanted with 10^{14}, 10^{15} and 10^{16} ions/cm^2. It is seen that the curves are almost indistinguishable; the low dose 10^{14} appears to create the same damage as the 10^{16} exposure. In principle the value of S is linearly related to the defect concentration C_v. Thus a high dose might be expected to cause greater damage (higher C_v) which would be indicated by a higher S. This is not the case here. The equal heights in S at 2.5 keV might suggest that all the positrons are being trapped in both cases; i.e we have a saturation of positron trapping. However, the left hand side of the curve yields a diffusion length of 500 Å which is larger than expected for positron saturation. Hence, we can conclude that we may have defect saturation, i.e. the defect concentration is independent of the dose.

Acknowledgments

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