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Enhanced Diffusion in Boron Implanted Silicon

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INTRODUCTION

When boron is implanted into crystalline silicon the dopant distribution includes a deeply penetrating tail due to ion channeling (1,2). This channeling tail is an unavoidable consequence of large angle scattering events occuring during implantation. When such samples are annealed it has been observed (3-6) that boron in the tail region diffuses anomalously fast. This occurs for both long (~30 min) furnace anneals at low temperatures (700-800°C) (3) or rapid (~10 sec) higher temperature anneals (1050-1100°C) (4-6).

The cause of this enhanced diffusion has been the subject of considerable discussion (7,8). One possibility, proposed by Fair (7), is that point defects created by the implantation (e.g., vacancies and/or self-interstitials) enhance the tail diffusivity. Because such defects are created primarily near the peak of the boron implantation distribution, this model must involve migration of such defects from the peak damaged region inward to the deeper channeling tail. In this paper we report an experimental test of this "non-local" diffusion model. Samples are annealed with and without the heavily damaged surface region and profiled by SIMS. Preliminary results show similar diffusion in both sample lots in contradiction to the Fair proposal, implying that the enhanced tail diffusion is a "local" phenomenon.

EXPERIMENTAL

Boron was implanted with two batches of 4" <100> 10 Ω cm P-type silicon wafers (#A and #B) using an Extrion DF4 implanter. The wafers were tilted ~7° off-normal, in an arbitrary rotational direction and implanted at room temperature. Boron energy was 40.0 keV and swept beam current was kept low (~100 μA) to avoid beam heating. After implantation wafers in each batch were divided and adjacent pieces were etched in an HF-HNO$_3$ solution to remove ~2000Å (as verified by Dektak profilometer measurement). This 2000Å region contained the peaks of both the boron and damage distributions. Adjacent unetched and etched portions of the B wafers were then annealed together in a rapid thermal annealing furnace at ~1100°C for ~10 sec. This yielded the following sample matrix

Table I. Sample Matrix

#	Implanted	Etched	Annealed
A	X		
A′	X	X	
B	X		X
B′	X	X	X

Boron profiles were measured using an Atomika A-DIDA-3000-30 ion microprobe. An O_2^+ primary beam was selected to enhance boron sensitivity. The O_2^+ beam was incident 2° off-normal at an energy of 10.0 keV. The 300 μA analysis beam was focused to ~100 μm and scanned over a 1/2 mm × 1/2 mm crater yielding an etch rate of ~1/2 μm/hr. Samples were analyzed back-to-back in a vacuum of 2×10^{-9} torr. Signal was collected only over the center 30% of the analysis crater to ensure adequate depth resolution.

Because the experiment depended on discrimination of subtle differences in diffusion profiles, two means were used to monitor and confirm stable SIMS operation. First, both boron and silicon $^{14}Si^{++}$ profiles were measured. Drift in the analysis beam current or detection sensitivity would then be revealed by drift of the $^{14}Si^{++}$ signal. Second, the depth integral of the $^{14}Si^{++}$ signal was compared to the measured volume of the analysis crater. Data was only used if both the $^{14}Si^{++}$ signal was constant during the run (within ± 5%) and if the integrated silicon count to volume ratio was constant sample to sample (within ± 10%).

Typical raw SIMS data is shown for samples #A in Fig. 1. Data for runs satisfying the two above tests were then converted to concentration vs depth profiles via the following processing. To generate a concentration scale, the $^{11}B^+$ count was first divided, point by point, by the $^{14}Si^{++}$ count. This would normalize out any residual drift in SIMS sensitivity. Second, the SIMS boron background signal (as indicated by the flat base count at the deep end of the distribution) was subtracted from the normalized boron count. Finally, the depth integral of the normalized boron count for samples A and B was compared to the stated implant dose of $2 \times 10^{15}/cm^2$ yielding calibration constants for each sample. The calibration constants for the A and B samples were then transfered to the A′ and B′ samples respectively. (A and B samples were calibrated separately to account for a slight discrepancy between implantation doses to the wafers.)

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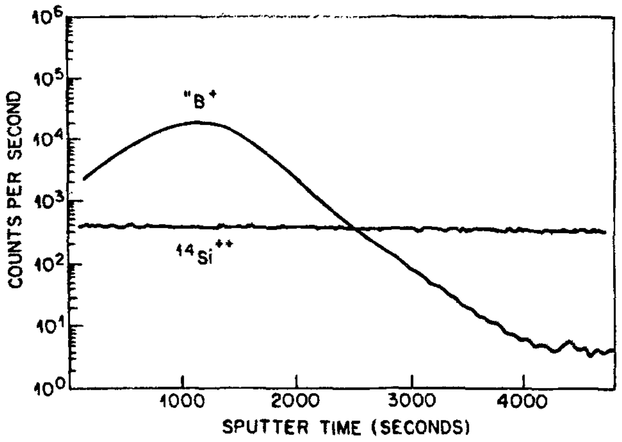

Fig. 1 Raw (unprocessed) data for control boron implanted sample (#A: unetched and unannealed).

The depth scale was established by setting the total sputter time equal to the total crater depth, sample by sample. Given that the samples were composed only of Si and trace B and that the $^{14}Si^{++}$ reference counts were constant during profiling, it can be safely assumed that the sputter rate was constant. Intermediate depth points were therefore established by linear interpolation of the total analysis depth.

RESULTS

Processed data are shown in Figs. 2 and 3. Figure 2 compares unannealed and annealed boron distributions in unetched samples (A and B). Figure 3 compares unannealed and annealed distributions in etched samples (A' and B'). In both figures the channeling tail falls at a rate of ~6.1 × 10^{15}/cm^3/Å in unannealed samples vs ~4.5 × 10^{15}/cm^3/Å in annealed samples. Within our experimental accuracy, the presence or absence of the maximally damaged near-surface region has no effect on the enhanced diffusion of channeled boron tail. Because samples were implanted at room temperature and subjected to no high temperature processing prior to etching, point defects created near the peak of the boron distribution should have been frozen in place and thus removed by the etch. The near identical diffusion of etched and unetched samples therefore indicates that these defects are not responsible for the enhanced channeling tail diffusion.

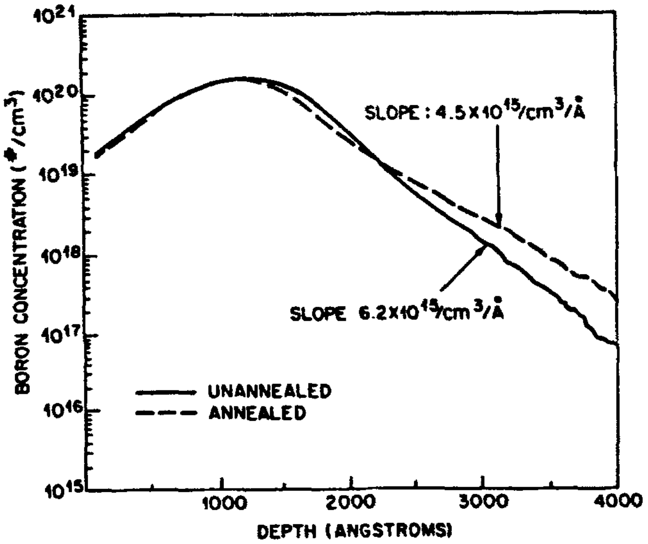

Fig. 2 Processed (calibrated) data for unetched samples with (#B) and without (#A) post implantation anneal.

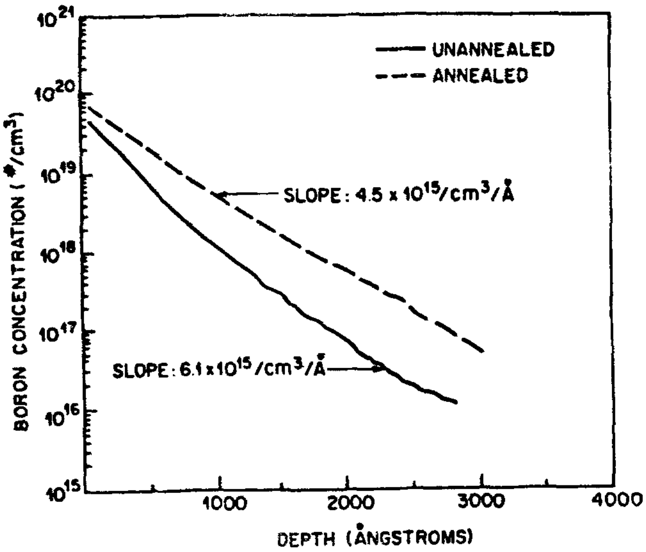

Fig. 3 Processed (calibrated) data for ~2000Å etched samples with (#B') and without (#A') post implantation anneal.

To summarize, SIMS profiling experiments on boron implanted silicon samples indicate that radiation damage created near the peak of the boron profile cannot be the dominant agent producing anomalous diffusion. Alternate models are therefore required to explain and predict the annealing behavior in this technologically important process.

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