Ion Implantation Applications for In-Line SIMS Metrology

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Abstract

In the semiconductor industry, ion implantation process has expanded to a wide range of applications with doses and energies spanning several orders of magnitude.

Ion implantation is a very complicated process with many parameters and factors that affect the implant profile. For example, shadowing effects from higher aspect ratio of photoresist opening, ion channeling or de-channeling effects due to implant angle variations, and dose and implant energy accuracies are all important factors in achieving uniform device performance and good product yield. In addition, current process controls are done on test wafers with certain time intervals, where broken sample pieces are sent outside of the fab for SIMS analysis. The turnaround time is generally long, and the results often do not reflect the actual production conditions. It is known in some cases that, while the control charts are in good standing, the product has failed to meet its specification. The demand for consistent implantation material is becoming more and more important. Hence, the desire for better implant process control is sorely needed.

This paper explores how utilizing Secondary Ion Mass Spectroscopy, (SIMS) in-line to measure peak concentration, peak depth, and dose simultaneously to provide better implant process control.

Background and Introduction

The implantation of ions, mainly Boron, Phosphorous, and Arsenic, have a long history of use in semiconductor manufacturing. By implanting ionized atoms into a semiconductor material n-wells or p-wells can be created, changing the conductivity of the material, a technique that is often used to control threshold voltages of MOSFET devices. The creation of p-n junctions via ion implantation can prevent current flow to the substrate. Alternatively, ion implantation can create contacts to lower contact resistance and prevent diode formation. In the semiconductor industry, ion implantation process has expanded to a wide range of applications, as shown in Figure 1, with doses and energies spanning several orders of magnitude. Depending on the device, a large number of implant operations may be required in the manufacturing process flow. For example, there are about 30 implant process steps in a 128-layer 3D NAND Flash device process flow.

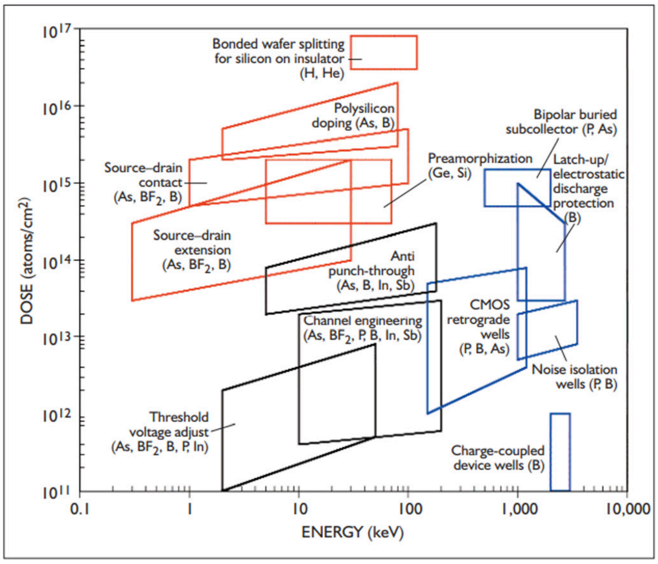

Figure 1. Ion implantation applications in silicon technology at various doses and implant energies[1]

After implantation, the concentration distribution of the implanted ions within the material will resemble a Pearson IV distribution, with the peak depth being controlled by the implantation energy and the concentration being controlled by the implantation dose. Due to the Pearson IV distribution of the implanted ions, the only metrology method capable of measuring the peak concentration, peak depth, and dose simultaneously is Secondary Ion Mass Spectroscopy, or SIMS. By sputtering down through a material, a depth profile of the implanted atoms can be measured, giving a complete look of the shape, amplitude, and depth of the implanted ion distribution. Figure 2 shows the distribution of implanted Boron in Silicon using a TRIM/SRIM Monte Carlo simulation.

(a) (b)

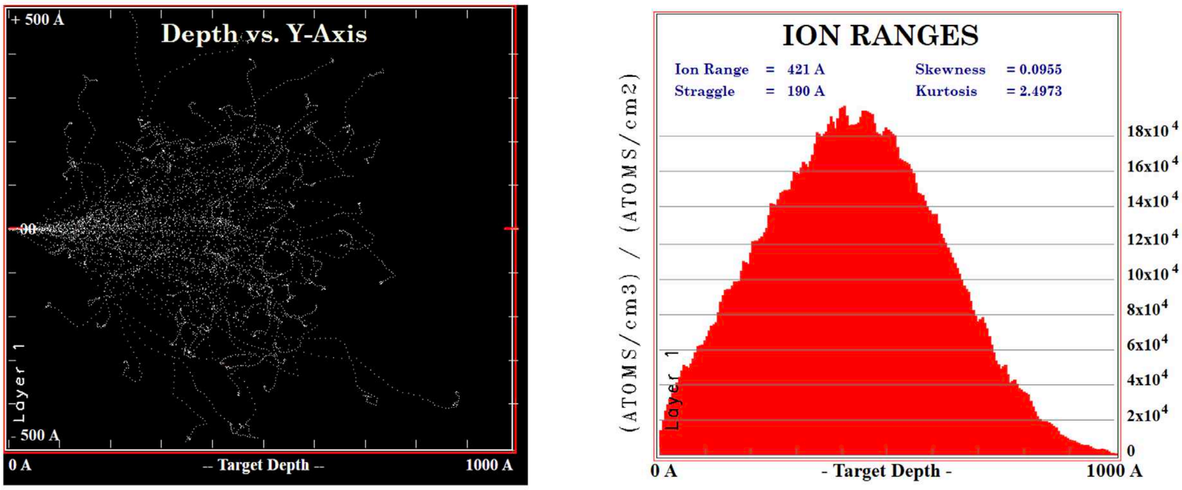

Figure 2. Using TRIM/SRIM, (a) Monte Carlo simulation of ion implantation, and (b) Distribution of implanted Boron atoms in Silicon.

Ion Implant Metrology Challenges

Ion implantation is a very complicated process with many parameters and factors that affect the implant profile. For example, shadowing effects from higher aspect ratio of photoresist opening, ion channeling or de-channeling effects due to implant angle variations, and dose and implant energy accuracies are all important factors in achieving uniform device performance and good product yield. In addition, current process controls are done on test wafers with certain time intervals, where broken sample pieces are sent outside of the fab for SIMS analysis. The turnaround time is generally long, and the results often do not reflect the actual production conditions. It is known in some cases that, while the control charts are in good standing, the product has failed to meet its specification. The demand for consistent implantation material is becoming more and more important. Hence, the desire for better implant process control is sorely needed.

METRION®

Nova's METRION® is a 300mm wafer-level in-line SIMS metrology system developed to seamlessly integrate with an automated high-volume manufacturing (HVM) fab environment. It is a fully automated recipe driven metrology tool utilizing a Magnetic Sector mass analyzer to provide high quality dynamic SIMS depth profiles. It has an O2 ion source that ranges from low to medium high in beam energy for a variety of applications. Because METRION® utilizes a low voltage secondary ion extraction field, it enables stable and repeatable measurements within a 50um x 50um metrology pad on product wafers. With multiple parallel detectors, METRION® can measure multiple species simultaneously through the entire film stack, providing high data density capable of achieving higher depth resolution. Process automation with built-in film analysis and recipe management make the system easy to use and shorten the time to data.

B-implant Application

Boron is one of the most commonly implanted species in semiconductors. It has one fewer valence electron than Silicon, which upon implant, results in a p-type semiconductor. As shown in Fig 1, Boron implant is used in a wide range of applications, in all types of devices in both logic and memory space.

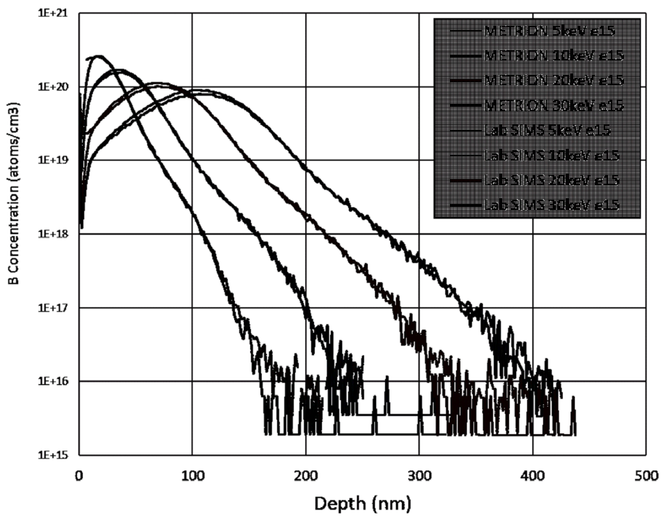

Figure 3. METRION® vs Lab SIMS results for 1e+15 Dose B Implant in Si wafers with Implant Energies of 5, 10, 20, and 30keV.

Figure 3 compares various B-implant SIMS profiles between METRION® and lab equipment. As can be seen, the Boron concentration vs depth profiles from METRION® matches very well with results from lab SIMS. With a full wafer measurement capability, wafer maps can easily be generated from measurements of multiple locations on the wafers, enabling within wafer uniformity process control charts. Figure 4 shows a wafer map example of the Boron peak concentration variation across the wafer, for the 10keV implanted B sample.

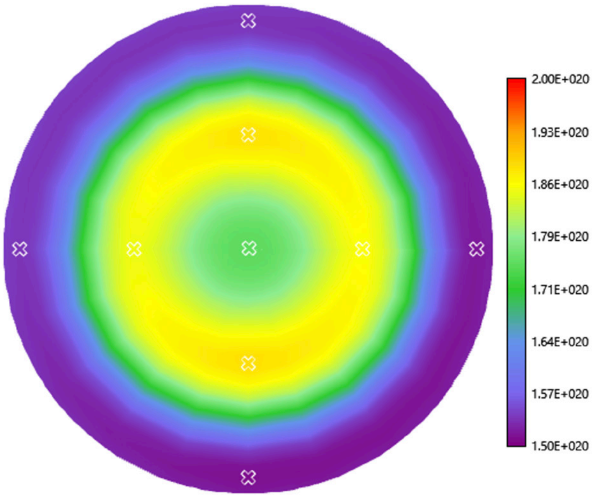

Figure 4. Wafer map of B peak concentration, 10keV Implant

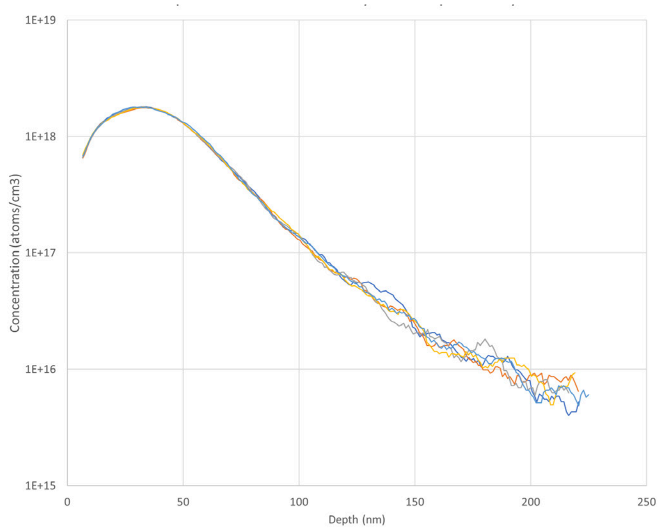

Figure 5. Overlayed of 5x repeat B-implant profiles

As a HVM metrology tool, precision of the measurement is an important metric. In Figure 5, five profiles, which were measured at locations adjacent to each other as proxy for repeatability testing, are overlayed. As can be seen, all the profiles match very well with each other, demonstrating the stability of METRION® SIMS measurements. For most implant dopants, a relative standard deviation (RSD) of <2% can typically be achieved.

Summary

Nova's METRION® system is an innovative SIMS platform designed for the Fab environment, seamlessly integrating into an automated factory workflow. The system is engineered to deliver wafer-based high precision metrology results for process control in logic and memory devices, as demonstrated on ion implant applications. This is enabling Statistical Process Control (SPC) of the ion implant process parameters and providing in-line data correlating to electrical performance.

References

[1] Leonard Rubin and John Poate, "Ion Implantation in Silicon Technology," The Industrial Physicist June/July 2003