"ENERGY CONTAMINATION CONTROL IN MULTIPLE CHARGED ION IMPLANTATIONS."

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ABSTRACT

Ion implantations with multiple charged ions have been shunned by the semiconductor manufacturing industry, because of a lack of control over energy contaminants. Multiple charged ions offer the advantage of extending the energy range of existing ion implanters. However charge exchange reactions can occur that are the core of energy contamination. Multiple charged ions can lose a charge in collisions with residual gas molecules. This causes them to accelerate to an incorrect energy, with subsequent incorrect implantation depth. This in turn leads to poor junction depth control, possible uniformity and dosimetry problems, and hence to unacceptable device yield losses.

Vacuum system pressure, which is often used as a control for multiple charged implantation processes, is not necessarily a good indication of charge exchange levels because of the difficulties associated with measuring and Thermawave, to evaluate the amount of energy contaminants in the implant. Hydrogen pressures, one of the most predominant residual gasses in a vacuum system.

In this article a real time method of measuring charge exchange levels prior to ion implantation of multiple charged ions is introduced, and the resulting capability of process control and recipe interlocking are discussed. The suggested pre-implantation measuring method is compared to several post-implantation analysis techniques such as SIMS.

INTRODUCTION

High energy implants (200 keV - 2 MeV) for (retrograde-) wells, CCD devices and ASIC (ROM) programming, are typically performed on dedicated high energy ion implanters. High cost, a large footprint, and the limited applications of these implanters have caused many semiconductor manufacturers to consider more efficient alternatives.

One alternative is to perform high energy implantations on existing medium current implanters using multiple charged ions. This extends the energy range (usually around 200 keV) of the implanter by a factor 2 to 3, depending on whether double or triple charged ions are used.

Historically energy contamination in multiple charged ion beams [1], has led to poor process control and device yield losses. In this article we present a new method to in-situ measure, and process-interlock the charge exchange reactions that lead to energy contamination. This measurement is performed <u>prior</u> to implantation. Implantation is not allowed to proceed if the contamination exceeds recipe specified limits.

THEORY OF ENERGY CONTAMINATION

Most all medium current implanters today are equipped with a beam filter system that effectively eliminates energy contamination caused by molecular ion species that analyze at the same magnet setting as the multiple charge ion needed for the implant [2,3]. However, charge exchange can occur after the ion beam passes through the beam filter by interaction of the ions with the residual gas of the vacuum system [4,5]. Such a reaction is represented by:

$$P^{++} + A^{o} \rightarrow P^{+} + A^{+} \qquad (1)$$

This reaction typically takes place before final acceleration in the beam line of an ion implanter, which is the reason why the final energy of the P^{+} ions differs from the final energy of the main P^{++} ions that have not undergone a charge exchange reaction. The result is a low energy "shoulder" on the surface side of the depth profile of the implanted peak, as shown by SIMS in figure 1.

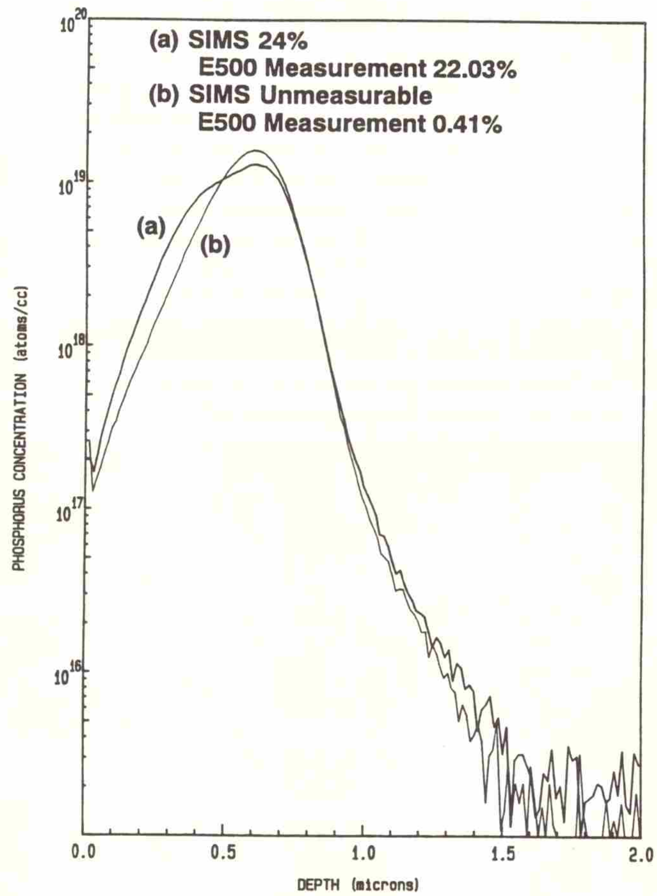

FIG. 1. SIMS profiles of 5e14, 500 keV P++ implants with (A) a high amount and (B) a small amount of energy contamination. The shoulder on profile A is caused by 320 keV P+ ions, which implant at the wrong depth (see text).

This shoulder causes poor control over device junction depth and base width, resulting in yield problems. Depending on the geometry and design of the scan system of the implanter, the presence of singly charged contaminants can also lead to uniformity and dose repeatability problems.

Uniformity problems are caused by different trajectories (by virtue of the different electrostatic and magnetic stiffness) of the single charged ions compared to the double charged ions. Dosimetry problems are simply caused by the fact that single charged ions only contribute one electron to the dosimetry system, thereby causing overdosing of the wafers.

The experiments in this article were performed on a Varian E500 medium current ion implanter that utilizes 70 kV extraction voltage, and 180 kV post acceleration. This allows for implantations up to 500 keV for double, and up to 750 keV for triple charged ions. A 60 kV electrostatic beam filter eliminates molecular energy contaminants.

BEAM PURITY MEASUREMENTS

The paths of single and double charged ion beams in the E500 are displayed in figure 2. The charge exchange reaction (1) occurs in regions labeled A and B in the figure. This reaction results in two, low intensity, single charged beams that are physically separate from the parent main double charge beam (C) at the wafer (see figure).

The separation of the single charged beams from the main beam allows the E500 to measure the intensity of both single and double charged beams individually. This measurement is done by using a movable Faraday cup across the beam path [5,6]. The Faraday cup is first used to measure both the double and single charged beam currents. Next, the voltage on the electrostatic deflector is changed in such a way that only the single charged ion beams are measured. From this data the Energy Contamination (EC%) of single to double charged ions can be calculated [4], using the formula below:

$$EC(\%) = \frac{P^+}{P_T} \times (100\%) = \frac{P^+}{(P^+ + P^{++})} \times (100\%) \qquad (2)$$

Where P^+ is the number of single charge contaminant ions, and P^{++} is the number of double charge ions. P_T represents the total number of ions. The percentage beam energy purity is now defined as:

$$PURITY(\%) = 100\% - EC(\%) \qquad (3)$$

The E500 software allows the user to set energy contamination (EC%) limits in the process recipe. This recipe interlock ensures that the beam purity stays within limits. Using this technique, one gets excellent process control by preventing the wafers from being implanted with energy contamination levels outside of the user-defined window.

For experimental purposes, we installed a series of Nitrogen bleed valves at the CCIG locations along the E500 beam line. This allows for achieving various levels of contamination by increasing the pressure in the vacuum system. Baseline vacuum pressures were about 5E-7 Torr.

All implants were done into <100> Silicon substrates with either P^{++} or B^{++} ions. Subsequent SIMS analysis was done at Charles Evans East on a Perkin Elmer 6600, using a 515 nA, 8 keV Cs^+ ion beam rastered over a 180x180 μm area. The depth axis was established using a calibrated profilometer. The overall accuracy of the profiles was estimated to be 10-15% [7].

The measured SIMS profiles were superimposed, using profile b of figure 1 as a reference. Profile b showed no measurable shoulder, however the electrical energy contamination level was 0.41%. Measurement of the integrated dose in the shoulder of implants that had higher levels of contamination, allowed us to get a post-implant measurement of the energy contamination. An example of such a measurement is depicted in profile a in figure 1. The corresponding software measurements that were done in-situ prior to the implants of figure 1 are given in figure 3a and 3b.

Figure 4 presents the energy contamination results of 10 samples analyzed with SIMS versus the same measurement done electrically before implantation. As can be seen from the figure

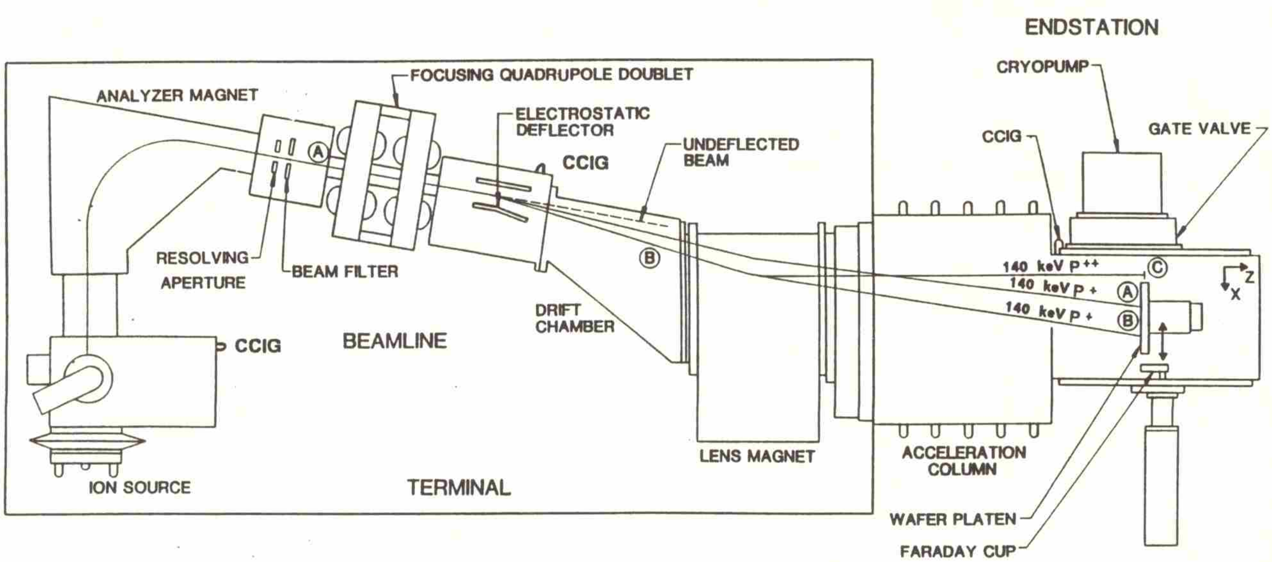

FIG. 2. Trajectories of single and double charged ion beams in the E500 beam line. Nitrogen bleed valves were installed at each CCIG location. No post acceleration is assumed.

there is a strong correlation between SIMS and the electrical method; both techniques basically give the same results. This indicates that the pre-implant in-situ measurement with the Faraday cup provides the necessary process control required for production applications of multiple charged beams.

Figure 5 contains two Thermawave maps of 1e13, 300 keV, B^{++} implants into 200mm wafers. The figure shows that uniformity is maintained well below 0.5% one sigma, even with an energy contamination level as high as 9.72%. This means that dose uniformity is not compromised on the E500, even at high contamination levels. Uniformity can therefore not be used as a process monitor for beam energy purity.

The reason for the good uniformity is the scan- and dose-correction system of the E500 implanter. The contaminant beams are scanned completely over the wafer along with the desired double charged beam. The implanter software measures the dose-uniformity of the swept beam along the X-axis (see figure 1). Any non-uniformity's are corrected out before the implantation begins [6].

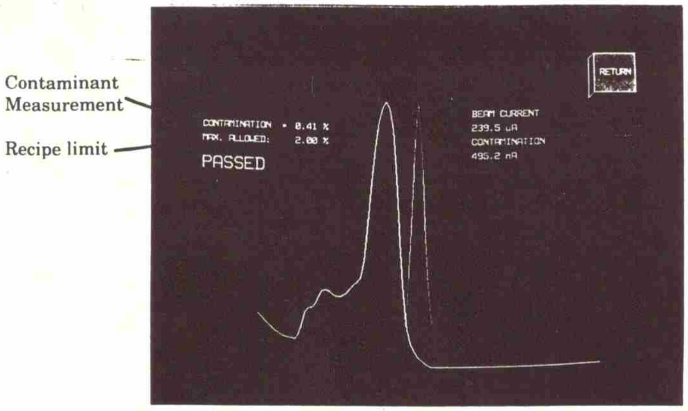

FIG. 3a. Computer screen display of the electrical check prior to implantation. Energy contamination = 0.41%. The recipe interlock allows 2.0% and the implant will proceed.

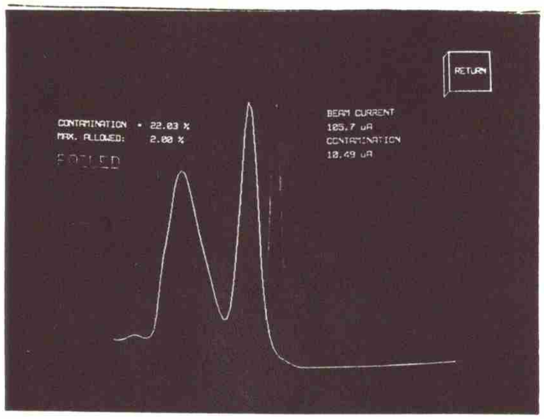

FIG. 3b. Computer screen display of the electrical check while bleeding gas into the beam line. Energy contamination is 22.03%. The implant is not allowed to proceed.

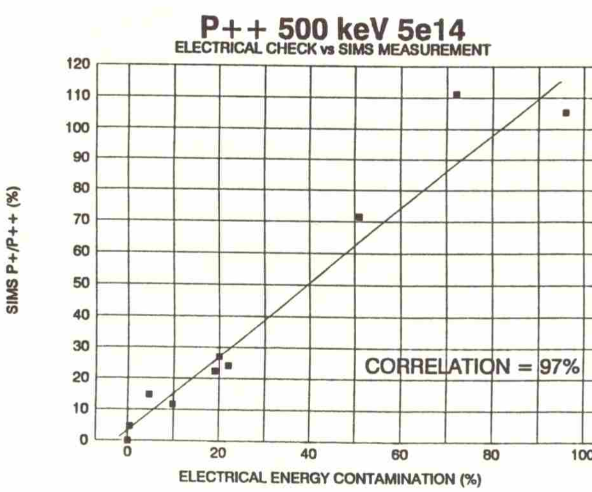

FIG. 4. Energy contamination measurement, before implantation (electrical technique), and after implantation, measured with SIMS.

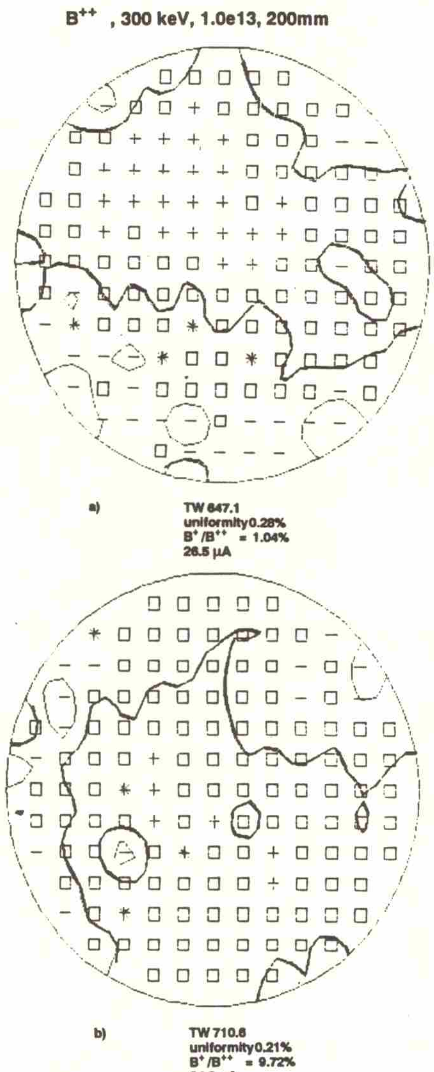

FIG. 5. Uniformity of high energy Boron implants on 200mm wafers with (a) normal energy contamination levels, and (b) artificially high contamination levels. Note that the uniformity is not affected by the contaminant.

Thermawave signals are quite sensitive to variations in contamination level as is demonstrated in figure 5 and 6. In figure 6 we have plotted Thermawave units as a function of the energy contamination level for a 300 keV, 1e13, B^{++} implant. There is a linear relationship between the two Thermawave signal and energy contamination numbers.

The change in Thermawave units is much larger than could be expected on the basis of a dose change caused by the single charged ions alone. The total dose change of an implant having around 3% single charged impurities would lead to an over doses of roughly 1.5%. Taking an estimate for Thermawave sensitivity to changes in dose of 0.3, we would expect a change of only 0.5% in Thermawave units. This would account for about a 3 Thermawave unit change in figure 6. However, figure 6 shows a change of almost 40 Thermawave units, which can be explained by the fact that the crystal damage produced by the single charged ions in the shoulder of the profile is closer to the surface. Thermawave units could therefore be used as a process monitor for this particular implant. Figure 6 also shows that there is virtually no change in uniformity with increased energy contamination levels.

This trend in increasing Thermawave units for increases in energy contamination is also observed for Phosphorus implants, although the differences are smaller. This is probably due to the larger straggle of the phosphorus ions which obscures the shoulder on the profile.

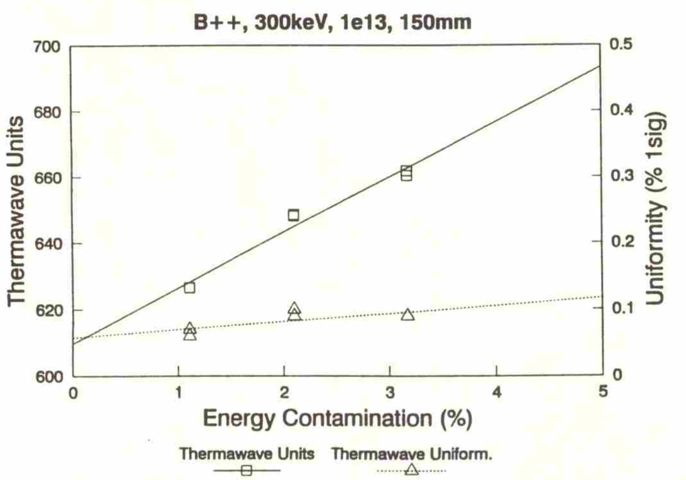

FIG. 6. Thermawave signal as a function of energy contamination. Note that the uniformity (left) is not affected by increased contamination levels.

DISCUSSION AND CONCLUSIONS

We have demonstrated a new technique for measuring and monitoring charge exchange reactions prior to implantation of multiple charged ion beams on an E500 medium current implanter. There is a clear relationship between the energy contamination level measured in-situ before implantation, and SIMS and Thermawave measurements afterwards. This technique establishes the process control capabilities needed for high energy implantations, giving the user predictable and repeatable high energy implants, with acceptable results for beam energy purity, uniformity and dosimetry.

This in-situ electrical technique, gives a unique process control capability for multiple charged implantations that was previously unavailable. Vacuum system pressure interlocks that are sometimes used, are not reliable enough since the vacuum gauges, that are used to measure system pressure, are not very sensitive to Hydrogen; an important residual gas in ion implanter systems. Vacuum gauges also only give an indirect control on the energy contamination process.

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