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ENERGY CONTAMINATION CONTROL IN A MEDIUM CURRENT ION IMPLANTER

First Results of an Experiment to Match Electrical and SIMS Measurements on an E500 Medium Current Ion Implanter

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First Results of an Experiment to Match Electrical and SIMS Measurements on an E500 Medium Current Ion Implanter

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Abstract

High energy implants (200 keV - 2 MeV) are typically performed on dedicated high energy ion implanters. High cost, a large footprint, and the limited applications of these dedicated implanters have caused many semiconductor manufacturers to seek more efficient alternatives.

One alternative is to optimize their usefulness in production by using high energy implanters to back up medium current implanters. However, this option is not feasible for many advanced processes because they require high wafer tilt angles and wafer rotation during implant.

Now, a new medium current implanter with high energy capability offers an efficient, cost-effective solution to high energy implants with excellent process control. Implants in the 200 – 750 keV range can be performed on this medium current implanter utilizing double or triple-charged ions [1].

Historically, energy contamination in the multiple-charged ion beam has resulted in poor process control [2]. In this report we present a new method to measure and process-interlock the ratio of single to double-charged ions during a double-charged implant. This measurement is performed *prior* to implant, and is compared to a programmable recipe limit. The energy contamination interlock provides the process control necessary to utilize multiple-charged implants in the production environment.

Energy contamination measurements performed on the new Varian E500 medium current ion implanter are compared with post-implant analysis using SIMS, verifying the implanter's in-situ beam purity measurement capability.

Charge exchange between double-charged ions and residual gas molecules leads to the presence of single-charged ions in the beam with different final energies [3,4]. This energy contamination (EC) affects the depth, uniformity and dosimetry of the implant. Energy contamination shows up in SIMS depth profiles as a "shoulder" on the main peak toward the substrate surface (Figure 1). If uncontrolled, this shoulder on the profile causes poor control over device junction depth and base width, resulting in uncontrollable yield problems. The charge exchange reaction that causes this form of contamination is given by

$$P^{++} + A^{0} \rightarrow P^{+} + A^{+} \qquad (1)$$

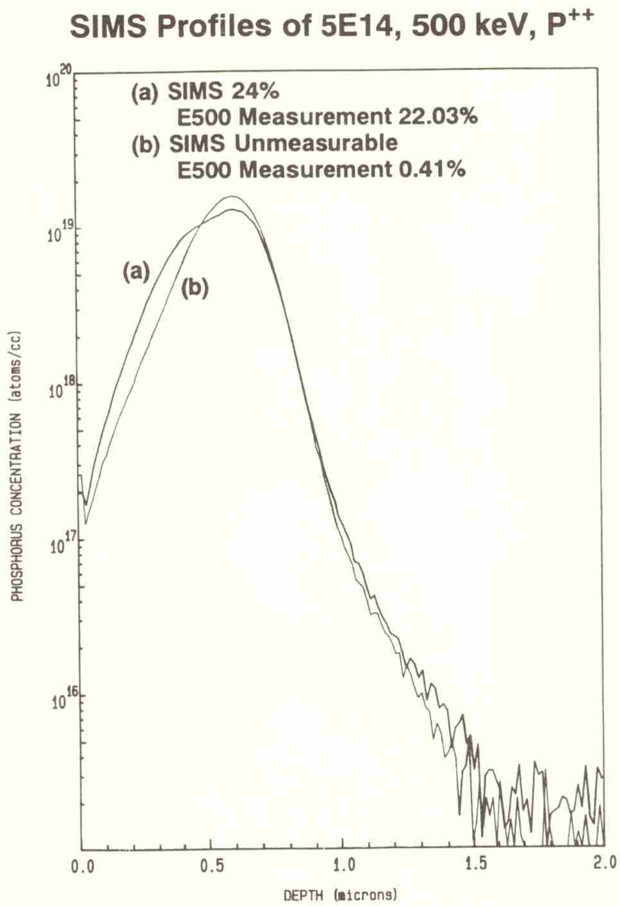

FIG. 1 SIMS profiles of 5E14, 500 keV P++ implants with (A) a high amount and (B) a small amount of energy contamination. The projected range of the 320 keV P+ contaminant is 0.37 μm compared to 0.57 μm for 500 keV P++ ions.

This reaction typically takes place before final acceleration in the beamline of an ion implanter, which is the reason the final energy of the P^{+} ion differs from the final energy of the P^{++} ions that have not undergone a charge exchange.

Depending on the geometry and scan system of the implanter, the presence of single-charged ions can also cause uniformity and repeatability problems. Uniformity problems are caused by the different scan pattern of the single-charged ions compared to double-charged ions.

Dosimetry problems occur because single-charged ions only contribute one electron to the dosimetry system, thereby causing it to overdose the wafers.

The E500 uses a 70 kV extraction voltage and a 180 kV post acceleration. The single charged contaminant therefore has an energy of 320 keV. The use of a higher extraction voltage gives the double-charged ions more speed in the beamline thereby reducing the cross section for charge exchange. It also leads to higher extracted beam currents.

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 A and B in the beamline, resulting in two, low-intensity, single-charged beams into the end station of the implanter. The physical separation of the single-charged beams from the main double-charged beam allows us to measure the intensity of the single and double-charged beams individually.

This measurement is done by using a movable Faraday cup [4,5]. The Faraday cup is first used to measure both 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 ratio of single to double-charged ions can be calculated [4], using the following formula:

$$EC = P^{+}/P^{++} = 2 * I^{+} / (I^{++} - I^{+}) \qquad (2)$$

The E500 software allows the user to set energy contamination [EC] limits in the process recipe. The EC recipe interlocks ensure that the P^{+}/P^{++} ratio stays within control limits. This technique provides excellent process control and prevents wafers from being implanted with energy contamination outside of the user selectable limit.

For experimental purposes we installed a series of Nitrogen bleed valves on an E500 beamline (Figure 1). The baseline vacuum pressure of the

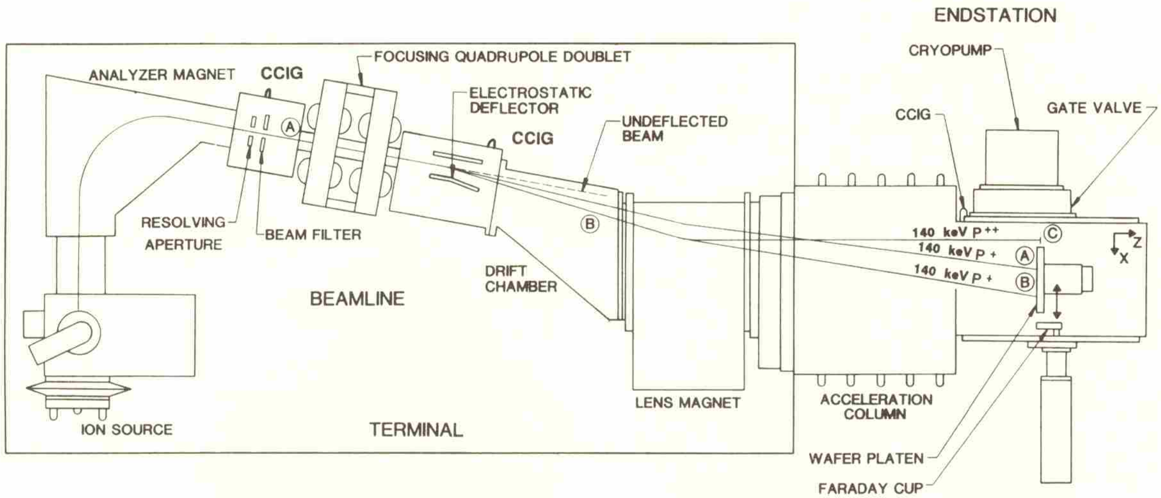

FIG. 2 Trajectories of single and double-charged ion beams in the E500 beamline. Nitrogen bleed valves were installed at each CCIG location. No post acceleration is assumed.

system was smaller than 5E-7 Torr throughout the system. Next we performed a series of 500 keV, 5E14 P^{++} implants (using a vaporizer Freeman ion source) into P<100> wafers with various vacuum conditions, each time measuring the ratio between single and double-charged ions with the translatable Faraday cup. All wafers were subsequently analyzed on a Perkin Elmer 6600 Secondary Ion Mass Spectroscope at Charles Evans East, 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%.

The measured SIMS profiles were subsequently plotted, with the cleanest implant profile (No Nitrogen bleeding into the system and EC = 0.41%) plotted as a reference (Figure 1). This allowed us to establish the P^+/P^{++} ratio for all samples. The P^+/P^{++} ratio measured with SIMS was then compared to the electrical values obtained with E500 before implantation (Figure 3a and 3b). As one can see from the figures, there is a very strong correlation between the two measurements (SIMS and electrical). This clearly indicates that the pre-implant measurement with the Faraday cup provides the necessary process control production applications of multiple-charged beams. In Figure 4 we have plotted the results of the other samples. The X-axis has the pre-implant electrical check results for each sample,

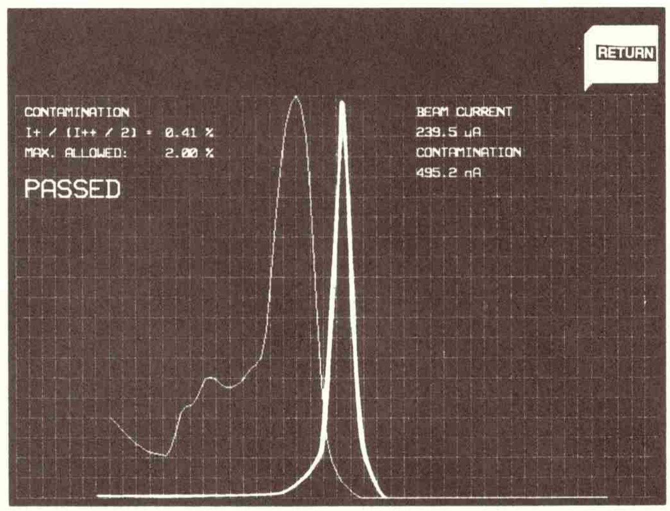

FIG. 3a Computer screen display of the E500 electrical check performed prior to implantation of sample (B). Energy contamination = 0.41%.

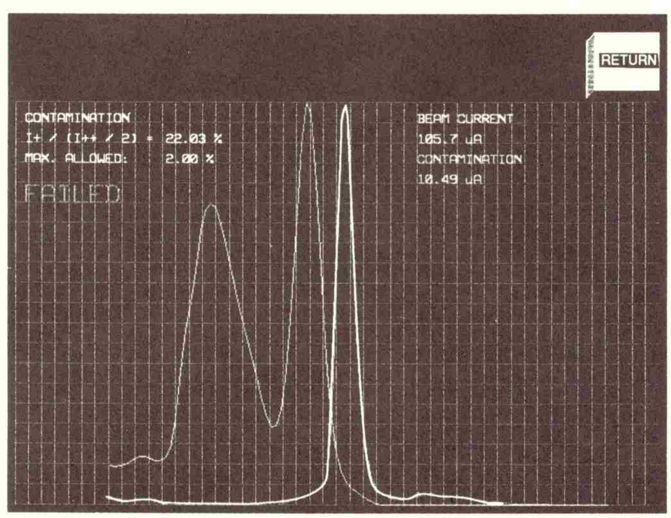

FIG. 3b Computer screen display of E500 electrical check of sample (A). Energy contamination = 22.03%.

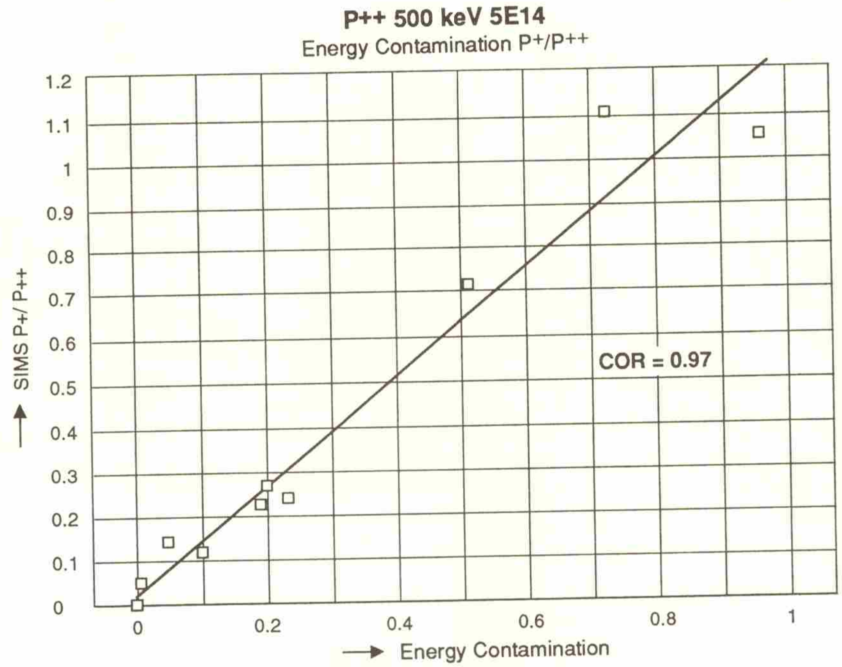

FIG. 4 Energy contamination ratio measurement (EC = P+/P++) measured electrically before implantation, compared to P+/P++ shoulder measurement with SIMS after implantation. Correlation = 0.97.

while the Y-axis contains the results from the P+ to the P++ dose ratio as determined from the shoulder on the SIMS profile. As can be seen from the figure, the post-implant SIMS results closely correlate to the electrical results (correlation is 0.97). This shows that the electrical check and the SIMS analysis give basically the same results. At the low EC level the SIMS analysis is quite inaccurate because the signal to noise ratio disturbs an accurate determination of the shoulder size.

We have demonstrated that a clear relationship exists between the single to double-charged ion ratio measured on the E500 prior to implantation and subsequent post-implant results measured with SIMS. This technique establishes the process control capabilities of the E500 ion implanter for double-charged implantations, giving the end user predictable and repeatable high energy implants. High energy implants can now be safely done on the E500 without the historical problem of unpredictable energy contamination.

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