THE E500 - A NEW MEDIUM CURRENT - HIGH ENERGY IMPLANTER

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High energy ion implantation provides minimal lateral dopant spread compared to a diffusion process, because of the anisotropic nature of the implant process. Ion implantation of retrograde wells for high density circuits allows a closer packaging of CMOS transistors than conventional diffused wells. The trend towards shallower junction depths and hence lower implant energies has brought the high energy implant process into the domain of conventional medium current implanters using doubly or triply ionized atoms.

A concern utilizing multiple charged species in a production environment has been the lack of control over beam energy purity generated by co-implantation of ions with a different energy from the primary beam. This has led to unpredictable yield problems related to junction depth variations, or uniformity and dose changes. The presence of energy contaminants can be dealt with as long as the amount can be predicted and controlled.

The solutions for the above mentioned problems are dealt with in the new Varian E500 medium current - high energy implanter. The E500 uses a combined hardware and software technique to measure and process interlock the acceptable amount of singly charged energy contaminants in a doubly charged ion beam. The operation is conducted prior to the implantation of the wafer.

Results of Thermawave and SIMS measurements on doubly and triply charged Phosphorus and Boron implants will be discussed. We will present the process control capabilities of the E500 and present the correlation between the E500 electrical technique and SIMS measurements of the impurity concentration. Also results of photoresist wafers and 200mm processes will be presented.

1. INTRODUCTION

Market research into the applications of high energy implants has indicated that there is a trend towards smaller device geometries. ($< 1\ \mu m$). The energies used for retrograde well processes have come down to well below 1 MeV [1]. Another factor that plays a role is that a large group of implants for CCDs, ROM programming, and memory well implants, that were traditionally performed on high energy implanters, have come down to energies between 300 and 900 keV. Some implants remain in the > 1MeV domain.

Implantation at these energies can be performed on a conventional medium current implanter using doubly or triply charged ions. A major concern, however, is the presence of beam energy contaminants and cross contamination by species with the identical magnetic or electrostatic stiffness.

The existing E220 medium current implanter has been modified with a higher extraction voltage (70 kV vs. 40 kV) and higher acceleration voltage (180 kV vs. 160 kV). This increases the energy range from 400 keV (double charged ions on the E220) to 750 keV (triple charged ions on the E500). Triple charged ions on the E220 are not generated in a large enough number to be deemed usefull. This energy range covers most of the high energy implants in the applications discussed above.

The higher extraction voltage increases the beam currents of multiply charged ion beams, to the extent that triply charged phosphorus beams can be generated at usable levels. Market research indicates that high energy P-type doping with boron is typically done at less than 350keV [2,3]. The E500 can perform boron doping up to 500 keV.

2. PRODUCT INTRODUCTION

For successful E500 product release into high energy applications, several obstacles had to be overcome. First of all, the capability of the implanter to measure and control single charge contamination in doubly (and triply) charged ion beams had to be proven [4]. Second, the capability of the implanter to function continuously at 250kV while at elevations of 5000 feet had to be proven. Third, performance criteria already established on the E220 had to be re-established on the E500. These criteria included: mass resolution, beam parallelism, beam stability, beam cooling, uptime, reliability, etc.

These obstacles were investigated on several pre-production E500 implanters. One system was used to implant retrograde wells in a 0.5 μm CMOS process [1]. Feedback from this and other applications indicated that multiply charged ion beams can be used with sufficient confidence for a repeatable production process.

Another requirement imposed was that the performance at high energy should not compromise the performance at low (< 250 keV) energy, but should be equal, or in some cases better, than that of the E220. This has been achieved. It is worthwhile to note that the E500 can also be used for formation of shallow junctions [6], and that the beam currents between 40 and 200 keV are substantially higher than the E220 beam currents due to the improved extraction efficiency.

3. EXPERIMENTAL RESULTS

3.1. Beam Energy Purity

The E500 uses a 60 kV electrostatic beam filter and a 240 l/s turbo pump at the resolving aperture. These features eliminate beam energy contamination by molecular break-up and reduce the beam line pressure, resulting in a lower level of charge exchange between the doubly charged ion beam and the residual gas. Furthermore the E500 software has the capability to measure [4,5] the level of singly charged ions in a doubly charged beam (or of doubly charged ions in a triply charged beam). This capability enables the software to interlock the level of impurity at a user defined set point, which guarantees repeatability of beam conditions. This assures implantations with a constant level of singly charged ions resulting in identical implant profiles from run to run.

In figure 1 we have shown the SIMS profiles comparing an implant into a photoresist wafer vs. a bare wafer. There is virtually no difference in the profiles, indicating that photoresist outgassing does not affect the amount of single charge contaminants in the beam, even though the end station pressure was a decade higher during the implant on the photoresist wafer. This can be explained by the fact that the largest amount of charge exchange happens in the beam line of the implanter, rather than in the accel column or in the target chamber. The charge exchange in the end station is insignificantly low compared to that in the beamline. Charge exchange

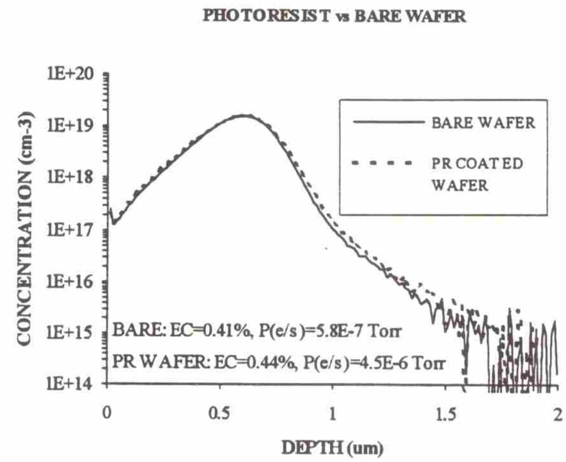

Fig. 1. SIMS profiles of 500keV, $5\cdot10^{14}$, P^{++} implants into a bare and a photoresist wafer.

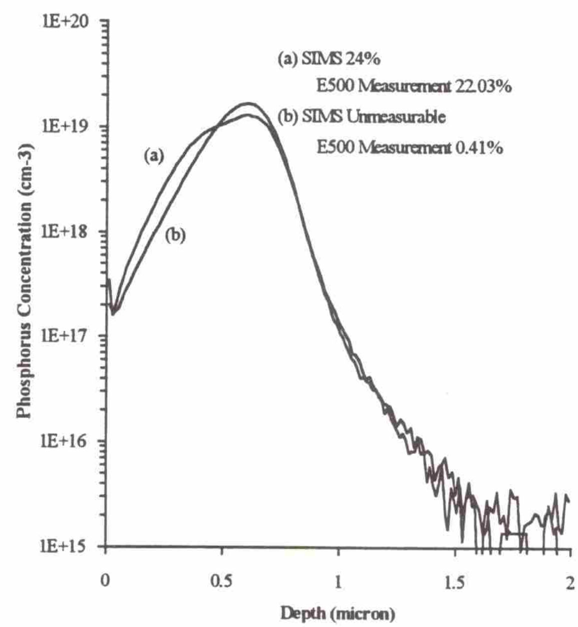

Fig. 2. SIMS profiles of 500 keV, $5\cdot10^{14}$, P^{++} implant comparing SIMS measurement to E500 electrical measurement.

in the end station results in a dose change only, rather than a depth change. This effect is similar to neutralization after post acceleration in singly charged beams. Furthermore, the end station pressure has very little influence on the pressure in the beam line.

The E500 software can measure and interlock the level of charge exchange. This is demonstrated by introducing nitrogen into the beam line, artificially increasing the level of impurity, which can then be measured. The measurement of the E500 software is compared to the measurement of the shoulder dose in SIMS profiles as shown in figure 2. The figure shows a high correlation between the pre-implant software measurement and the post-implant SIMS analysis. Other measurements are compared in figure 3. The correlation between the SIMS measurements and the electrical technique is shown to be around 97%. This indicates that the software can forecast the distortion in the implanted profile.

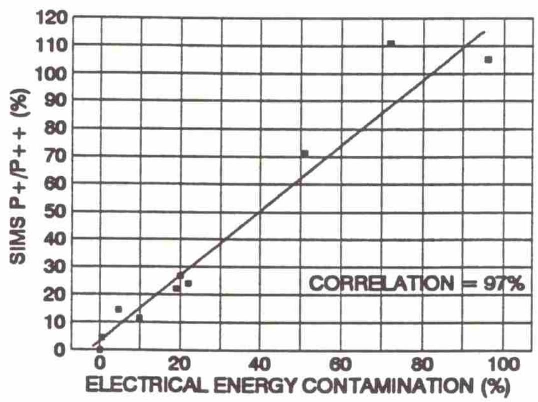

Fig. 3. Chart showing correlation of electrical check vs. SIMS measurement for a 500keV, 5e14, P^{++}, implant.

Although the level of contamination can change with varying beam line pressure, the uniformity of the implant is not affected. This is demonstrated in figure 4, where implants into 200mm wafers with a low and high level of contaminants are presented.

Thermawave measurement are very sensitive to changes in the level of contamination as demonstrated in figure 5. The figure shows that the average Thermawave signal increases with an increase in contamination. This increase is larger than can be expected from the increase in dose alone. A likely explanation is that the damage caused by the single charged ions is closer to the wafer surface, thereby giving an additional increase in Thermawave signal.

3.2. Mass Resolution

The mass resolution and cross contamination of

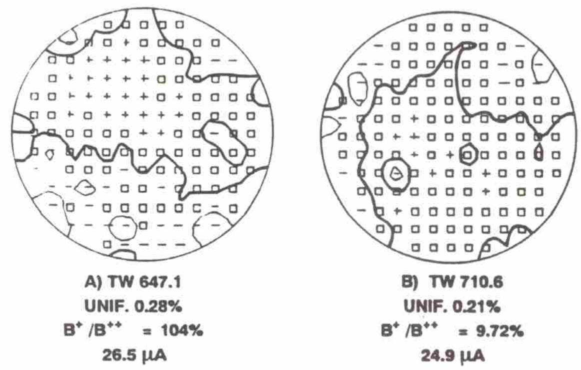

Fig. 4. Thermawave plots showing uniformity of a 300keV, 1e13, B^{++}, implants with low and high levels of B^{+} contamination.

the E500 are particularly important for implantation with P^{+++}. This is because P^{+++} analyses at 10.3 AMU, which is very close to the mass of $^{10}B^{+}$ and $^{11}B^{+}$. As a result, an implantation with P^{+++} could be contaminated with boron. Figure 6 shows that the implantation of P^{+++} after a 1 hour boron beam run does not result in a measurable level of boron cross contamination. Both the ^{10}B and ^{11}B SIMS profiles are at the background level.

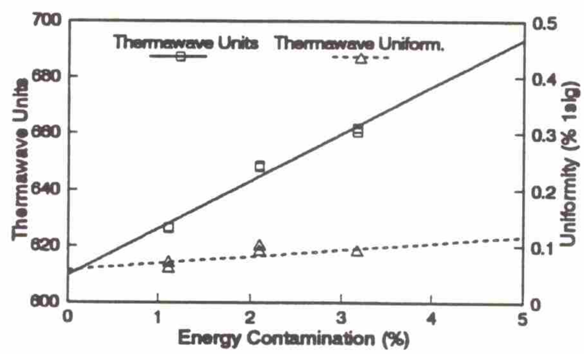

Fig. 5. Chart showing energy contamination vs. Thermawave signal for a 300keV, 1e13, B^{++}, implant.

3.3. Voltage Stability

To prove the E500's capability to hold voltage at both sea level and at 5000ft altitude, several high voltage tests were performed. Figure 7 shows that the E500 will run a 250 keV, 0.5 mA, $^{11}B^{+}$, ion beam for a period of 168 hours while maintaining a glitch rate of less than one glitch per hour for both the ion source and high voltage sections. Source glitches are temporary interruptions of the extraction current, high voltage glitches are temporary breakdowns of the accelerated beam.

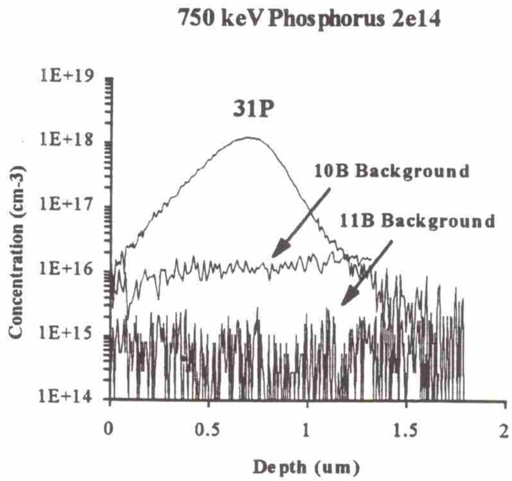

Fig. 6. SIMS profile showing $^{10}B^+$, and $^{11}B^+$ contamination at background levels of the SIMS apparatus in a 750keV, 2e14, P^{+++}, implant.

The E500 uses the same dosimetry system as the E220 which actively corrects total dose and uniformity deviations caused by beam current glitches.

In order to simulate high voltage operation at 5000 ft altitude, the E500 was tested at extraction and acceleration voltages of 15% above the rated maxima. This additional potential translates to the same electrical breakdown potential as the lower atmospheric pressure at 5000ft would generate.

Tests at specified beam current over several hours did not show any sign of corona discharges, which means that the voltage holding capabilities of the E500 will allow operation at 250 kV at high altitude without problems.

4. CONCLUSION

The E500 medium current high energy implanter has been proven capable of implanting doubly and triply charged ion beams with a correct forecast of the amount of single charge contamination.

At this point in time (9-92), six E500s have been installed for high energy implantations. They are mostly used for retrograde well processes in production environments.

Integration of the E500 in a production CMOS N-well process has given satisfactory process control [1]. The E500 is capable of extending the performance of the E220 medium current implanter, without compromising any of the E220 performance parameters, such as reliability, uptime, and low energy performance. Furthermore, the single charge beam current between 40 and 200 kV has improved considerably, (3 mA of As @ 100 keV on E500 vs 1.6 mA on E220) allowing the E500 to be used to backup existing high current implant steps, particularly for As and BF_2.

An additional advantage of using 70 kV extraction is that most BF_2 implants can be performed with extraction voltage only [8], which prevents molecular disassociation before post acceleration and hence energy contamination.

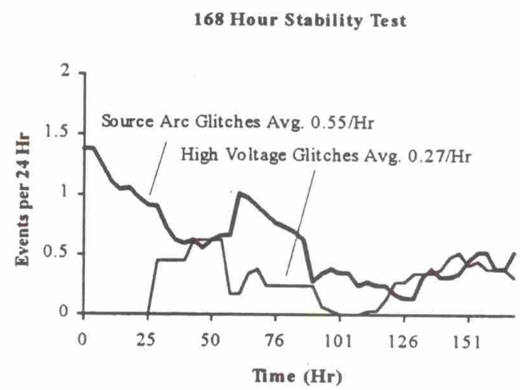

Fig. 7. Chart showing glitch rate over 168 Hr. period with a 250 keV, 0.5 mA, $^{11}B^+$, beam.

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