IntelliScan, Real-Time Scan Waveform Correction for Dose Uniformity on Extreme Photoresist Implant Conditions with Optima XEx

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Abstract. To take full advantage of the high beam current capability of the Optima XEx on photoresist implants, a new, real-time uniformity correction scheme, IntelliScan, was developed. IntelliScan compensates for the dose asymmetry in beam-scan direction developed by charge exchange reactions due to severe photoresist outgassing. It continuously modifies the 1 KHz beam-scan waveform in real-time, according to instantaneous vacuum level in the angle corrector area. Since IntelliScan does not involve any extra steps in wafer handling, such as alternating 180° twist on every pass, high wafer throughput and implant angle integrity can be maintained throughout the entire implant process. This paper will describe the IntelliScan system and its performance on photoresist implants under extreme beam power conditions.

Keywords: dose control, charge exchange reaction, photoresist outgas, ion implantation.
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INTRODUCTION

Electric charge of ions is the fundamental parameter to give ion implantation all the advantages as a dominant doping method. However, in a condition in which the electrical charge of ions changes or even disappears, as seen in photoresist (PR) outgassing, some of the advantages are severely compromised.

The Axcelis Optima XEx higher energy implanter [1] produces a beam current up to 1.5mA for a MeV ion beam, which inevitably results in a severe photoresist outgassing condition during the entire duration of the implant. As reported previously [2], the unique PR cup dosimetry system of the Optima XE maintains good dose integrity on photoresist implants at the wide range of beam current level without any corrections necessary. However, at beam power levels near 2KW, dose non-uniformity resulting from the geometrical asymmetry in the angle corrector magnet becomes non-negligible.

To take full advantage of the high beam current of the Optima XEx, a new, real-time uniformity correction scheme, IntelliScan, was developed. IntelliScan continuously modifies the 1 KHz beam-scan waveform in real-time, utilizing the instantaneous vacuum level in the angle corrector area. Since IntelliScan does not involve any extra wafer handling steps, such as alternating 180° twist on every pass, high wafer throughput, and implant angle integrity can be maintained throughout the entire implant process.

NON-UNIFORMITY DURING PHOTORESIST OUTGASSING

The Optima XEx PR cups-based dose system samples the beam current immediately after the exit of angle corrector magnet using two narrow faraday cups with built-in collimators.

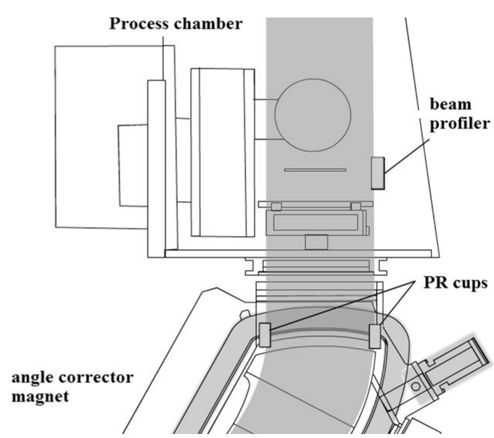

FIGURE 1. The main dosimetry components in the Optima XEx beam line.

The placement, and narrow angle acceptance of the PR cups, Fig.1, essentially eliminates all the influences of charge exchanges on dose measurement that occur in the last, long drift section of the beamline. On traditional rotating disk implanters this has been the major cause of dose shifts and non-uniformities during photoresist implant.

Fig. 2 shows Rs profiles in the beam-scan direction at three levels of beam current for P+ 1200KeV implants on PR wafers (without IntellliScan), along with the bare wafer result. The figure shows that the PR outgassing causes a left-to-right dose asymmetry in the horizontal direction which is very linear in position. The pattern is analogous to tilting the Rs profile, whose slope increases with beam current in a linear fashion.

Figure 2 also shows that the dose shift at x=0, is rather small, even under the most severe outgassing condition in which the PR cup current dipped by >30% at the center of wafer. The small dose shift indicates that the uniformity in the slow scan direction is maintained quite well by the PR dose system of the Optima XEx.

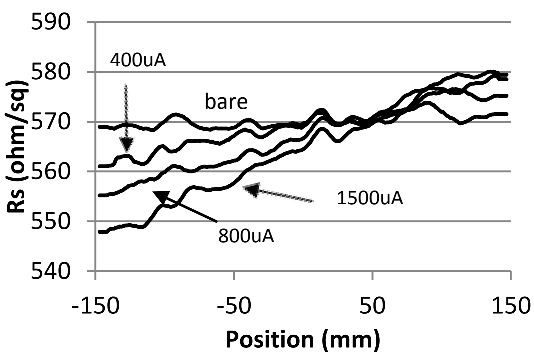

FIGURE 2. Rs profiles of PR wafers in the beam-scan direction for a P+1200KeV implant at three different beam currents along with a bare wafer result.

P+1200KeV, the highest energy beam for single charged phosphorous on Optima XEx, is the most sensitive condition to cross-wafer uniformity. Compared to B+ and P++, which can be run at higher energies, higher beam powers, and produce even worse outgassing pressure, those two species/charge states produce far less uniformity variation from PR outgassing than the P+ 1200keV condition.

Origin of the Rs profile tilt in beam-scan direction.

Because of the magnetic field, all the charge-exchanged ions produced in the angle corrector magnet, change direction from their original trajectories and for the most part are not implanted in the wafer. Since the beam path length in the magnet varies linearly according to the final beam position on a wafer, and a longer beam path length increases the chances of charge exchange, this is the most likely cause of the observed dose non-uniformity due to PR outgassing.

We can make a first order estimation of the dose difference between the left and right edges of a wafer, assuming; 1) all the charge-exchanged ions do not reach a wafer, 2) all the charge-exchange reactions happen only in corrector magnet, and, 3) the pressure distribution in the magnet is uniform. Let +/-φ be the scan angle that covers the full width of the wafer, R the radius of curvature in the magnet, p pressure in the gap of the magnet and σ the total charge exchange cross section for the beam. The difference of dose between left and right edges on the wafer, ΔD, is given as,

$$\Delta D \approx 7\times 10^{16} R\varphi p\sigma \qquad 1)$$

In addition to the obvious dependence on PR outgassing pressure p, Equation 1) hints at a competing situation between the outgassing pressure, which increases with energy, and the total cross section σ, which tends to decrease with energy. With the given Optima XEx configuration, this formula gives about a 1.3% dose difference for a pσ value of 2E-20 cm^2.torr, or, for example, at a pressure of 5E-5 torr in the magnet and 4E-16 cm^2 total charge exchange cross section.

A correction to the above formula can be made, since some of the charge-exchanged ions near the exit of the corrector magnet actually reach the wafer. All ions from electron-capturing reaction, e.g., 1+→0 reaction, get bent less in the magnetic field and tend to spread toward the outer trajectory, which reduces the asymmetry given by eq. 1). All ions from electron-stripping reactions, e.g., 1+→2+, have an opposite tendency, which worsens the asymmetry.

The effects of these corrections on the wafer uniformity are not negligible. For a pσ value of 2E-20 cm^2torr, the dose on the outer side of wafer would increases by about 0.4% due to particles from the 1+→0 reaction, reducing the dose asymmetry given by eq. 1). For the 1+→2+ reactions, almost the same 0.4%, increase on the other side of wafer is expected, which worsens the dose difference.

Precise estimation of the dose asymmetry is difficult since the values for the charge-exchange cross sections for the energy and species of interest are scarce or non-existent. There is also a difficulty in knowing the pressure distribution within the area of interest.

INTELLISCAN

To solve the dose asymmetry due to PR outgassing, Optima XEx adopted a very orthodox method of changing the instantaneous scan velocity, although in this case it is the beam fast-scan velocity of 1 KHz which is modified.

Pressure change from PR outgassing can be quite rapid, even changing by one order of magnitude in less than one second, as a PR wafer moves in and out of the beam in the mechanical scan direction. The Optima XEx beam-scan waveform is digitally produced from 1000 points, at the clock speed of 1MHz. Changing the instantaneous beam-scan velocity means changing the 1000 data points according to the rapidly changing pressure in real time.

IntelliScan performs this seemingly impossible task by making three assumptions; 1) the required shape of the scan velocity correction is known, e.g., the linear dose variation in beam position as shown in Fig.2, 2) the amount of correction required is proportional to the measured pressure, although its sensitivity may vary by ion species, and 3) the sensitivity varies only according to ion species, but not energy.

Since the observed dose variations by PR outgassing is very linear in position, IntelliScan modifies the dV/dt of scan voltage linearly, according to instantaneous scan voltage, instantaneous vacuum pressure, p, and a species dependent sensitivity factor, S_x.

$$\frac{dV}{dt}(t) = \frac{dV0}{dt} + S_x p V_0(t) \qquad 2)$$

$V_0(t)$ is typically an almost pure triangle waveform, making dV_0/dt a constant. Integration yields a scan voltage with two terms, pure triangle, line A in Fig.3, and a quadratic correction term, line B. The final corrected waveform is shown as C.

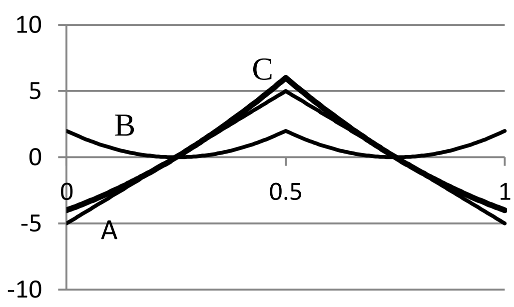

FIGURE 3. Beam-scan waveform with the linear correction of dV/dt (exaggerated for clarity).

Only the amplitude of the quadratic term has to be changed with instantaneous pressure and ion species. The upward bowing of the corrected waveform, line C, increases as the pressure worsens, changing dV/dt linearly from one end to the other.

Since creating and downloading a new digital waveform quickly enough to follow the rapid pressure change is unrealistic, Intelliscan [2] performs the correction entirely with hardware by mixing the two waveforms from two separate ARBs (arbitrary waveform generator). The first ARB (ARB1) produces a triangular main wave, and the second ARB (ARB2) produces a quadratic correction wave. Due to the assumption of a constant correction shape, only the amplitude of ARB2 is adjusted. The generator output amplitude is set according to ion species through the sensitivity Sx, and then the output is varied by an analog voltage controlled attenuator (VCA) which continuously adjusts the amount of the correction waveform in the final mixture according to instantaneous pressure, Fig.4. This architecture of the IntelliScan produces the required waveform correction without any abrupt discontinuities or time delay from a pressure burst. Also, the method can be employed even if a required correction is not linear in position.

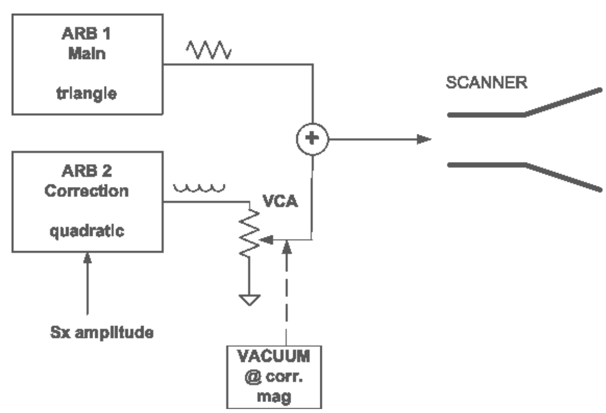

FIGURE 4. Block diagram of IntelliScan.

IntelliScan also utilizes the pressure information to correct small uniformity change due to PR outgassing in the mechanical scan direction, as seen by the small dose shift shown in Fig.2, by setting up another sensitivity factor, Sy. It employs the same principle as the traditional pressure compensation used widely in a rotating disc batch implanter [4], but since the required correction is far smaller on Optima XEx, a simple linear modulation of the slow scan velocity according to corrector magnet vacuum is applied, with the vertical scan sensitivity factor for each ion species given as Sy.

RESULTS

In Fig. 5, the Rs profiles of P+1200KeV PR implants obtained with the IntelliScan are shown. Results from four levels of beam currents, up to 1500uA are shown, and improvement in Rs uniformity is obvious when comparing to the original uncompensated results in Fig. 2. The small deviation in the 1500uA data relative to the rest of the data is due to a separate beam setup on a different day, which also proves the excellent repeatability of the system.

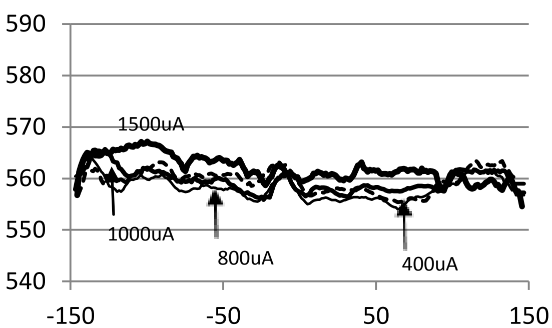

FIGURE 5. P+1200KeV Rs profile of PR wafers in the beam-scan direction, at four beam currents, using IntelliScan

More results of the IntelliScan in production environment are shown in a companion paper [5].

DISCUSSION

The dose asymmetry due to PR outgassing is determined by several factors: outgassing pressure (which is a function of beam energy), implanter beam current capability, type of photoresist, overall pumping efficiency, and charge exchange cross sections for both electron-capture and electron-stripping.

As stated earlier, the observed dose asymmetry is small on B+ and P++ PR implants, although the outgas pressure is twice or three times higher than that for P+, which suggests that the total charge exchange cross sections for B+ and P++ at the energies of interest are far smaller than for P+. Also, since 2+→1+ reaction dominates for P++ in our energy range, down-charged ions near the exit of corrector reduce the dose asymmetry as described earlier. Therefore, the sensitivity factors, Sx, for B+ and P++ tend to be quite small compared to P+.

In Fig.6, an Rs profile from a PR implant of P+500KeV with 1500uA beam current without IntelliScan is shown.

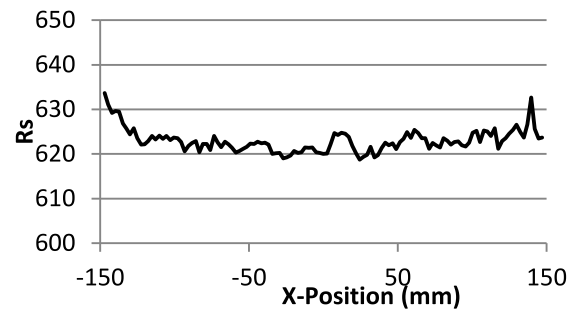

FIGURE 6. Rs profile of PR wafer in beam-scan direction of P+500KeV1500uA implant without IntelliScan.

The lack of the tilt in the Rs profile tells us that the decrease of outgassing dominates over the possible increase in the cross section at the lower energy. Also, near-exit 1+→0 charge exchanged ions could have helped reduce the dose asymmetry since the 1+→0 cross section increases at the lower energy. Finally, it could also be a result of a faster reduction of outgassing than a first order in beam energy, as suggested in [2].

We have observed this tendency of decreased Rs profile tilt at lower beam energies across all the ion species, and in most cases, recipes with energy ≈<500KeV show very little dose non-uniformity on PR implants.

SUMMARY

IntelliScan, a real-time scan-waveform modulation system that compensates beam-scan direction dose non-uniformity due to PR outgassing, was developed and shown to successfully remove non-uniformity at the highest beam current produced by Optima XEx.

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ACKNOWLEDGMENTS

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