

Advances in Cross-Contamination Control Using Single-Wafer, High-Current Implantation

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Abstract - The Varian VIISta 80 is a single-wafer high-current implanter, which uses a ribbon beam and a single-direction mechanical scan for implantation. The placement of the wafers on an electrostatic platen, and the absence of end station parts in the vicinity of the wafer during implant, translate into an expected advantage in implanter memory over batch tools. This paper focuses on P-in-As cross-contamination and compares the performance of the VIISta 80 to a representative of the batch family of high-current tools - the Varian VIISion 80. The results of experiments designed to understand the mechanisms of phosphorus build-up in machine parts exposed to the P^+ beam, as well as their cleanup by a variety of subsequent ion beams, are discussed in detail. Phosphorus levels in arsenic-implanted wafers are assessed using secondary ion mass spectrometry (SIMS) and four-point probe sheet resistance measurements. Typical cross-contamination performance is presented and recommendations on further reduction of the memory effects are made. Additionally, data on P-in-B, B-in-As, and B-in-P cross-contamination modes are reported.

I. INTRODUCTION

Cross-contamination of implant species can occur in ion implanters, especially high-current, batch-type tools, as an effect of "implanter memory" -- previously implanted species continue to arrive on the wafer surface when they are no longer desired. Most pronounced is the manifestation of phosphorus cross-contaminating arsenic (As) or antimony (Sb) implants. If phosphorus is present in the wafer even at low concentration levels, it exhibits anomalously high diffusivity in the presence of As or Sb [1]. The diffusivity may be sufficiently high, so that the phosphorus will diffuse through the As implant to form an extended doped tail, thus significantly increasing the intended junction depth. In many devices, the unwanted and uncontrolled presence of phosphorus would lead to unacceptable variation in the device performance. This necessitates either dedicating tools in the fab to particular implant species, which can adversely impact tool utilization, or the application of some method to reduce the residual levels of previously implanted species before committing the sensitive device product to implant.

It is generally accepted that in high-current batch tools >80% of the cross-contamination is generated from the disc or

wheel [2]. Historically, high-return reduction in cross-contamination was achieved early on by redesigning the tools to reduce the amount / portion of machine parts exposed to the beam above the wafer plane [3]. Further reduction on batch tools can be expected only by modifying the ways in which the implanters are used. Similarly, it should be expected that single-wafer tools have better cross-contamination performance due to the smaller number / area of tool parts in the end station exposed to the ion beam.

Generally, efforts to clean up implanters before switching to production implants with a new species include the running of argon beams for some period of time, performing several cycles of partially venting and pumping down the implant chamber / end station. All of these commonly used techniques take the tool "down," so that it is not available for production.

This paper presents results of a dedicated study of the mechanisms of phosphorus accumulation and cleanup performed on a Varian VIISion batch high-current implanter. Data on the cross-contamination performance of the Varian VIISta 80 single-wafer, high-current ion implanter are also presented.

II. EXPERIMENTAL

In the end station of modern implanters, many critical beamline parts that are exposed to beam strike are silicon-coated. This study set out to understand the mechanisms of accumulation of the implanted species (primarily phosphorus) and its subsequent release upon switching to a different ion beam. Toward this end, 200mm silicon wafers were bead-blasted to simulate the surface morphology of the silicon coating. In a control experiment, a silicon-coated part and a bead-blasted wafer were exposed to the same phosphorus dose and then analyzed by secondary ion mass spectrometry (SIMS). The analysis produced the same integrated phosphorus dose for both materials, allowing us to proceed with the experiment using the bead-blasted silicon wafers as an easily handled model of the tool surfaces.

Before starting the experiment, the implanter was run using only arsenic for more than 48 hrs. The disc was loaded with bead-blasted wafers and a 15mA 70keV P^+ beam was run until a dose of $1 \times 10^{18} \text{ cm}^{-2}$ was accumulated. In order to

avoid any possible passivation by exposure of the wafers to atmosphere [4], they were unloaded into one of the tool's load locks and kept there under vacuum for the duration of the experiment.

Two experiments were then performed. In the first experiment, we assessed the rate of phosphorus cleanup from implanter parts previously exposed to a P⁺ ion beam. For this purpose, after the $1 \times 10^{18} \text{ cm}^{-2}$ P⁺ dose described above, we continuously ran a "standard" implant recipe - $5 \times 10^{15} \text{ cm}^{-2}$ 80keV 15mA As⁺ - for a period of several hours. Monitor wafers were introduced at regular intervals; clean dummy wafers were used to fill up the disc. The monitor wafers were annealed at 1100°C for 10 sec using a rapid thermal annealer (RTA) and the sheet resistance of the implant was measured using a four-point probe. This experiment provided data on the level of phosphorus delivered to As⁺-implanted wafers after similar elapsed times. The results of this experiment are discussed in Section IV.B below.

In the second experiment, after running the above As beam for more than 24 hrs, the bead-blasted wafers were moved to the disc one by one. These steps were taken to ensure that the implanter was phosphorus-free. These wafers were then subjected to bombardment with different ion species for periods of one and two hours. This experiment provided direct data on the efficiency and speed of clean-up of the tool parts themselves. The results of this experiment are discussed in Section IV.A below.

III. EFFECT OF PHOSPHORUS CROSS-CONTAMINATION ON SHEET RESISTANCE OF ARSENIC IMPLANTS

The effect of anomalous co-diffusion of phosphorus and arsenic is shown in Fig. 1 for a wafer implanted with a $5 \times 10^{15} \text{ cm}^{-2}$ dose of 80keV As⁺ in the presence of residual phosphorus in the implanter. Note that before annealing, the phosphorus is strictly on the surface. After a 30-min furnace

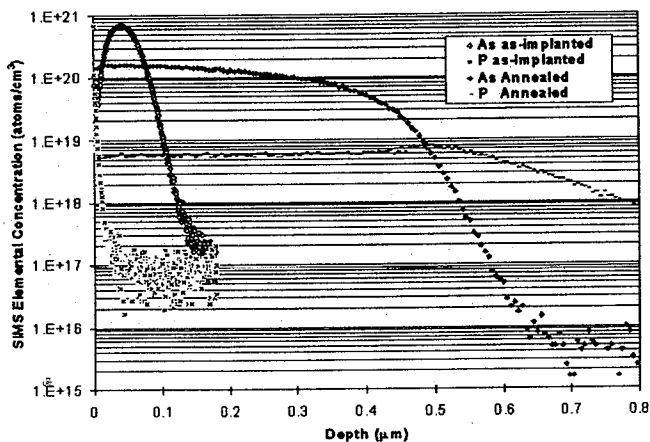


Fig. 1. Illustration of anomalous P and As co-diffusion in silicon. Phosphorus-contaminated implanter. Implant: As⁺ 80 keV $5 \times 10^{15} \text{ cm}^{-2}$. Furnace anneal: 1000°C 30 min.

anneal at 1000°C, it is seen that the phosphorus has diffused through the entire arsenic distribution and is the determining factor for the obtained junction depth. This behavior produces a decrease in the sheet resistance (Rs) of the required implant.

The effect of a known phosphorus surface concentration on the Rs value of a furnace-annealed "standard" arsenic implant - 80 keV, $5 \times 10^{15} \text{ cm}^{-2}$ - is shown in Fig. 2. The figure shows that, for the dose range investigated, there is good correlation between the retained phosphorus dose as measured by SIMS, and the sheet resistance of the standard implant. This correlation confirms that the phosphorus is responsible for the resulting Rs drop in the arsenic implants. It also yields a cost effective, timely method for evaluating phosphorus cross-contamination levels without performing SIMS analyses.

IV. MECHANISMS OF BUILD-UP AND CLEANUP OF PHOSPHORUS

A. Phosphorus Build-Up and Retention by Implanter Parts

It is important to note that longer exposure to phosphorus does not necessarily lead to an increased phosphorus cross-contamination risk. In other words, the quantity of retained phosphorus dose, as a fraction of the incident phosphorus dose, is a non-linear function. As the incident dose increases, the retained-to-incident phosphorus ratio gradually decreases as exposed machine parts become saturated and cannot retain any additional phosphorus despite its continued arrival. A steady-state condition is reached, in which the amount of phosphorus arriving to the wafer is exactly balanced by the amount of phosphorus leaving the wafer by either backscattering or sputtering. This phenomenon is illustrated by the analysis results for the simulated silicon coating implanted with a P dose of $1 \times 10^{18} \text{ cm}^{-2}$. The actual phosphorus dose

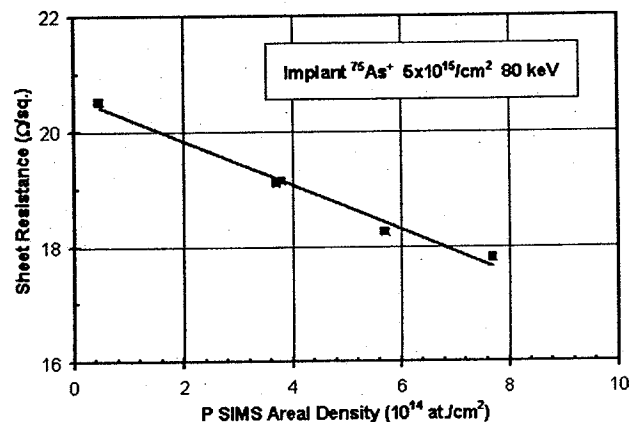


Fig. 2. Correlation of sheet resistance of 80-keV $5 \times 10^{15} \text{ cm}^{-2}$ implant to phosphorus SIMS integrated dose in the wafer. Furnace anneal: 1000°C 30 min.

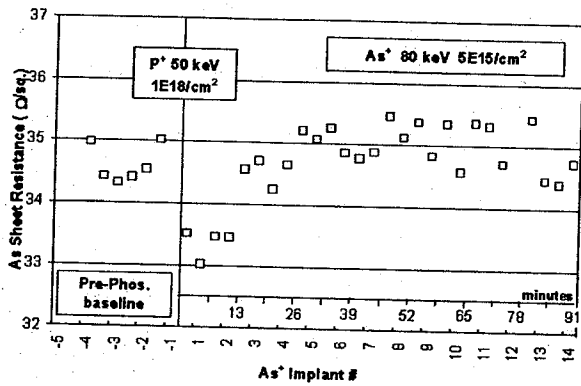


Fig. 3. Clean-up of phosphorus-contaminated implanter by 80-keV As⁺ monitored via the Rs of monitor wafers implanted with a standard 80-keV 5×10¹⁵ cm⁻² As⁺ implant.

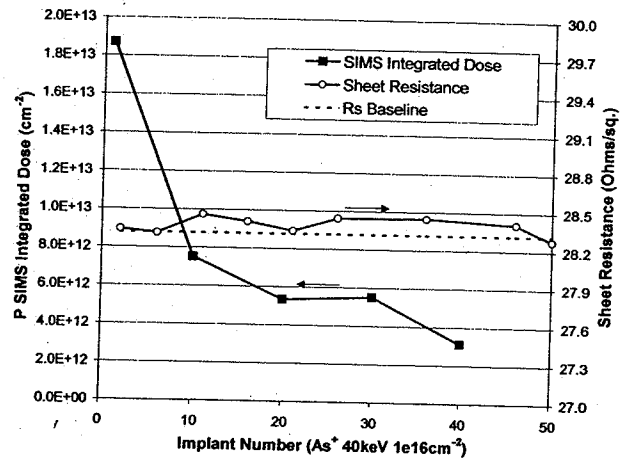


Fig. 5. Phosphorus cross-contamination level and clean-up rate for VISta 80 high-current single-wafer ion implanter. Implant: 20-keV 5×10¹⁵ cm⁻² As⁺ following a phosphorus dose of 1×10¹⁸ cm⁻² accumulated running 40-keV P⁺.

phosphorus cross-contamination model - using an implanter previously dedicated to phosphorus to perform As⁺ implants.

B. Phosphorus Clean-Up from Implanter Parts

A comparison of the rate of cleanup of the phosphorus-contaminated machine parts, as modeled by the bead-blasted silicon wafers, by ion bombardment with different species is presented in Fig. 3. The different cleanup techniques are compared by applying them for equal amounts of time.

Fig. 3 presents the phosphorus levels measured in the wafers after the respective cleanup technique is applied by secondary ion mass spectrometry (SIMS). The SIMS results represent the total amount of phosphorus in the wafer as obtained by integrating the phosphorus profile over its entire depth. Another analytical technique - x-ray photoelectron spectroscopy (XPS) - was used to characterize the amount of phosphorus present on the roughened silicon surface. This value is perhaps more significant since it is well known that over 97% of the sputtered material originates from the top two-three monolayers of the target. The comparison of the surface cleanup rates is presented in Fig. 4.

It is seen that the most effective mechanism of removing phosphorus from the silicon material is physical sputtering. As and Ar produce the fastest cleanup rate. Based on the earlier experimental results of decreasing P cross-contamination after partial venting, it was expected that bombardment by oxygen- or hydrogen-containing species would lead to the fastest cleanup effect. The results of these experiments show that this is not the case. Also, no increase in the cleanup rate was observed by using other chemically reactive species, like fluorine. Actually, all chemically active cleanup species led to an increase of the phosphorus concentration at the surface of the silicon coating. This would lead us to expect higher cross-contaminating phosphorus concentrations.

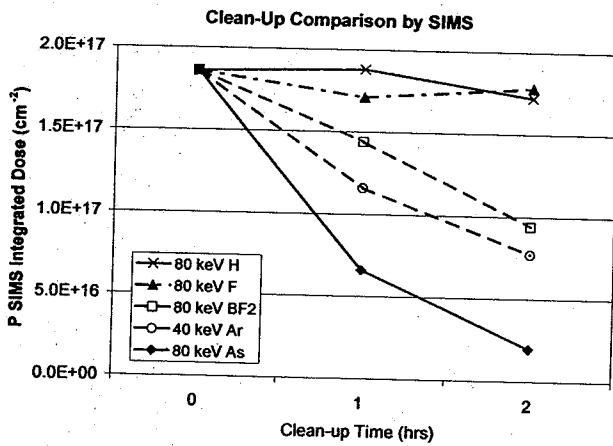


Fig. 4a.

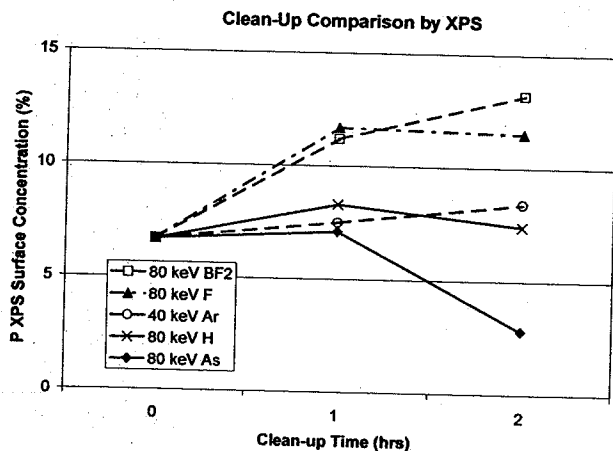


Fig. 4b. Comparison of the clean-up of silicon-coated implanter parts by different energetic ion species a) total integrated P dose measured by SIMS, b) surface P concentration measured by XPS.

retained in the wafer, as analyzed by SIMS, is of the order of 2×10¹⁷ cm⁻², cf. the first data point in the SIMS clean-up comparison presented in Fig. 3.

These results indicate that implanting P at doses in the high-10¹⁷ to low-10¹⁸ cm⁻² can serve as a valid "worst case"

Clearly, the results discussed in this section required significant time to be acquired. Special care was taken to ensure that the storage of the wafers in the load lock for the extended duration of the experiment and the sequence in which the cleanups were performed did not influence their outcome. To this end, the last wafer was brought out of the load lock without receiving any cleanup. The phosphorus levels in this wafer were the same as in the very first wafer removed, even though its residence time in the load lock was approximately three times longer than the first wafer.

In summary, the arsenic implants produced the fastest cleanup in this study. The use of arsenic, rather than, e.g. argon, has the added advantage that it does not necessarily make the implanter unavailable for production. In fact, product wafers carrying devices which are less sensitive to P cross-contamination may well be run in production while simultaneously cleaning up the residual phosphorus from the tool prior to implanting phosphorus-sensitive product.

V. CROSS-CONTAMINATION PERFORMANCE OF VIISTA 80 SINGLE-WAFER, HIGH-CURRENT ION IMPLANTER

In this Section, we present the results of phosphorus cross-contamination studies performed on the Varian VIISTA 80 high-current, single-wafer ion implanter. It is in principle expected that the smaller the area of the implanter parts in the immediate vicinity of the wafer that are exposed to the beam, the lower the cross-contamination effects on the subsequent implanted species and the quicker the cleanup. Thus, a single-wafer tool design, which eliminates disc or wheel, should perform significantly better.

The results presented in Fig. 5 show that this is indeed the case. It is seen that after implanting a $1 \times 10^{18} \text{ cm}^{-2}$ phosphorus dose at an energy of 20 keV and immediately switching to a 40 keV $1 \times 10^{16} \text{ cm}^{-2}$ arsenic implant, the level of phosphorus delivered to the first arsenic-implanted wafer is less than $2 \times 10^{13} \text{ cm}^{-2}$, corresponding to 0.8 % of the implanted As dose. It is important to note that this phosphorus level is obtained without running any intermediate gases like argon to clean up the source or the system before performing the arsenic implants. This detected amount of phosphorus is a factor of five-to-ten lower than typically observed on the first wafers implanted after switching from P to As on a batch implanter.

In addition to the lower initial phosphorus level, Fig. 5 also shows that a single-wafer tool recovers more rapidly, i.e. the residual phosphorus is "forgotten" by the system faster than in the case of a batch tool. Finally, the sheet resistance of the arsenic-implanted monitor wafers is essentially unaffected by the phosphorus implants.

Exposing the tools to the same phosphorus dose requires different amounts of time on a batch implanter and on a single-wafer tool and consists of implanting different numbers of wafers. Despite this, the dose criterion is the correct one for

this comparison, since that is what determines the level of contamination of machine parts with phosphorus. Furthermore, as already shown in Fig. 3, the amount of phosphorus actually retained by machine parts saturates after a received dose in the mid-to-high 10^{17} cm^{-2} .

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