

# Energy contamination of $P^{2+}$ ion beams on the Varian, EXTRION 220 medium current implanter

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Singly charged contaminant beams have been analyzed during  $P^{2+}$  implants on an EXTRION 220 medium-current ion implanter. A method has been developed for measuring the amount of contamination prior to the actual implant. The measured amount of singly charged energy contamination in the doubly charged ion beam has been related to a shift in sheet resistance of the implanted layer. This shift is proportional to the amount of energy contamination. This measurement proves to be more sensitive than SIMS analysis for the implant that was monitored.

## 1. Introduction

The use of doubly charged ions for ion implantation is an accepted method to extend the energy range of ion implanters. Doubly charged ion beams have several disadvantages compared to singly charged beams. First, the yield of doubly charged ions in most conventional ion sources is much lower. This limits the available beam current and hence reduces wafer throughput. Second, doubly charged beams can contain ions with an energy different from the main beam. This is called energy contamination. It is caused by the interaction of ions extracted from the ion source with residual gas molecules. Energy contamination can result in a degradation of implant uniformity, junction depth variations and dosimetry problems [1]. In this paper we will

discuss how these effects can be measured and controlled on the EXTRION 220 medium-current ion implanter [2,3].

## 2. Energy contamination

As on most ion implanters, one can distinguish two types of energy contamination on the E-220. The first type of contamination occurs when molecular ions (such as  $P_2^+$ ) that are extracted from the ion source dissociate before they reach the mass analyzer magnet. The dissociation process leaves an ion with a quarter of the energy of the doubly charged ions. This ion has the same magnetic stiffness as the doubly charged ions and therefore is transmitted through the analyzing magnet.

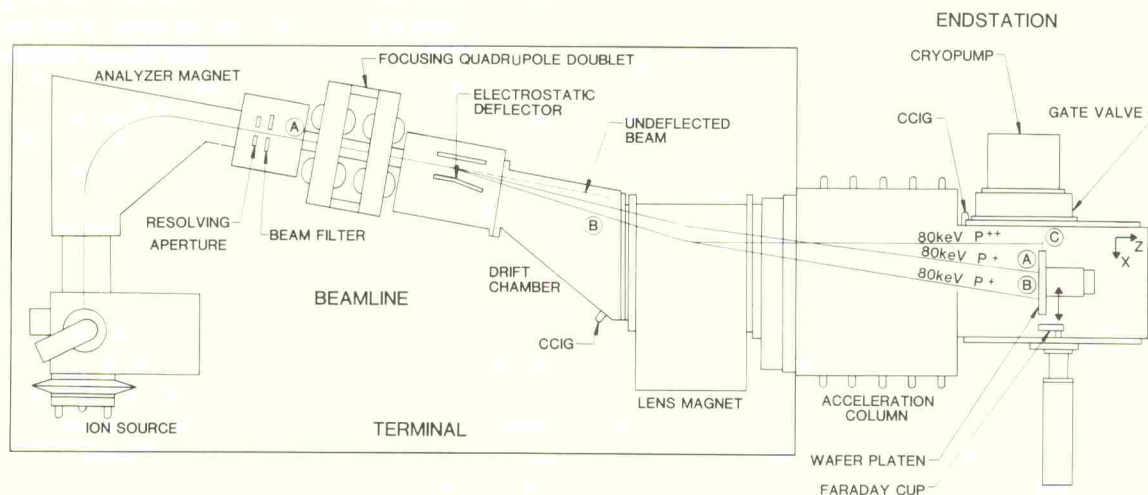


Fig. 1. Ion trajectories in the E-220 beamline for 40 kV extraction and no acceleration voltage. The main contaminant beams are labeled A and B. Beam C is hidden in the main beam.

However, it can be effectively removed from the main beam by an electrostatic beam filter [4,5]. The second type of energy contamination occurs after the beam passes through the electrostatic beam filter. Doubly charged ions ( $I^{2+}$ ) exchange charge with a residual gas molecule/atom (A):



The energy loss of the ion  $I^{2+}$  in this reaction is negligible compared to its total energy. The amount of doubly charged ions in the main beam that lose part of their charge this way is proportional to the pressure in the system and to the length of the path that the ions travel before they reach the wafer surface. The design of the vacuum system and beamline influences the amount of energy contamination and thereby the quality of the implanted layer. There are three sections (labeled A, B and C in fig. 1) in the E-220 beamline where this charge exchange occurs.

The first section (A) is between the beam filter and the deflector. Ions that have lost part of their charge in (A) will be deflected over half the deflection angle of the doubly charged ions.

The second section (B) is between the deflector and the angle correction magnet (also referred to as lens magnet) [6]. Both singly charged beams produced in section A and B have a higher magnetic stiffness than the main beam. This means that they will be underbent (smaller deflection) in the angle correction magnet. The main beam, on the other hand, will be bent in such a way as to become perpendicular to the endstation. Calculations show that contaminant beam A crosses over the main beam somewhere in the acceleration column. Both beams A and B, therefore, end up on the same side of the main beam.

The third section (C) is between the angle correction magnet and the wafer. Ions which undergo charge exchange in this area are not separated from the main beam. The contribution of section C to energy contamination is less significant since the pressure in this area is lower than in the rest of the beamline ( $\approx 5 \times 10^{-7}$  compared to  $1-2 \times 10^{-6}$  Torr). Also the higher energy of the doubly charged ions after acceleration reduces the cross section for charge exchange. If the main beam is scanned across the wafer, all three contaminant beams will also scan across, thereby contributing to possible dose offsets and non uniformities.

### 3. Measurement of energy contamination

The electrostatic scanner on the E-220 can be set in spot mode, that is, with a fixed potential on the scan plate. The spot mode allows us to measure the integrated ion beam current as a function of position. This is done by moving a slotted Faraday cup with a

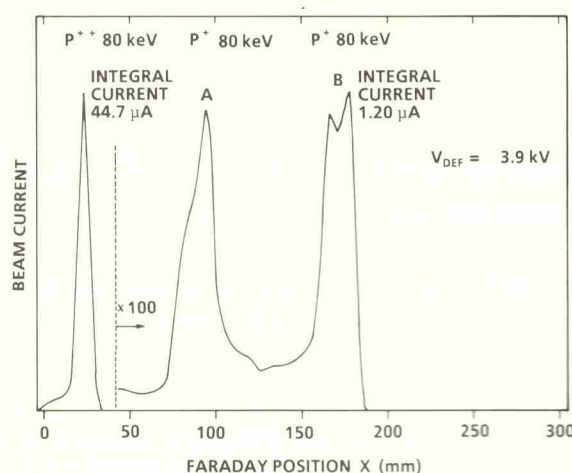


Fig. 2. Beam current measurements as a function of Faraday cup position. The doubly charged main beam and singly charged contaminant beams A and B are shown.

0.635 cm horizontal and 6.35 cm vertical opening across the end station in the X-axis (fig. 1). Since the beam is smaller than the cup in the vertical direction but larger in the horizontal direction, this offers the ability to measure beam current as a function of X-position. In fig. 2 we have plotted the beam current of a doubly charged beam as a function of X-position. The E-220 software calculates the integral beam current over the scanned length. The calculated integrated current contains contributions from the contaminant singly charged beams. However, by selecting a lower voltage on the scanner and by using a 100 times larger amplification, we can determine the integral current peaks A and B without getting a contribution from the main beam. Before each implant we perform therefore two integral current measurements. One with the beam in the center of the endstation to measure the total integral current of the main beam and peaks A and B. The second measurement is with a lower scanner voltage and a 100 times higher amplification to measure only peaks A and B. The relative amount of energy contamination (EC) is then given by (as a percentage of particles):

$$EC = \frac{I^+}{\frac{1}{2}(I^{2+} - I^+)} \times (100\%). \quad (2)$$

In this formula,  $I^{2+}$  is the integral current of the main beam plus the contaminants A and B and  $I^+$  is the integral current of only peaks A and B. The factor 2 arises from the fact that each doubly charged ion is counted twice by the dose amplifier. The number from eq. (2) can now be related to other measures of energy contamination such as sheet resistance changes or SIMS concentration profiles.

### 4. Experiments

All measurements were performed on the E-220 equipped with a 10 kV in order to avoid molecular beam source was vaporizer or

All implants were performed on (boron) (10 oxide. Phosphorus)  $2 \times 10^{14}$  ions/cm<sup>2</sup> to avoid charge mapping with native oxide and the wafer RS30 system Evans East, using a 400 of 8 keV. calibrated p is considered

Implants conditions:

- With a scan rate of the lowest and
- With a gas system position causing
- As before, implanting in a vacuum

As a control, identical samples were implanted with the same parameters used to get there was no



Fig. 3. Uniform phosphorus concentration profiles.



#### 4. Experimental

All measurements were performed on an EXTRION 220 equipped with an electrostatic beam filter set at 28 kV in order to eliminate energy contamination from molecular breakup. Feed material for the Freeman ion source was either solid phosphorus evaporated in a vaporizer or hydrogen buffered 15%  $PH_3$  gas.

All implanted wafers were 150 mm (100) p-type (boron) (10–20  $\Omega$  cm) SEMI standard wafers with no oxide. Phosphorus implants were done at 180 keV and a  $2 \times 10^{14}$  ions/cm<sup>2</sup> dose with a 7° tilt and a 22° twist to avoid channeling. Wafers used for sheet resistance mapping were RTP annealed at 1100°C for 10 s. The native oxide was subsequently stripped in buffered HF and the wafers were probed on a Prometrix Omnimap RS30 system. SIMS measurements were performed at Evans East, Inc. on a Perkin Elmer 6300 SIMS system using a 400 nA  $Cs^+$  primary ion beam with an energy of 8 keV. The depth axis was established using a calibrated profilometer. Overall accuracy of the profiles is considered to be within 10%.

Implants were performed under three different conditions:

- With a solid phosphorus vaporizer source, to get the lowest amount of contamination.
- With a gaseous phosphine source, resulting in a higher system pressure and hence higher energy contamination caused by the presence of hydrogen.
- As before, but with all cryo pumps closed off, resulting in a worst case system pressure.

As a comparison to the doubly charged implants, an identical singly charged phosphorus implant was done with the same dose and energy. These implants were used to get an idea of what the result should be in case there was no energy contamination.

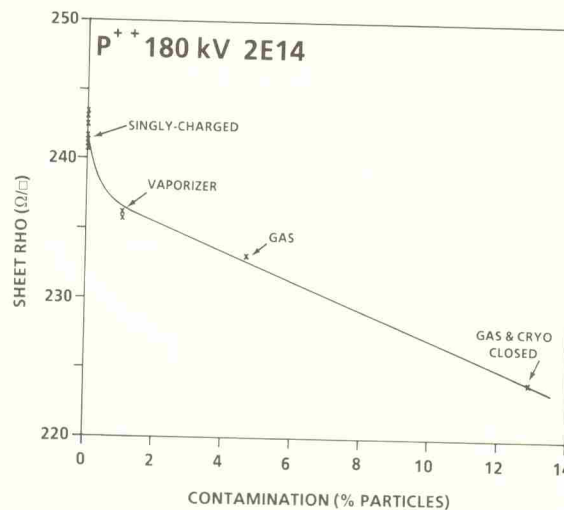


Fig. 4. Sheet resistance as a function of energy contamination for a 180 keV,  $2 \times 10^{14}$  phosphorus implant.

#### 5. Results and discussion

In fig. 3 we show three sheet resistance maps of singly and doubly charged implants. As can be seen, the uniformity is maintained well below the 0.5% level, even at the highest amount of energy contamination. In fig. 4 the mean sheet resistance of all implants is plotted versus the amount of energy contamination measured before the implant. For doubly-charged implants, there is a linear relationship between the sheet resistance and the measured amount of energy contamination. However, there is a nonlinear change in sheet resistance between 0% energy contamination (singly charged implant) and the first doubly charged implant with the vaporizer.

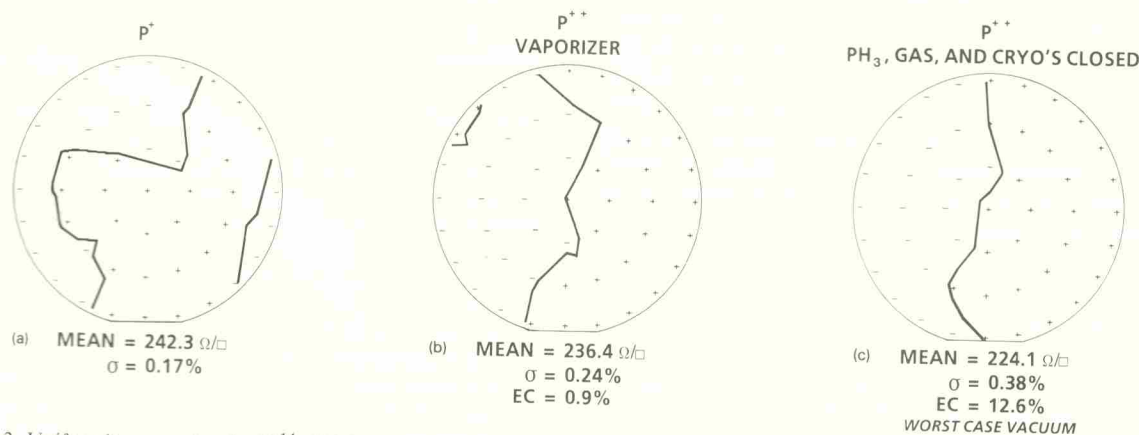


Fig. 3. Uniformity maps for  $2 \times 10^{14}$ , 180 keV phosphorus implants. Shown are (a) singly charged phosphorus, (b) doubly charged phosphorus with the least amount of contamination, and (c) doubly charged with the largest amount of contamination.

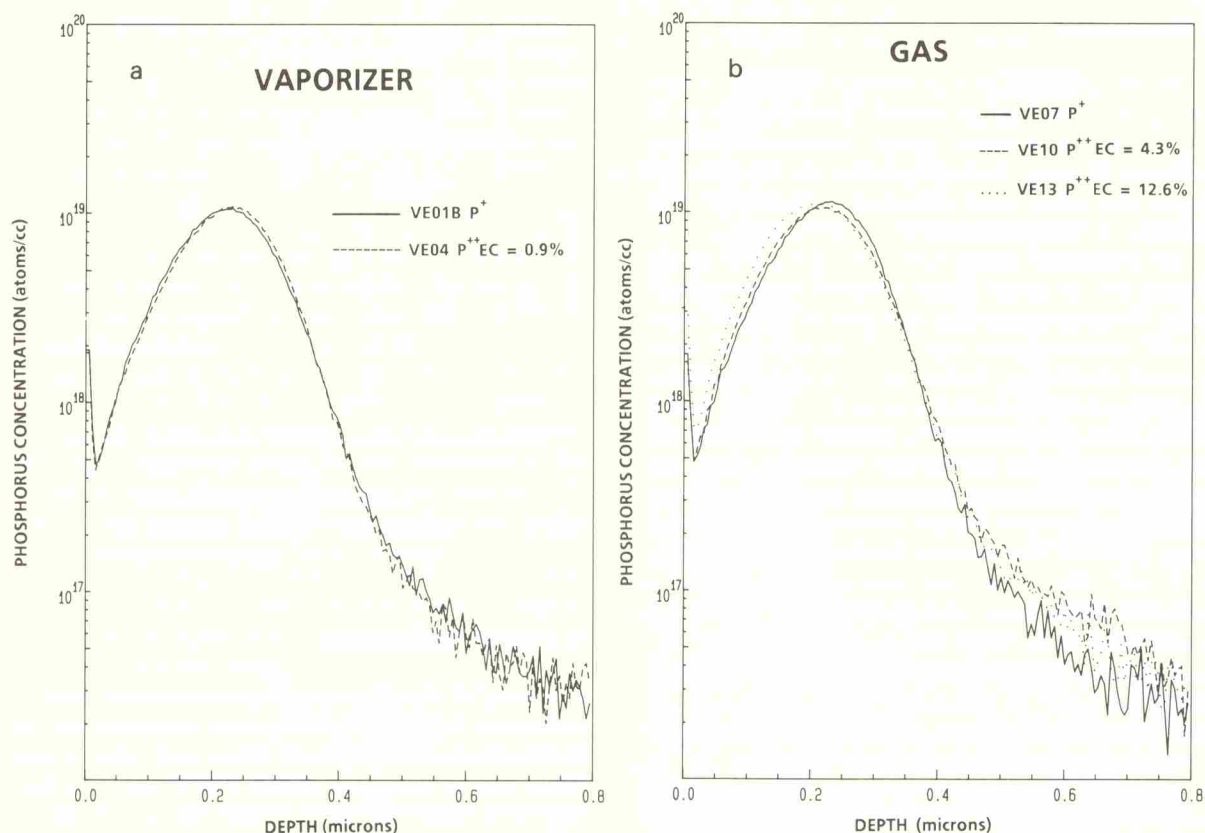


Fig. 5. SIMS measurements of as-implanted profiles for a 180 keV,  $2 \times 10^{14}$  ions/cm<sup>2</sup> phosphorus implant. Profiles for (a) vaporizer feed and (b) gas feed material.

Fig. 5 shows the results of SIMS depth profiles. In fig. 5a the profile for a singly charged implant and a doubly charged implant using a vaporizer are plotted. The difference between the two profiles is minimal indicating that the amount of energy contamination is very low indeed. The implanted dose calculated from the profile is the same as in the singly charged implant, within the accuracy of the SIMS measurement. In fig. 5b the results for the implants using  $PH_3$  gas are shown. Again, the singly and doubly charged implants differ very little. Only the implant under worst case vacuum shows a definite change in dose and depth. However, this shift was still not large enough to relate to an amount of contamination.

## 6. Conclusions

It is possible to measure and monitor the amount of energy contamination on the E-220 implanter. This measurement gives an accurate result that can be related to a shift in sheet resistance for the investigated

implantation. The changes are too small to resolve in SIMS measurements for this implant. The described method is much faster and easier to do than a SIMS measurement. One can get a value for the EC just before starting the implant instead of afterwards.

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