Monitoring of Ion Implanters Using Multiple Dopants

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***Abstract*—A methodology for the monitoring and charting of the monitor results using multiple species on a single chart id demonstrated. The technique utilizes the concept of sensitivity in the correlation of the different species and the associated uniformities. The methodology permits the charting of the data in Equivalent Dose values or in Equivalent Boron Resistivity values. Resistivity and sensitivity data for boron, arsenic, and phosphorus is presented from 1e14 to 1e16. Sensitivity is demonstrated to be the slope of the Resistivity/Dose curve on a log log graph.**

Keywords-resistivity, sensitivity, monitor, boron, arsenic, phosphorus, process control

I. INTRODUCTION

The monitoring of implanter performance for most of the parameters for implantation is straight forward. The monitoring of delivered dose is more problematic. There is very little that can be directly measured. The implant ions represent only a small fraction of the atoms in the structure of the silicon crystal. There is no direct measure. The indirect measures involve measuring the impact on the electrical characteristics of the silicon. The most common characteristic measured is resistivity. This characteristic does not change linearly with dose and is a function of the implantation species. The goal of this work is to develop algorithms that permit us to relate the resistivity characteristics of the three common implantation ions over a broad dynamic range. From the understanding derived, one can then determine the dose that gives the most resolution across all three common species and develop algorithms to relate the resistivities of one to the others with the goal of charting results from all three species on the same trendchart.

II. EXPERIMENTAL DESIGN

A. *Equipment*

An Axcelis 6200 was used to implant arsenic, boron, and phosphorus at 80KeV from doses of 1e14 ions/cm^2 to 1e16 ions/cm^2 into 4 inch wafers. Twenty one doses were selected across this range to be uniformly distributed logrithmically. The implants were all performed with a tilt of 7 degrees and a twist of 45 degrees.

An AG Associates 610 RTP unit was used to activate the implanted dopant. The annealing was performed at 1100ºC for 10 seconds in a nitrogen ambient. A Prometrix RS55 equipped with a type B 4 Point Probe head was used to measure 49 points across each wafer.

B. *Data Treatment*

In the comparison of the data from one species to the date of another species it is important to understand the sensitivity of resistivity to dose change. The definition of sensitivity is:

$$S = -(\Delta R/R)/(\Delta D/D) = d \log R / d \log D \qquad (1)$$

From this one can see that the sensitivity is the slope of the data on a log log plot..

S	Sensitivity
R	Resistivity
ΔR	Change in resistivity
D	Dose
ΔD	Change in dose

The regression analysis was performed on the log of the resistivity and log of the dose using a third order polynomial.

$$\log R = C_0 + C_1 \log D + C_2 (\log D)^2 + C_3 (\log D)^3 \quad (2)$$

The sensitivity can then be calculated from the following:

$$-S = C_1 + 2\,C_2 \log D + 3\,C_3 (\log D)^2 \qquad (3)$$

III. DATA AND DATA REDUCTION

A. *Regression Analysis*

The regression analysis results in the following derived constants:

Species	C0	C1	C2	C3	Max Error
As	-341.57	72.5389	-5.0411	0.11547	+/-1.0
B	-239.70	49.2188	-3.2790	0.07146	+/-1.5
P	-493.16	101.125	-6.8227	0.15208	+/-2.5

The data is plotted along with the fitted curves for arsenic, boron, and phosphorus in figures 1, 3 and 5. The derived sensitivities for these three species are plotted in figures 2, 4, and 6.

B. Physical Interpretation

The sensitivities drop at the higher concentrations for each of the ions under study. This can be understood when one considers: 1) That the higher doses, the peak concentrations approach the saturation concentrations of the individual dopants. 2) The deeper the projected range of the ion, the lower the peak concentration. 3) The greater the diffusivity of the dopant in silicon, the more quickly it will reach equilibrium in the silicon lattice.

With these considerations, one can conclude a priori that arsenic will reach saturation limits before the other two dopants and that boron will be the last to reach its saturation limits. This resistivity data in figures 1, 3, and 5 indicates that the resistivities are approaching asymptotic limits. This can also be seen from the sensitivity calculations in figures 2, 4, and 6.

At the e14 end of the range of study, the peak concentrations are in the e18 atoms/cm^3 levels. These concentration levels are associated with the transition concentrations between the upper limit in mobility associated with lattice scattering and the lower limit in mobility associated with impurity scattering. (see figure 7) Hence the drop off in the sensitivity for these dopants in the low e14 dose range is associated with the transition from lower mobility limit associated with impurity scattering to the upper mobility limit associated with lattice scattering.

C. MultiSpecies Trend Charting

A comparison of the sensitivities of the 3 species indicates that all 3 would have at least a sensitivity of 0.8 at dose of 5e14 ions/cm^2. For a fixed target dose and with the assumption of near constancy over small ranges the following can be derived for conversion of resistivity to Equivalent Doses and Equivalent Dose Uniformities:

$$D = D_t * (R/R_t)^{-1/S} \tag{4}$$

$$\sigma_D = \sigma_R/S \tag{5}$$

D_t	Nominal implant dose
R_t	Target resistivity
σ_D	% Std. Dev uniformity in Dose (calculated equivalent)
σ_R	% Std. Dev uniformity in Resistivity (measured)

Conversely the implantation community has become acclimated to resistivities as the measure of dose. The equations above can be used to translate the resistivities and uniformities of one dopant to the equivalent resistivities and uniformities of another dopant.

$$R_B = R_{t,B} * (R_x/R_{t,x})^{SB/Sx} \tag{6}$$

$$\sigma_B = \sigma_x \, (SB/Sx) \tag{7}$$

R_B	Calculated Boron Equivalent Resistivity
$R_{t,B}$	Target Boron Equivalent Resistivity
R_x	Measured Resistivity of species “x”
$R_{t,x}$	Target Resistivity of species “x”
σ_B	% Std. Dev uniformity in equivalent boron resistivity
σ_x	% Std. Dev unif. in measured species “x” resistivity
SB	Sensitivity of Boron
Sx	Sensitivity of species “x”

An example of resistivity trend chart that translates the resistivities of arsenic, phosphorus, and antimony into the Boron Equivalent Resistivity and Uniformity is shown in figure 8.

IV. CONCLUSION

A technique is demonstrated for the collection of resistivity data that leads to the derivation of sensitivity data for a broad dose range. The technique is demonstrated for boron, arsenic and phosphorus.

Algorithms are demonstrated for the curve fitting of the resistivity data and the calculation of the sensitivities from that data.

With the assumption of constant sensitivity over a small range of dose, algorithms are demonstrated for the calculation of Boron Equivalent Resistivity and Uniformity. A sample of the application of this technique is presented.

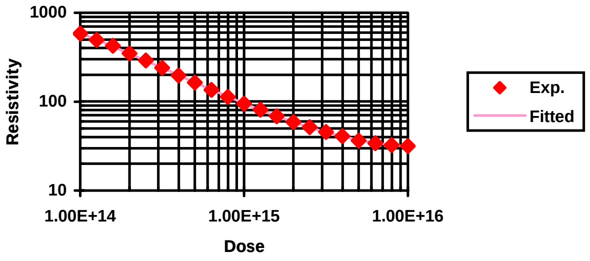

Figure 1 – Arsenic Resistivity

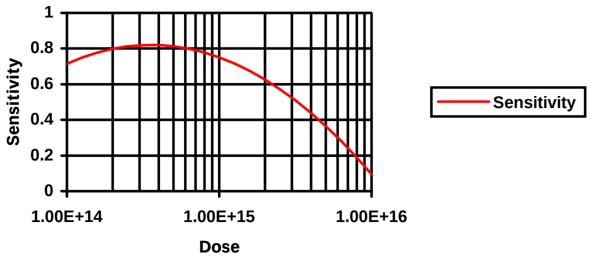

Figure 2 – Arsenic Sensitivity

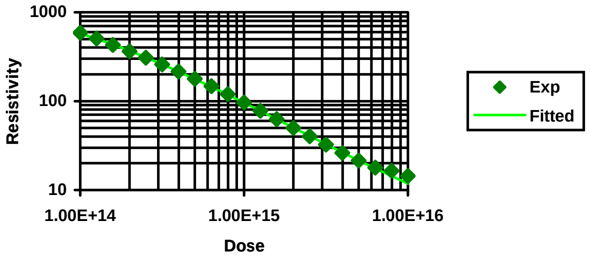

Figure 3 – Boron Resistivity

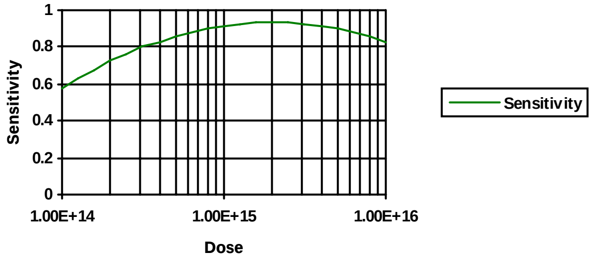

Figure 4 – Boron Sensitivity

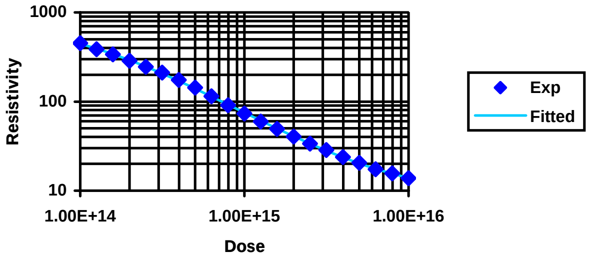

Figure 5 – Phosphorus Resistivity

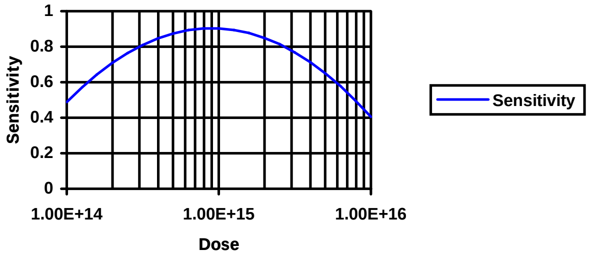

Figure 6 – Phosphorus Sensitivity

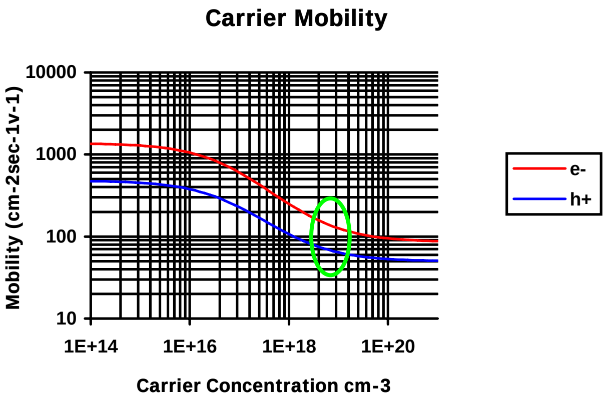

Figure 7 – Available from a number of sources, Technology Associates, Sze, etc.

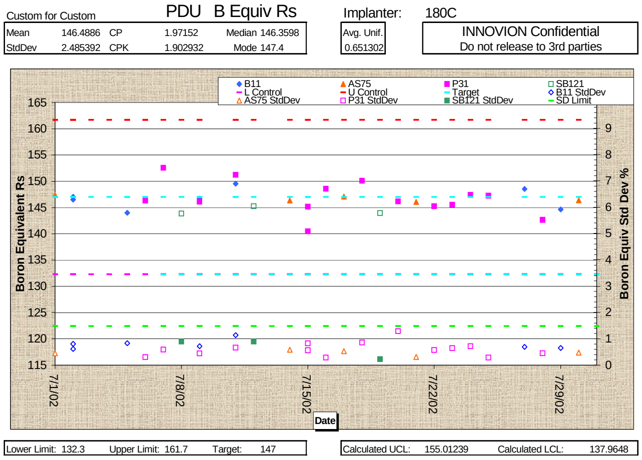

Figure 8 – An example of a trend chart that converts boron, phosphorus, and antimony resistivities and uniformities to their Boron Equivalent Resistivity and Uniformity.