Correlation Of Measured Surface Contaminants As A Function Of Ion Beam Current In GSD Ion Implanters

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Abstract. An investigation into measured differences in surface contaminant levels when evaluating several ion implant tools and/or tool types. For a given species and energy, beam current appears to have a strong effect on final contaminant levels. Ideally one evaluates process integrity at machine set-up conditions that approximate or exceed the worst case conditions required for regular, volume wafer production. Some contaminants may exhibit a ‘threshold’ effect where they are easily observed with sufficient beam current, but not present at all for lower beam currents. Knowing the characteristics of the measurement process is essential in obtaining reliable results with a clear interpretation and better facilitates cross-site or cross-platform comparisons.

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INTRODUCTION

Analysis of surface contaminants for most semiconductor manufacturing equipment is a mandatory activity to ensure on-going process integrity. In ion implantation, the nature of the interaction of the ion beam with the materials of construction of the machine is of primary concern. In addition to run to run variability of internal cleanliness of a particular machine, there can be run to run variability in ion source and beamline settings that cause variations ion beam current density, et cetera.

In the course of conducting a variety of process qualifications, surface contamination data, usually TXRF or TOF-SIMS and sometimes VP-ICPMS, is routinely requested. The qualification activity can be either between sites within an organization or between different organizations. A normal protocol would be for identical processes to be run on a qualified machine and a target machine for best comparison (reduced variability) using single-sourced wafers from the same batch. It does happen that identical processes are not always executed leading to uncertainty in explaining deviations in the final data. This investigation sought to provide a measure of quantification of the variability as a function of beam current (or beam current density).

EXPERIMENT DESCRIPTION

The standard process for Innovion is a 5.0E15 at/cm^3 arsenic process at nearly maximum beam current capability. For the GSD machine, this beam current has been set to 15 mA. An energy of 80 keV was chosen for the process as it is the energy most used by our daily equipment monitor recipes and is also a reasonable reflection of average customer conditions. An additional factor for our operation is that the energy be something that can be compared very directly across multiple tool platforms. Since there is a significant implanter in our inventory that is limited to 40 kV Extraction voltage (Varian E220), the Metals Survey process also limits Extraction voltage to 40 kV even though our GSD tools are capable of 90 or 80 kV.

An experiment of this sort required some consideration for implant sequence and tool ‘conditioning’ to ensure a reasonable outcome (and therefore justification of the laboratory fees!). The concept is that each test wafer needs to have a reasonably identical process environment. We elected to process dummy wafers through an Argon conditioning implant prior to the beginning of the test sequence and in-between each of the test wafer runs. In all, four test wafer runs were completed at beam currents of 1 mA, 5 mA, 10 mA and 15 mA. In addition, 1 unimplanted wafer was analyzed as a control. It is important to note that the test implanter is SMIF-equipped, which means process wafers are not exposed to Fab air, though they are exposed to HEPA-filtered air in the end-station.

Finally, the analysis method used was TOF-SIMS as offered by EAG, Sunnyvale, CA. This method has been used for the prior two years and offers a good survey of the surface, including aluminum detection. The primary trade-off between TOF-SIMS and TXRF (or VP-ICPMS) is one of small analysis spot size versus large spot (or whole wafer). Overall, the technique provides good value for the cost and has comparable or better detection limits compared to TXRF.

Process Sequence; additional operating conditions

The final process sequence is listed in Table 1.

TABLE 1.
TOF-SIMS Test Wafer Implant Sequence

Process Parameters	**# Batches / Net Dose**
1. 75As+, 5E15, 80 keV, 15 mA	2 / 1E16 at/cm^3
2a. 40Ar+, 5E15, 80 keV, 10 mA	2 / 1E16 at/cm^3
2b. 75As+, 5E15, 80 keV**, 1 mA**	1 / 5E15 at/cm^3
3a. 40Ar+, 5E15, 80 keV, 10 mA	2 / 1E16 at/cm^3
3b. 75As+, 5E15, 80 keV**, 5 mA**	1 / 5E15 at/cm^3
4a. 40Ar+, 5E15, 80 keV, 10 mA	2 / 1E16 at/cm^3
4b. 75As+, 5E15, 80 keV**, 10 mA**	1 / 5E15 at/cm^3
5a. 40Ar+, 5E15, 80 keV, 10 mA	2 / 1E16 at/cm^3
5b. 75As+, 5E15, 80 keV**, 15 mA**	1 / 5E15 at/cm^3

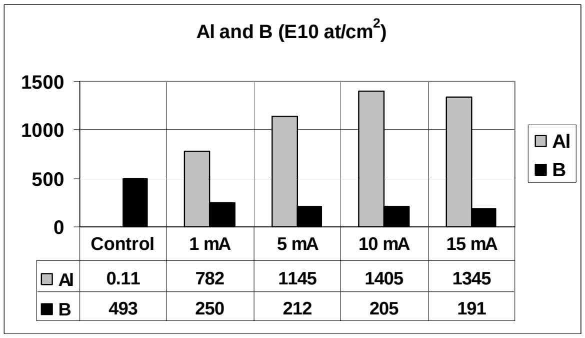
The other important implant conditions to state are for the configuration of the Secondary Electron Flood system. The SEF system is enabled, i.e., ON, for all high dose processes on the GSD. This system will add to the vacuum load (and interactions) in the process chamber and will also contribute some particles/contamination via the action of the filament. For the TOF-SIMS experiment, the SEF gas flow was set to 3 sccm (Argon), and the Primary Emission Current was set to a multiple of 15x beam current which is a fairly standard level for this system.

EXPERIMENTAL RESULTS

The primary data are reported in multiples of E10 at/cm^2. See Table 2 for a complete listing of species and data. What stands out about these results is how clean the test implanter is, independent of beam current. Most elements in the survey are below the detection level of the measurement technique. Only Al, B, Mg and Zn show any levels above 1E10 at/cm^2. All of these species, with the exception of Zn do show a correlation to beam current. Among the other elements in the survey, only Ca shows a beam current dependence. The details of the data will be discussed below.

Aluminum and Boron Trends

The Boron level decreased with increasing beam current and was highest in the Control wafer. See Figure 1 for a plot of the Aluminum and Boron levels. The Al level trended with beam current, but reached a plateau at 10 mA. In this type of implanter with a non-Si coated disk, these levels are not unusual. Figure 2 is a plot comparing reduced Boron level with increasing beam current density.



	Control	1 mA	5 mA	10 mA	15 mA
▨ Al	0.11	782	1145	1405	1345
■ B	493	250	212	205	191

FIGURE 1. Plot of Al and B concentration v. beam current.

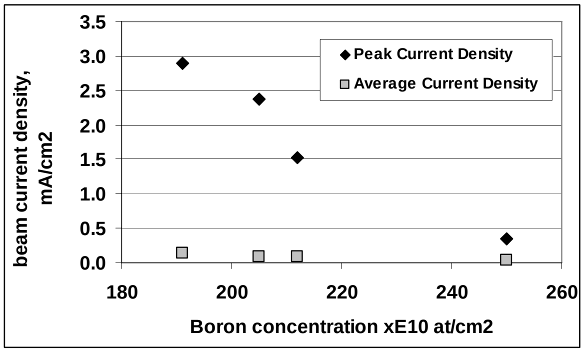
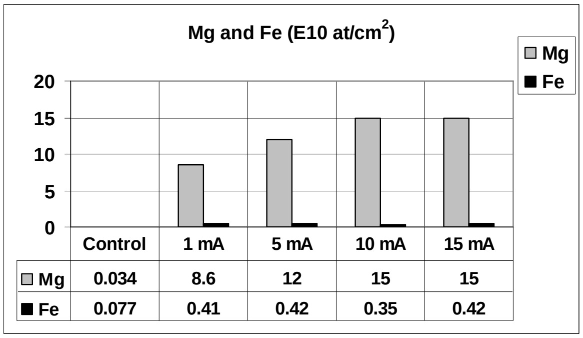


FIGURE 2. Plot of Boron concentration v. beam current density; highest density corresponds to 15 mA condition.

Boron is usually understood to be sourced from the materials used for HEPA filter construction and other environmental sources. In the layout of the Fab, the wafers only see HEPA filters briefly during wafer loading and the Control wafer, with the highest Boron level did not leave its original cassette. This result can be explained by the action of the beam having a ‘cleaning’ effect on the B levels that correlates to beam current density. As beam current density increased, perhaps due to local heating, the B levels were reduced on the wafer. This result may explain why B levels can sometimes be variable in these types of tests.

Magnesium and Iron Trends

The level of Mg had a trend similar to Al for the four test conditions while Fe was constant (approximately 0.4). An interesting feature of this data is the ratio of Mg/Al that was measured: 91:1, 88:1, 90:1 and 90:1 for the four conditions in increasing beam current. This ratio reflects the expected composition of Al 6061 alloy[1] that is typically used for implanter construction. Expected level of Magnesium is between 0.8% and 1.2% (80:1 and 120:1, respectively).



	Control	1 mA	5 mA	10 mA	15 mA
▨ Mg	0.034	8.6	12	15	15
■ Fe	0.077	0.41	0.42	0.35	0.42

FIGURE 3. Plot of Mg and Fe concentration.

CONCLUSION

The test results suggest the implanter under test was in good operating condition. Only a handful of elements exceeded a level of 1E10 at/cm^2, and with the exception of Zn, all are well understood. There was good correlation of beam current to Al levels and a counter trend of Boron reduction correlated to increasing beam current density. This work suggests low risk in using higher beam currents for production processes.

The one anomaly was the Zn level for the 10 mA condition. This test had neither the highest beam current nor the highest beam current density, yet a large Zn response was seen. In some cases, a high Zn level is seen for this type of test, though it is usually associated with a newer disk and sometimes a conditioning protocol is used to reduce the Zn level prior to introducing product wafers. The disk in these tests had been in operation for about one year, so another mechanism is needed to explain the result. It is possible that the small analysis area contributed an exaggerated response to the presence of some Zn on the wafer surface. Also, disks under extended usage may exhibit behaviors where the Zn segregates in the Al and migrates to the surface. To sort this out would require a more ambitious study.

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REFERENCES

1. International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys (Revised 2001)
2. Private communication with Peter Kopalidis, 6/2/08, Technological Educational Institute of Thessalonica, Greece.

Table 2. TOF-SIMS Analysis Survey; all values x E10 at/cm^2. '<' denotes Detection Limit

Beam current, mA	**Control**		**1 mA**		**5 mA**		**10 mA**		**15 mA**	
specie	*Spot 1*	*Spot 2*	*Spot 1*	*Spot 2*	*Spot 1*	*Spot 2*	*Spot 1*	*Spot 2*	*Spot 1*	*Spot 2*
Li	<0.017	<0.017	<0.010	<0.010	<0.012	<0.011	<0.012	<0.012	<0.012	<0.012
B	504	481	253	247	210	194	210	199	193	190
Na	0.12	0.2	0.04	0.041	0.11	0.11	0.16	0.15	0.16	0.14
Mg	<0.034	<0.034	8.7	8.5	13	12	16	15	15	14
Al	0.11	0.11	792	772	1150	1040	1450	1360	1360	1330
K	0.0057	0.56	0.012	0.011	0.0087	0.022	0.0082	0.012	0.0099	0.012
Ca	<0.022	<0.022	0.044	0.045	0.062	0.11	0.11	0.14	0.1	0.1
Ti	<0.57	<0.57	<0.34	<0.34	<0.40	<0.36	<0.41	<0.40	<0.41	<0.40
V	<0.037	<0.037	<0.026	<0.036	<0.026	<0.023	<0.026	<0.026	<0.029	<0.026
Cr	<0.044	<0.044	0.18	0.16	0.19	0.19	0.21	0.22	0.21	0.2
Mn	<0.049	<0.045	<0.14	<0.12	<0.13	<0.12	<0.17	<0.15	<0.18	<0.15
Fe	<0.077	<0.077	0.41	0.41	0.39	0.43	0.35	0.35	0.38	0.46
Ni	<0.15	<0.15	<0.092	<0.090	<0.11	<0.098	<0.11	<0.11	<0.11	<0.11
Co	<0.096	<0.097	<0.057	<0.057	<0.067	<0.062	<0.069	<0.067	<0.070	<0.068
Cu	<0.33	<0.33	<0.22	<0.28	<0.23	<0.23	<0.25	<0.28	<0.33	<0.29
Zn	<0.63	<0.63	<0.52	<0.49	<0.43	<0.40	3.6	2.2	<0.47	<0.46
Sn	0.53	0.67	nm	nm	nm	nm	nm	nm	nm	nm