Dose Reproducibility in Axcelis GSD Implanters Using Stabil-Ion Gauge

Ron C. Johnson, Randy Tysinger
INNOViON, Inc.
Gresham, OR United States
rcjohnson@innovion.cc
rtysinger@innovion.cc

Abstract---Long-term dose reproducibility and tool to tool dose matching in the Axcelis GSD end-station is critically dependent on process chamber pressure measurement and Pressure Compensation factor selection. Pressure Compensation factor (PCOMP) determination is well established. Pressure measurement in the GSD end-station depends on accurate, repeatable gauge capability: incorrect pressure measurements directly lead to dose errors. For example, the dose equation using PCOMP tells us that for a modest PCOMP value of 30%, a chamber pressure measurement error of 2E-5 torr can result in a dose error up to 6% at normal process pressures. The original HCIG used for pressure measurement was not capable of meeting the requirements for good dose control since gauge to gauge differences were not controlled and gauge accuracy was only on the order of 25%. Axcelis introduced the Granville-Phillips 360 Stabil-Ion gauge to improve dose reproducibility through much improved gauge to gauge matching (+/-6%) and more accurate gauge output. This paper discusses the details of the care and feeding of the Stabil-Ion gauge system and it's impact on process dose and process trends.

I. INTRODUCTION

The purpose of Pressure Compensation is to ensure dose accuracy, repeatability and uniformity during process chamber conditions which result in charge neutralization of the ion beam. In the Axcelis GSD end-station, beam current is used for both dose measurement and as a feedback for linear scan speed control and so beam current is also a primary determinant of dose uniformity. Ion beam neutralization is induced by high pressures in the small-volume GSD process chamber and is affected both by flood system gas and photoresist out-gassing. By definition, at a pressure of 1.0E-4 torr, the Pressure Compensation equation yields a percentage correction factor to the measured beam current that is the Pressure Compensation (PCOMP) value itself [1]. For example, at a process chamber pressure of 1.0E-4 torr, and a PCOMP factor of 20%, the measured beam current will be multiplied by a factor of 1.20 for the purposes of calculating dose. For processes that utilize high beam currents, i.e. 10 mA or higher, with photoresist coated wafers, pressures of 3.0E-4 torr and higher are not unusual. In these instances, the beam current correction factor grows very large. For example, for a PCOMP value of 20% and a pressure of 3.0E-4 torr, the beam current correction factor is 1.73. A correction factor of 1.73 implies an ion beam neutralization rate of 42% since 1.73 * 0.58 = 1.00; a surprising condition for those unfamiliar with Eaton/Axcelis end stations. [Above 3.0E-4 torr pressure, Axcelis recommends alternative hardware for maintaining dose accuracy and repeatability; please refer to their Threshold Activated Dose Control Option.] Also, for a high dose implant, the net time that the process is exposed to such high pressures is typically 10% or less of total process time.

Since pressure compensation can have a profound effect on dose measurement, the effects of ion gauge deviations on process control when ion beam neutralization is present are significant. Traditional hot cathode ion gauges, or HCIGs, are known to have poor gauge to gauge repeatability (+/-15%) and poor gauge accuracy (+/- 25%) [2]. As with any physical device, HCIGs also exhibit aging effects that lead to pressure measurement errors over time – usually as a drop in measured pressure due to surface coatings accumulated during operation, especially from photoresist. HCIGs are replaced often, 1-2 times per year or more, depending on usage and process conditions. This fact complicates the business of maintaining accurate dose measurements even further.

II. PRESSURE COMPENSATION EQUATION

The Pressure Compensation equation is given as follows:

$$I_{dose} = I_{disk}*\exp(K\rho) \qquad (1)$$

Where I_{dose} = compensated ion beam current, I_{disk} = ion beam current measured by the disk faraday, ρ = pressure[torr] measured at the process chamber ion gauge (IG3) and K = (1E4)*ln(1 + PCOMP/100). At a pressure of 1E-4 torr, the equation reduces to, $I_{dose} = I_{disk}*(1 + PCOMP/100)$ as described earlier. An alternative formulation which delineates the role of PCOMP more clearly can be given as:

$$I_{dose} = I_{disk}*(1 + PCOMP/100)^{(1E4*\rho)} \qquad (2)$$

Chart 1 illustrates the dependence of the amount of correction to I_{disk} for a given PCOMP value vs. pressure. A PCOMP value less than zero implies a condition of charge stripping in the process chamber which occurs for some high energy processes. If there is an error in the readback from the process chamber ion gauge, IG3, it will affect dose measurement during the entire implant. Average process pressure (largely determined by electron shower gas flow), beam current, quantity of photoresist and optimum PCOMP value all participate in dose measurement. Large PCOMP values and/or high average pressures coupled with IG3 readback errors represent worst-case conditions.

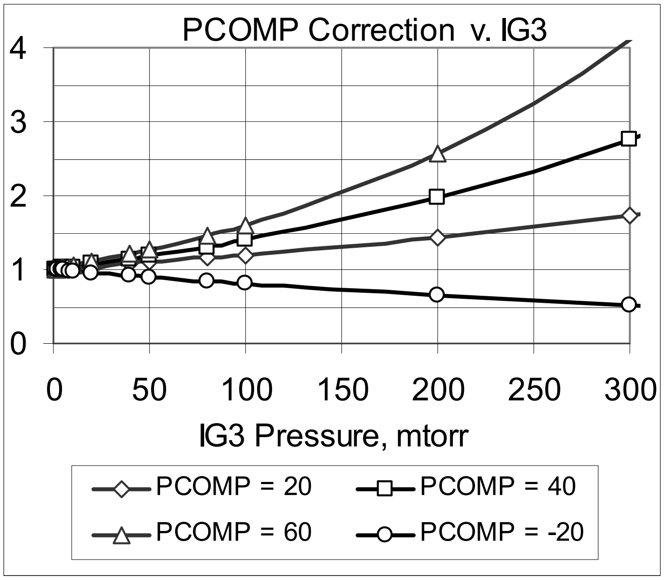

Figure 1. PCOMP Correction Factor vs. IG3 pressure

III. STABIL-ION GAUGE PERFORMANCE

Stabil-Ion gauge systems have been installed on INNOViON GSD implanters at the Portland, Oregon facility to improve process uniformity and dose repeatability between gauge changes [3]. OEM recommendations for the gauges include regular, extended degas of the gauge filaments and pressure response tracking of the gauges as a means to evaluate when a gauge is failing and also to determine whether a replacement will deliver comparable process results. The current PM schedule for these implanters calls for an extended filament degas (15 minutes) on a weekly basis. Early experience with the Stabil-Ion gauge, where a high degas frequency was not observed, led to several premature gauge failures. The regular degas of the filament is key to overall lifetime since a gauge whose performance is beginning to decline cannot be restored by repetitive degas operations. A twice weekly degas schedule test is in progress which will not be resolved for several months since gauge lifetime is already quite good.

A simple procedure for tracking pressure response of the gauges on each GSD has also been implemented and assigned to a biweekly PM schedule. The procedure consists of monitoring gauge pressure vs. Electron Shower argon flow. For example, MFC setpoints of 0,1,2,…,9 sccm are used and the pressure is recorded for each flow level. The procedure is also exercised on new gauges after an extended degas cycle has been completed to establish baseline data for that gauge. The data is then charted and compared to either the prior gauge's response in the case of a new gauge or to itself over time in the case of an in-use gauge. The data is then used to populate an SPC chart using data from a particular MFC setpoint. The chosen data point represents average chamber pressure for most proceses. Currently, control limits are set at about +/-20% of nominal. Though, in practice, we observe mainly that pressure response decreases over time and so the lower control limit provides a signal for when to change the gauge.

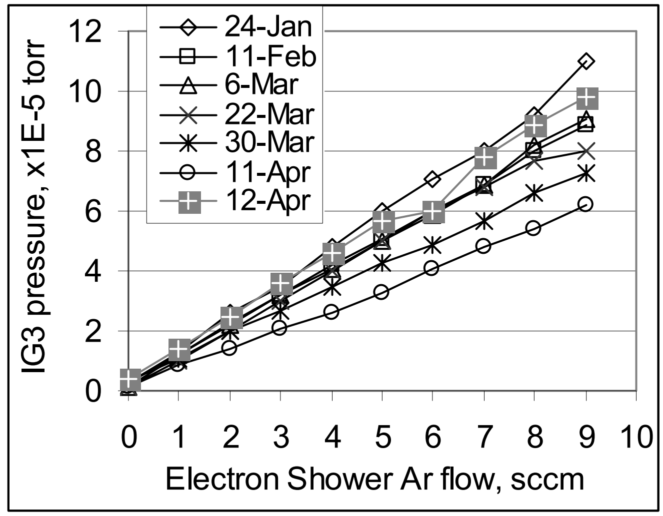

Figure 2. IG3 Response vs. Ar flow over time; infrequent degas

The plots in Figure 2 illustrate the pressure response tracking data for one GSD system prior to implementing correct degas frequency. The decline from nominal performance to OOC can be very rapid. Of note is that the gauge response at all Ar flow settings is self-consistent, i.e., if the pressure reading at 4.0 sccm has declined by 10%, then the pressure at 9.0 sccm has also declined by 10%. The plot for 12 April is for a replacement gauge demonstrating gauge-to-gauge repeatability.

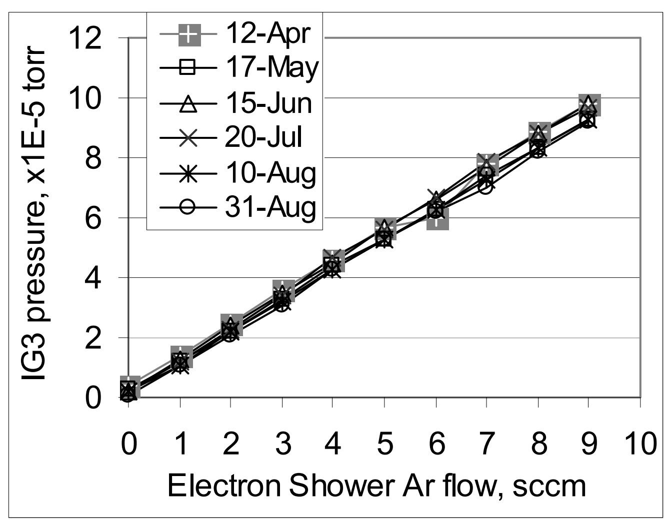

Figure 3. IG3 Response vs. Ar flow over time; weekly degas

The plots in Figure 3 demonstrate that good repeatability over time can be achieved with the Stabil-Ion gauge system with frequent extended degas. The data were derived from the same system as in Figure 2 after the implementation of a weekly extended degas. The time sequence begins with the plot from 12 April from Figure 2.

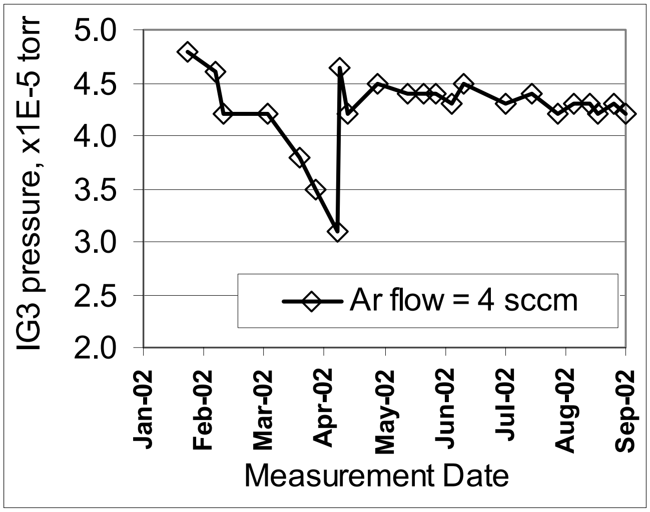

Figure 4. IG3 Response for Ar flow = 4 sccm over time

The plot in Figure 4 shows the variation over time for the same GSD system that was charted for Figures 2 and 3, but for an Ar flow of 4 sccm only. Though not rigorously studied, this plot shows reasonable gauge to gauge repeatability. At the time of the first ion gauge change in April, control limits had not yet been set for this chart, hence the rather large excursion from nominal. This plot also indicates that gauge degradation is much more gradual with the weekly degas PM in place.

IV. PROCESS EFFECTS

A simple calculation will illustrate the risk to device performance. Suppose nominal process chamber pressure is 5E-5 torr with a PCOMP value of 30. If ion gauge performance drifts to the point where the process chamber pressure readback is now only 3E-5 torr, then the difference in ion beam correction factors is equivalent to 3.1% of process dose. This assumes that beam neutralization is equivalent in both instances and that the pressure change is due to the ion gauge alone. The dose shift will, generally, be towards higher dose since the pressure compensation calculation is no longer accounting for beam neutralization correctly due to the erroneous gauge readings. For most device designs, a shift of 3.1% implant dose will not have a severe impact on parametric response. However, the dose change is large enough that it will generate an easily observed trend in parametric performance. In a situation where one wants several implanters of the same type to produce identical process results and where one wishes to maximize available process margins for other process steps, this magnitude of dose/parametric shift is very significant. Such shifts also complicate troubleshooting of potential process issues from other areas in a fab since any given implant will impact numerous device parameters and potentially mask other process trends. When one surveys process trends, it is usually done without filtering data by individual machine. If dose mismatch between machines causes wide parametric variation, this can also obscure other process trends and/or necessitate more time-consuming data analysis.

V. CONCLUSION

The Stabil-Ion gauge system for GSD implanters does fulfill its claims of increasing long-term gauge stability and gauge to gauge repeatability. A quantitative study of actual gauge to gauge repeatability may be warranted, though data gathering will be slow due to good gauge lifetime. Important areas not investigated in this paper, are MFC stability, and high-vacuum pumping health. Since variation in process chamber pressure could also depend on these factors it is worth finding a means to distinguish their effects from actual gauge drift. Developing a protocol to evaluate GSD implanters with these effects in mind would not be difficult to accomplish. Finally, the key learning to date is the need for frequent (weekly or more often) extended filament degas cycles. The Stabil-Ion gauges and their successors are considerably more expensive than standard HCIGs and therefore require measures to maximize their working life.

VI. REFERENCES

[1] "Best Methods and Practices for Determining Pressure Compensation Factors for the GSD Series High Current Implantation Systems", Axcelis, P/N 9510584, Rev. B, 12/2000

[2] John F. O'Hanlon, A User's Guide To Vacuum Technology, 2nd edition, Wiley-Interscience, 1989, pp. 96-97

[3] Axcelis presentation on "Stabil-Ion GAUGE UPGRADE", 6/22/2000