Results and Adoption of Safe Delivery Source® (SDS®4) on VIISta® HCP

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INTRODUCTION

The semiconductor device manufacturing of today requires improved quality designs to meet customer reliability requirements. Device geometries continue to shrink, device requirements continue to advance, and device yields still need to achieve satisfactory levels to allow reasonable manufacturing cost and meet device volume demands. No aspect of materials quality can be overlooked to achieve the most consistent manufacturing processes. Entegris' commitment to the semiconductor industry focuses on quality, safety, and performance. In the early 1990s, SDS®1 was developed to provide a safe delivery gas source for highly toxic gases. This provided ion implant customers increased ion beam performance over typical high-pressure mixture dopant gases, with the safety of sub-atmospheric gas delivery. In the mid 1990s, SDS2 replaced SDS1, providing increased gas deliverables using the same size cylinder. SDS2 is still available, but customers required more gas deliverables from the cylinder, so SDS3 was released in 2005. Since this time, SDS3 has effectively met the needs of the industry; however, increasing requirements, coupled with Entegris' drive to bring continuous innovation to the market, has led to the development of SDS4.

In 2018, SDS4 was developed to take advantage of new features now available in the creation of the absorbed cylinder construction. Four key features were considered in the construction of the SDS4 cylinder. First, improved manufacturing processes of the carbon puck and the installation/preparation to fill the cylinder. This provided an increase in surface binding area in the carbon puck for the physisorption of the gas onto the carbon. This increased the gas deliverable specification on arsine and phosphine by up to 8% at 5 Torr cylinder pressure. Second, the internal SDS4 filter is 9 LRV for particles >0.003 μ, but still allows ample gas flow for any implant setup. This means 99.9999999% (9 LRV) removal of particles greater than 3 nanometers. Third, the SDS4 manufacturing improvements and additional factory analytical capabilities enable post-fill analysis of the delivered dopant gas. Validating the gas impurities coming out of the cylinder is critical to achieve the highest quality standards. Fourth, an improved tied-diaphragm dual seat designed valve provides improved performance specifications and includes an open and closed indicator to easily identify the position of the valve.

When making any process change, predictability is key. Confidence that the process change will not negatively impact the device and that the change is stable and dependable allows the process owner to take advantage of new features or value with assurance of the results. The information provided comes from customer results running SDS4 and SDS3 on an Applied Materials VIISta® HCP implanter. Since SDS4 is the exact same form factor as SDS3, installing SDS4 in place of SDS3 cylinders is straightforward. As with all new material testing, some basic checks were made after the installation of SDS4. A 30-minute gas flow stability check was performed with arsine and phosphine gas and verified by an ion beam stability test as seen in Figures 1 and 2. No issues or concerns arose during the use of the cylinders with regards to cylinder performance during the life of the cylinders.

Figure 1: SDS4 AsH_3 Stability

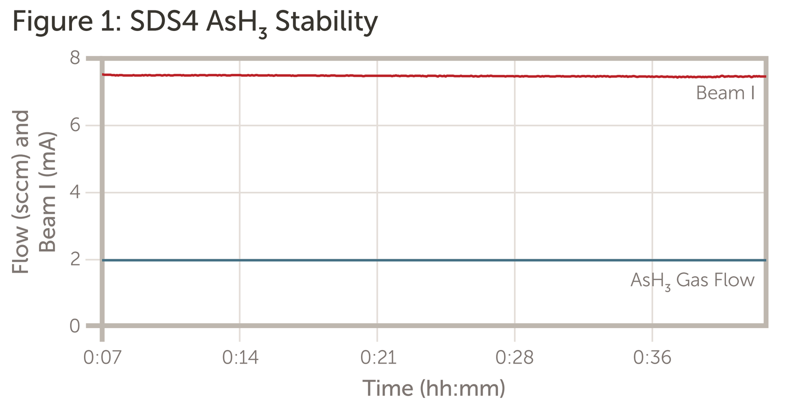
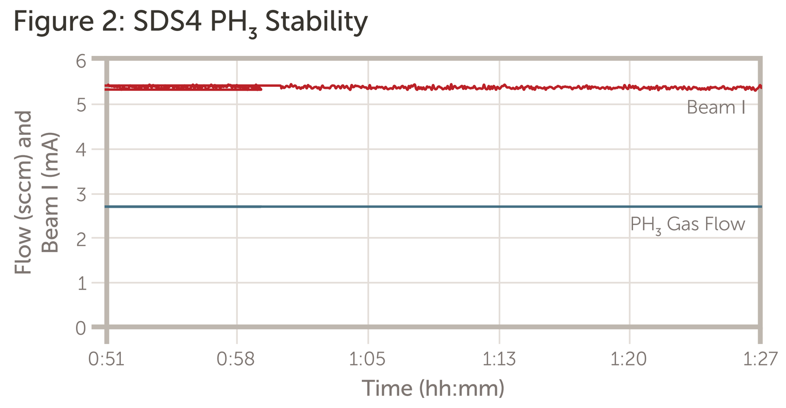


Figure 2: SDS4 PH_3 Stability



After the initial beam setup and stability test, ion beam mass spectra were checked to ensure no unusual peaks were observed from the SDS4 dopant gas. Ensuring clean mass spectra is important since all impurities emitted from the cylinder will collect in the beamline and possibly migrate onto the wafer. As shown in the arsine and phosphine beam spectra (Figures 3 and 4), no unusual peaks are displayed with SDS4.

Figure 3: SDS4 AsH_3 Beam Spectrum

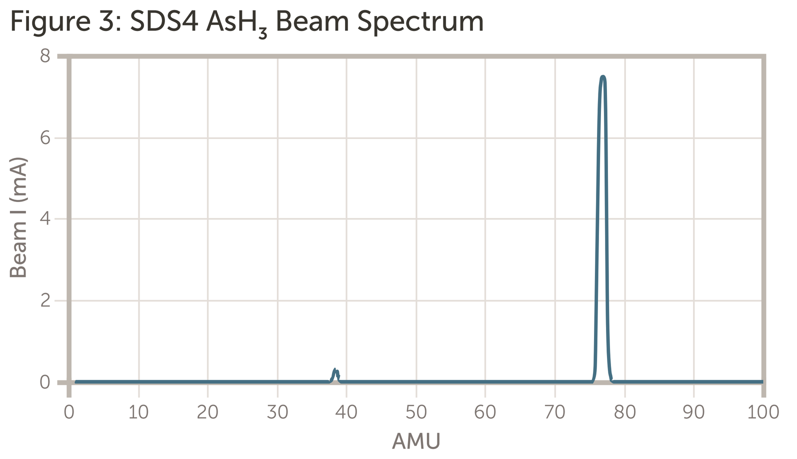
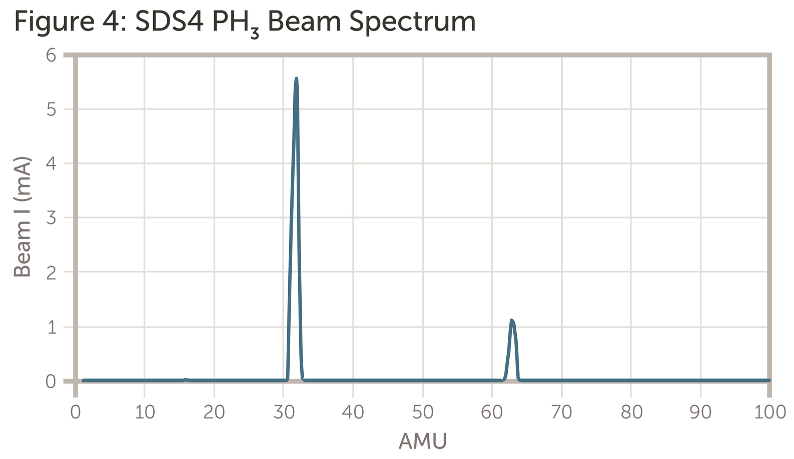


Figure 4: SDS4 PH_3 Beam Spectrum



The sheet resistance was measured with a four-point probe on arsenic doped P-type test wafers. Over the duration of the cylinder life, periodic test wafers verified proper dosing operation of the implanter. Sheet rho outlier data and any tool excursions were reviewed and removed to help concentrate on the normal equipment condition. The dosing of the test wafers over time shows a flat trend for both SDS4 and SDS3 arsine cylinders as seen in Figure 5. Using a two-sample t-test analysis of SDS3 and SDS4 arsine, the p-value was less than 0.05, which means with 95% confidence the two mean sheet rho values are statically significant, meaning they are different, but as reported the values are very close. With the large sample size, a difference in means of about 0.6 standard deviations can be detected statistically. Although the sheet rho values are statistically significantly different, the difference of 0.956 ohms/sq is not considered practically significant.

The two-sample t-test Rs mean for SDS3 is 172.852 and the SDS4 Rs mean is 171.896, shown in the box plot analysis in Figure 6.

Figure 5: Arsenic Rs Run Chart

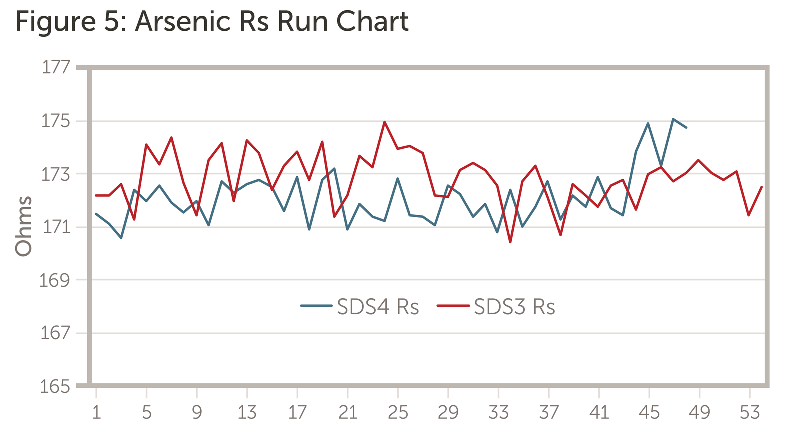
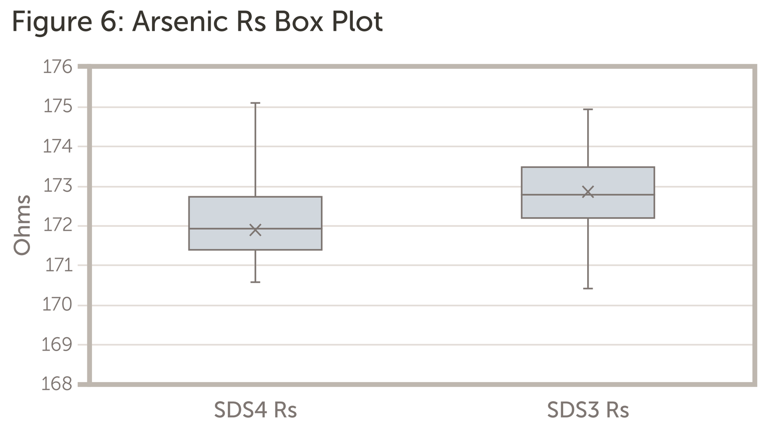


Figure 6: Arsenic Rs Box Plot



A parametric check was completed on the Rs data for SDS3 and SDS4 using a probability plot. The p-value from the probability plot was greater than 0.05, signifying normally distributed data as presented in Figure 7 and Figure 8 histograms.

Figure 7: SDS4 Rs Histogram

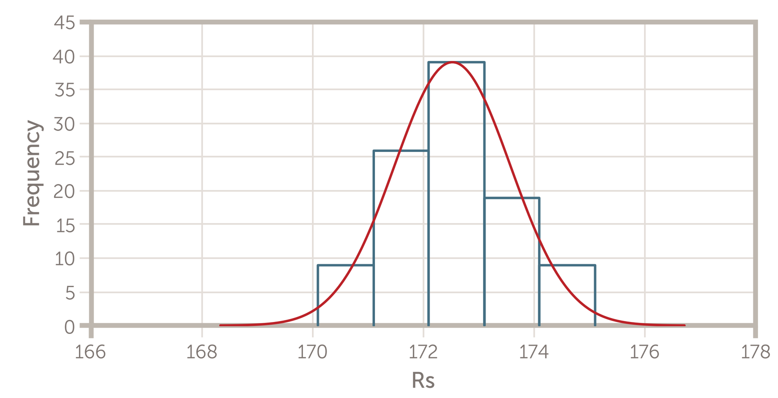
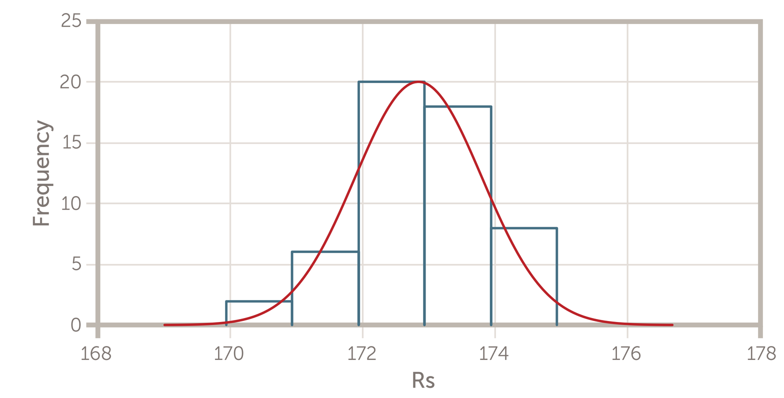


Figure 8: SDS3 Rs Histogram



Pre and post particle data were collected at the same time the arsenic test wafers were run on the VIISta HCP implanter. Many factors contribute to particle data on test wafers. The volume of production wafers processed through the implanter, the preventive maintenance schedule, implanted dose, particles from upstream in the beamline migrating to the wafer, photoresist coverage of the production wafers, and beam power can all affect particle data. During the evaluation period of SDS4 and SDS3, the factors just described remained similar. Particle outlier data and any tool excursions were reviewed and removed to help concentrate on the normal equipment condition. During the life of the cylinders, the particle trend was relatively flat as seen in Figures 9 and 10. Since the particle data are not normally distributed, the nonparametric Mann-Whitney test was used to compare particles for the two dopant cylinders. During the time the SDS4 cylinder was installed on the implanter, the median particle adders were 6. During the time the SDS3 cylinder was installed on the implanter, the median partial adders were 15, as shown in the box plot in Figure 11. The Mann-Whitney test reported a p-value of 0.000 which indicates the SDS4 is statistically significantly lower in particle adders, but more testing is needed to attribute the shift to an assignable cause.

Figure 9: SDS4 PC Trend

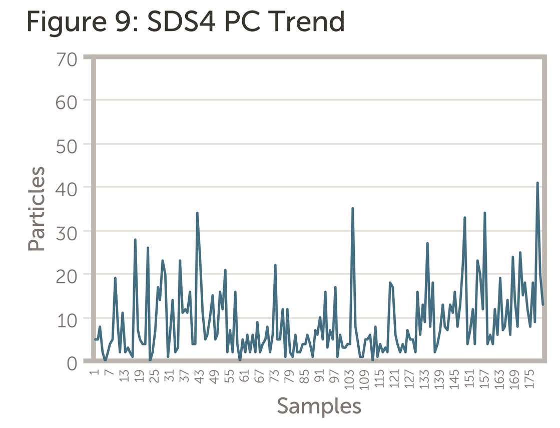


Figure 10: SDS3 PC Trend

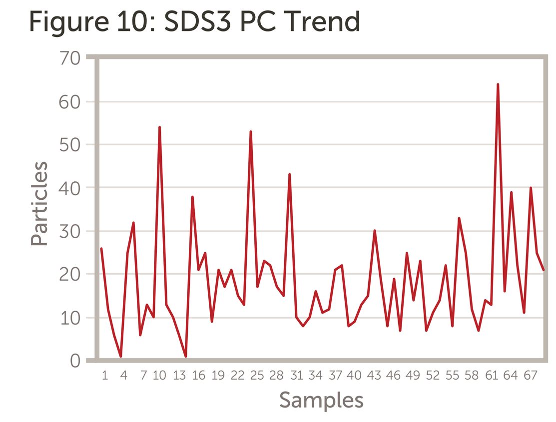
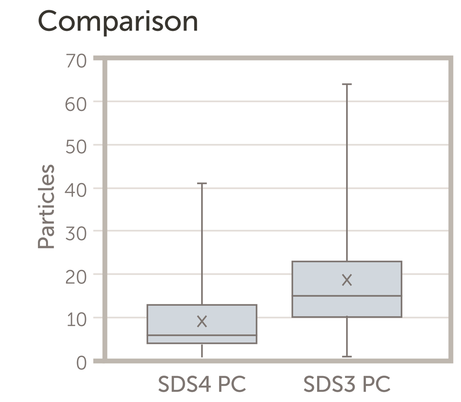


Figure 11: Particle Box Plot Comparison



The particle count histograms display a shift in particle adders to the left during the time the SDS4 cylinder was installed on the implanter compared to the time when SDS3 was on the implanter, confirming the reduction in partial adders as seen in Figures 12 and 13.

Figure 12: SDS4 PC Histogram

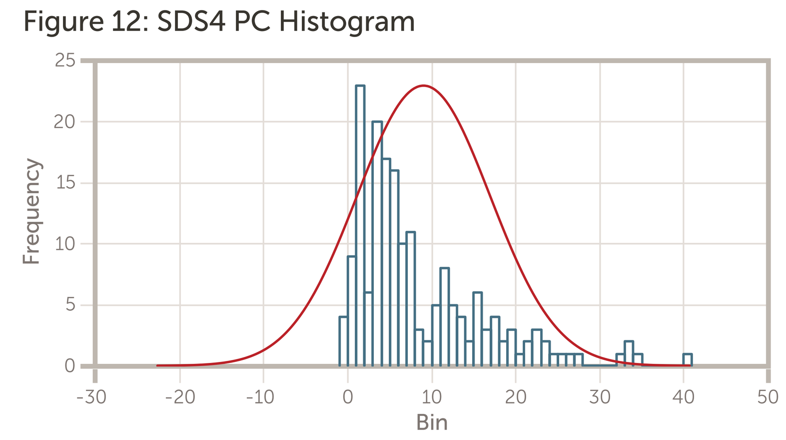
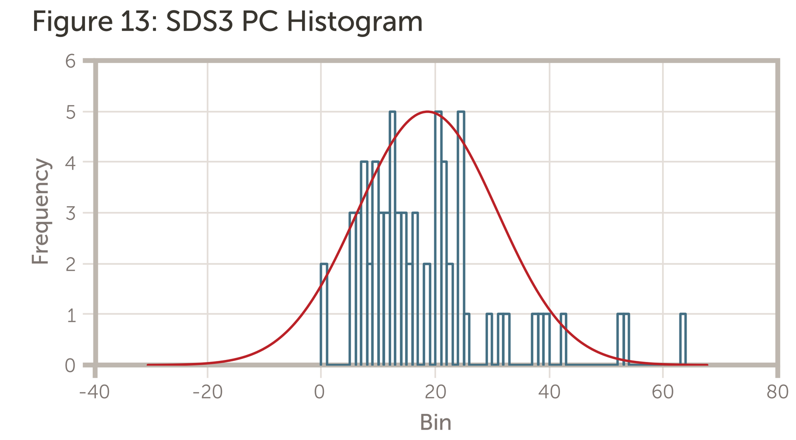


Figure 13: SDS3 PC Histogram



The last customer aspect to review is the implanter beam uniformity at the region of interest (ROI). The beam setup time and ROI uniformity were nominal for both cylinder packages. The beam profile uniformity was well below 1% as seen in Figures 14 and 15, and the beam setup consistently without issue.

Figure 14: SDS4 AsH_3 Beam Profile

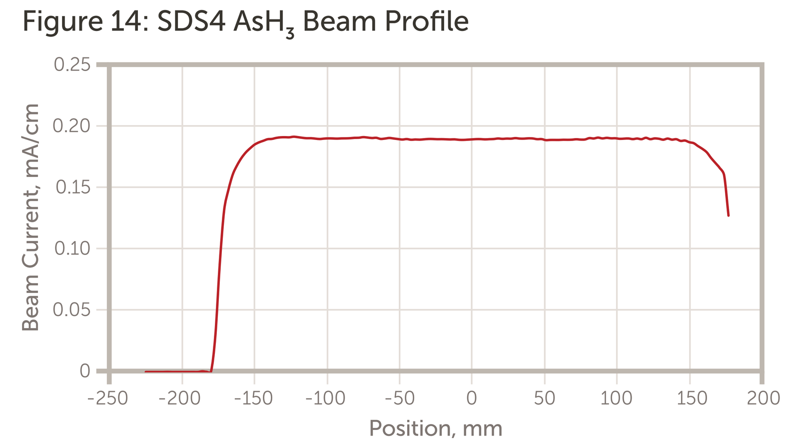
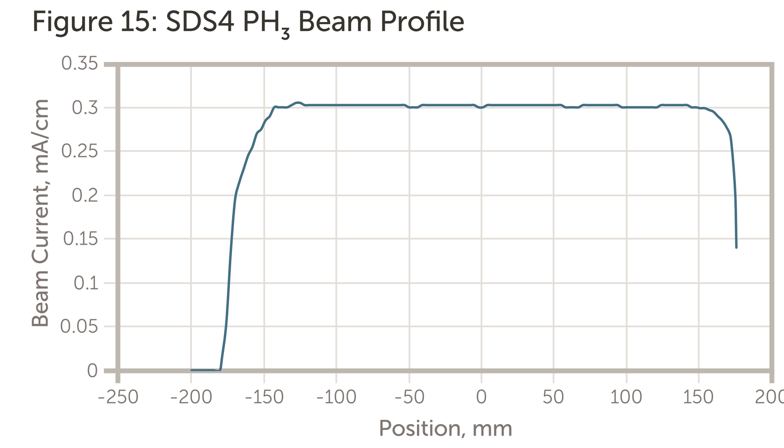


Figure 15: SDS4 PH_3 Beam Profile



CONCLUSION AND DISCUSSION

In summary, SDS4 provides improvement in gas deliverables by providing 8% more gas in a cylinder package that is exactly the same size and form factor as SDS3. Highly purified carbon is still the absorbent material, removing concern for any unusual impurities emitted from the cylinder. Test wafer data shows no change to the dopant interaction with the silicon lattice structure. This is expected, since the source gas is the same for SDS3 and SDS4. Improved analytical capabilities which include post fill analysis provide enhanced quality data over other implant gas packages. Improved internal filter specifications to 9 LRV for particles >0.003 μ still allows sufficient gas flow for any implant recipe. Implanter particle results are encouraging but more targeted testing is needed to confirm the results from this evaluation. The SDS4 package still provides inherent safety by storing gas below atmospheric pressure, but also is now equipped with an upgraded valve containing a visual open/close indicator.

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