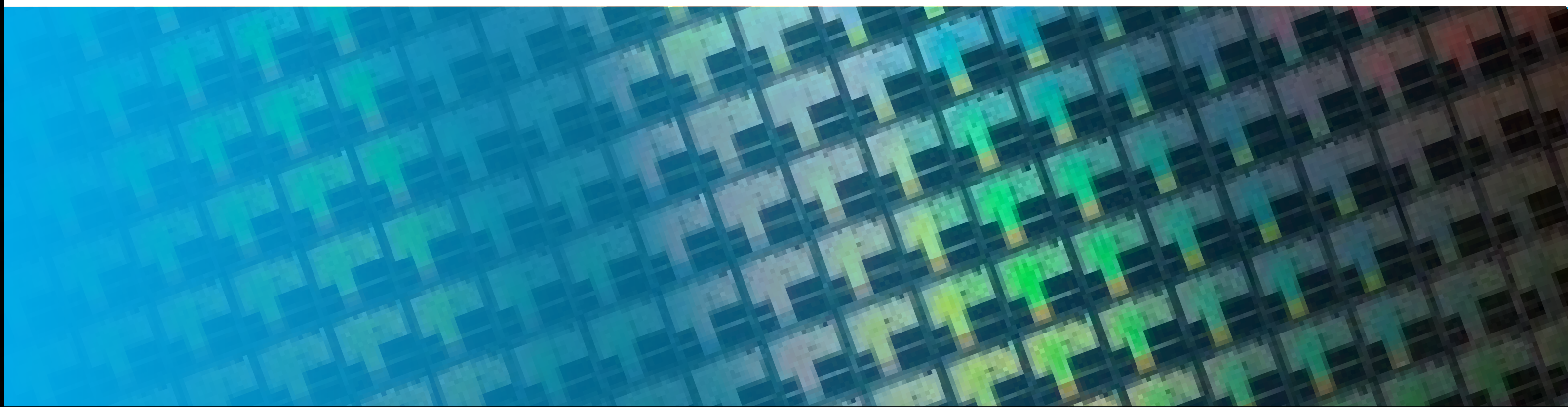
# CVD RISK MITIGATION:
## DECREASE DEFECT DENSITY AND INCREASE MEAN TIME BETWEEN MAINTENANCE (MTBM) WITH MORE EFFECTIVE FILTRATION

BY KATHY ERICKSON (MSP – A DIVISION OF TSI)



## I. Introduction

Chemical Vapor Deposition (along with ALD and other sub-sets of CVD like PECVD and MOCVD) is one of the most important steps in microelectronic device fabrication. The quality and uniformity of the CVD layer is one of the key factors enabling smaller device features. Many advanced CVD processes require use of a liquid source, and many PECVD/ALD processes require reduced pressure processing. Optimizing your post liquid vaporization filtration method can reduce CVD defects, increase mean time between (MTBM) maintenance and enable lower pressure plasma-enhanced processes.

Generating a vapor from a liquid source can create defects in three different ways. 1) Impurities in the source liquid can create solid particulates in the source vapor. 2) Incomplete vaporization can result in liquid droplets which act as defects on wafer - or at minimum can create pressure fluctuations which can create arcing for plasma processes. 3) Thermally sensitive liquids can decompose into solid particulates when the necessary heat is applied to create a vapor. One solution to these three issues is to be very selective in the vaporization technique - ensuring the method employed results in 100% vaporization of the liquid and minimized thermal decomposition of the source.

However, even with a high quality, carefully selected vapor delivery solution; the high penalties of device defects, process instability and down-time make risk mitigation in semiconductor fabrication a must. Optimizing post vapor filtration is an inexpensive and smart way to protect the integrity of your semiconductor fabrication process.

### Choosing a High Quality Filter

When choosing a filter to protect your semiconductor device; four things must be taken into consideration. 1) Filtration efficiency, 2) pressure drop, 3) thermal mass, 4) thermal and chemical resistance.

## II. Filtration Efficiency

Airborne filtration is a story of competing forces - or capture mechanisms. Very large particles (micron size) are caught by interception and impaction. Very small particles (nanometer size) are strongly affected by the random motion of diffusion, and are easily caught and captured on any nearby surface. However diffusion is a less effective capture mechanism for larger particles. Because of this, the size range where it is most difficult to capture airborne particles is where the particle is large enough that the effect of diffusion wanes, AND the particle is still too small to be very easily caught by inertial impaction and interception. This is referred to as the Most Penetrating Particle Size (MPPS) and for

MSP®
A DIVISION OF TSI®

ultra-high efficiency filters, tends to be in the 50nm – 80nm range (for very low efficiency filters the MPPS is larger).

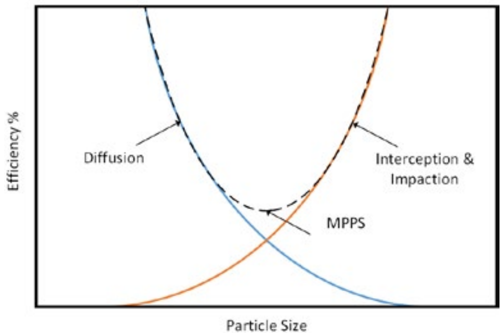



*Figure 1: Filtration efficiency curve (dashed line). Illustrating the diffusion and interception/impaction particle capture mechanisms as a function of particle size, and the MPPS (Most Penetrating Particle Size). 100% filtration efficiency means all of the particles are removed by the filter.*

Since process nodes are down to 3 – 7 nm; killer particles (minimum particle size which significantly affects wafer yield) are also in the low nanometer size range; this is a good thing, because most filters are very effective in removing extremely small particles. However, un-vaporized liquid droplets typically are much larger – so the capture efficiency in the more difficult filtration range of 50-80nm is still very important for CVD/ALD process risk mitigation.

Filtration efficiency is frequently discussed as the 'number of nines'. For example, if the efficiency at a certain particle size is 99.99% - there are four nines in the significant digits of the filtration efficiency percentage number, so 99.99% is referred to as '4 nines'. If the efficiency is 99.9999% that is 6 nines. Make sure the filter you are selecting captures at least 12 'nines' of the small nanometer particles (efficiency of 99.9999999999% @ 2.5nm); but also ensure it has high efficiency at 50 or 80nm as well (7 'nines' or 99.99999%).

Note: if the filter you are buying claims good efficiency below 1 nm be wary of poor specsmanship. Below 1nm, the particles are SO SMALL that filtration-wise they effectively act like a gas. This behavior is caused by what experts have termed as thermal rebound. The particles are so small that any amount of thermal energy greatly affects them – causing them to have so much impact velocity when they hit the filter media that they rebound, and do not adhere. Meaning they can pass through filter media without being captured – much like a gas.

## III. Pressure Drop

Pressure drop can hurt a CVD process in three ways: 1) it will reduce pump lifetime and increase energy usage; 2) it can eliminate the ability to process at extremely low chamber pressures; and 3) it can potentially cause gas phase conversions in the filter.

Everything upstream of the pump adds load to the pump. Pump load is a major component in pump lifetime. The higher the pressure drop of the upstream filter, the shorter your pump life. Fundamentally, the pump you use has limited capacity – the more pressure drop you add to your system, the less vacuum you can pull (and the more energy you consume). Too much pressure drop upstream of your pump may prevent you from processing at the low pressure your process requires – often resulting in poorer thin film quality.

Finally, a high pressure drop increases the residence time of gases inside the filter and can potentially lead to some undesirable gas phase conversions within the filter, which could cause process and maintenance issues.

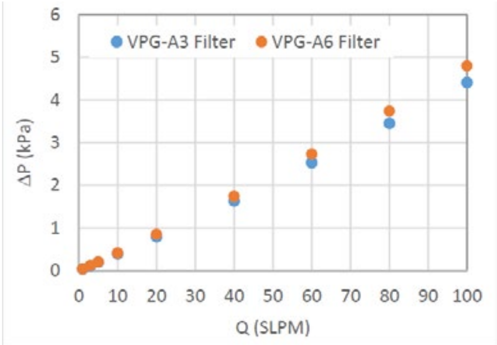



*Figure 2: Pressure drop vs volumetric flow rate for the ultra-low pressure drop MSP VPG-A6 and VPG-A3 in-line 316SS Vapor Process Gas Filters.*

## IV. Thermal Mass

Thermal mass is a criteria that is often overlooked in filter selection downstream of a vapor delivery solution. However, if for some reason the vaporizer/bubbler is outputting some liquid (not 100% vaporization) – or there is some condensation downstream caused by temperature/pressure drops in the tubing or valves – having enough thermal mass in the filter to provide re-vaporization is key.

The tubing downstream of the vaporizer is heat wrapped (Figure 3). However most tubing has very low thermal mass (the ability of a material to absorb and store heat

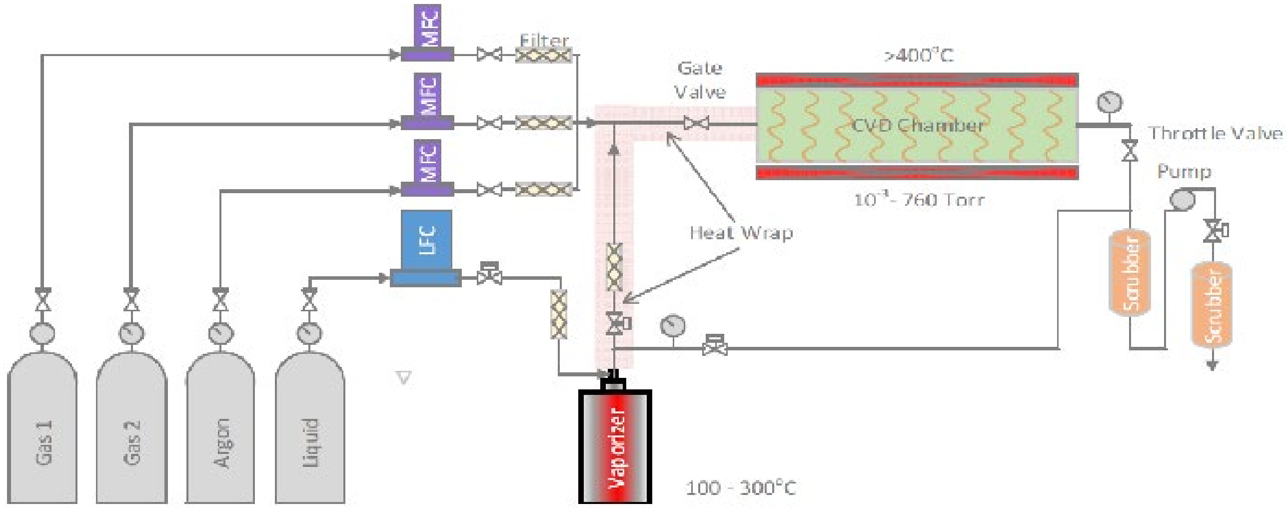



*Figure 3: CVD Schematic – illustrating heat wrap downstream of the vaporizer or bubbler. Tubing, valves, MFCs, LFCs, vaporizers and filters all add to the pressure drop across the system. [3]*

energy). Vaporization of a liquid pulls in quite a bit of heat (heat capacity + enthalpy of vaporization). Liquid in the downstream lines that is re-vaporized will cause the tubing to cool quickly (evaporative cooling), and even though the tubing is heat wrapped, there is not enough wattage (Joules/s) to offset the fast cooling meaning the heat wrap cannot deliver the heat fast enough. Thermal mass provides stored heat, which slows down the cooling and allows the heat wrap wattage to be effective in pumping heat back into the system.

Downstream of a vapor delivery solution, look for a filter with increased thermal mass – so it can provide the energy needed to re-vaporize any liquid that may have gotten downstream. Don't underestimate the power of a high quality filter with high thermal mass – the installation of one has saved processes with poorly performing liquid delivery solutions.

## V. Thermal and Chemical Resistance

Downstream of the vapor delivery system, the lines must be heated to reduce the risk of condensation which can be very problematic in several different ways: clogging (requiring maintenance), wafer defects (liquid droplets entering the chamber act as defects), and pressure instability (liquid entering the chamber creates pressure fluctuations which causes arcing). Since the lines downstream of the vaporizer/bubbler are exposed to heat, using a polymer/plastic solution where you need to consider polymer outgassing, plastic aging and material sloughing may not be the best choice for many processes. 316SS is a good solution due to its robust chemical and thermal resistance.


*Figure 4: 316SS Vapor Gas Filter MSP VPG-A6.*

## VI. Summary

Installing a high quality filter downstream of your liquid source delivery system is an easy and inexpensive way to protect your CVD/ALD process and your microelectronic device yield. Ensure the filter is suitable for the application by considering filtration efficiency, pressure drop, thermal mass, and thermal and chemical resistance. By choosing the appropriate filter, you can reduce the risk of defects, maintenance and process variation – saving time and money.

## VI. References

[1] William C. Hinds, "Aerosol Technology: Properties, Behavior and Measurement of Airborne Particles," Wiley-Interscience, (9):182-206, 1999.

[2] Raheleh Givehchi, Zhongchao Tan, "An Overview of Airborne Nanoparticle Filtration and Thermal Rebound Theory," Aerosol and Air Quality Research 14(1):45-63, 2014.

[3] Amit Gupta, D. Paramanik, S. Varma, C. Jacob, "CVD Growth and Characterization of 3C-SiC Thin Films, "Bulletin of Materials Science," 27(5):445-451, 2004.

MSP® A DIVISION OF TSI®

**MSP** - Visit our website **www.mspcorp.com** for more information.

5910 Rice Creek Parkway, Suite 300
Shoreview, Minnesota
55126, U.S.A.
**Tel:** 651.287.8100