Optimised MFCs make SDS economic

Kinetics Fluid Systems explains how the development of a Mass Flow Controller, optimised for Safe Delivery Source (SDS) gas delivery, makes it possible to extract 90% or more of a cylinder's contents with pressures below 10 torr, taking full advantage of the special benefits of SDS.

The safety advantages of using SDS gas supplies (technology developed and owned by Trigas, Matheson and ATMI) are well understood. The storage of hazardous dopant gases like arsine, phosphine, silicon tetraflouride and boron triflouride at sub-atmospheric pressures has virtually eliminated the risk of local and environmental release, and semiconductor manufacturers are now keen to exploit the further, major potential benefits of better productivity and greater flexibility, to balance the higher costs of this form of storage.

In SDS, pure dopant gas is stored by adsorbtion on a solid mass, increasing the overall capacity by as much as 15 times compared with gases stored conventionally in a diluted form under high pressure. This increased capacity can reduce the frequency of cylinder changeovers - which translates directly into increased tool uptime and better productivity - but only if the gas delivery system can meet the specific demands of low pressure storage. (Box story over page: SDS in ion implant).

ECONOMY AND EFFICIENCY

SDS has appeared to be an expensive option, because of the difficulty of extracting the maximum cylinder contents. The source dopant is adsorbed in the cylinder at typically 660 torr and most of the gas is released at pressures below 100 torr. To extract 90% or more of the cylinder contents, the release pressure needs to be reduced to a low pressure differential, below 10 torr (figure 1). Maximum desorption of the source dopant depends on the pressure-drop across the mass flow controller (MFC). Until recently the available flow control techniques have been unable to supply the stability and response time required at low operating pressures. At the low pressures required by SDS, conventional pressure-based flow controllers suffer from inadequate flow control and very slow response times - anathema to the goal of consistent implanter operation - while needle valves require constant adjustment to maintain the same flow into the chamber.

Fig 1: The lower the pressure at which the MFC can control SDS gas flow, the more dopant can be extracted. Unit Instruments' SDS MFC provides flow control to 8 torr and below, extracting up to 60% more dopant compared with conventional MFCs.

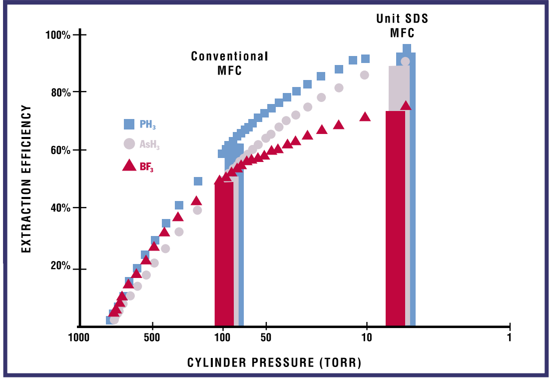
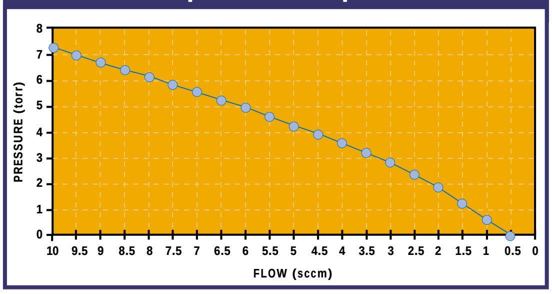


Fig 2: Unit Instruments' SDS MFC minimal pressure drop.



SDS DELIVERY ISSUES

When SDS was first developed it was assumed - correctly - that conventional thermal MFCs would also be inadequate: the high pressure drop of 50-100 torr meant that more than 50% of the potential usable contents routinely remained in the cylinder. But, the advantage of thermal-based MFCs is that they use only the thermal properties of gas to measure the mass flow rate, and ignore gas pressure. Because mass flow can be measured independently of gas pressure, this technique is - potentially - ideal for low-pressure applications.

THE RIGHT MFC FOR THE JOB

The development of a thermal-based MFC optimised for SDS requires particular attention to four interrelated areas: pressure differential, flow, stability, and calibration.

- Understanding rarefied flow

High pressure MFCs operate in the laminar flow region, where gas flow characteristics are predictable. At sub-atmospheric pressures, however, gas velocities increase due to the reduced gas density. When the gas velocity reaches Mach 1 a "choked flow" condition is produced, which restricts further flow. To increase flow under these conditions requires an increase in gas density or upstream pressure, and this was one of the problems which faced the low-pressure application of early thermal MFCs.

The problem has been solved through a special sensor designed to address rarefied flow conditions, by making flow improvements to the valve and by reducing dead space volumes, allowing flow rates of 10 sccm below 8 torr (figure 2).

In a thermal mass flow sensor, gas is heated in a sensor tube and resistor devices measure the temperature along

Fig 3: Sensor tube.

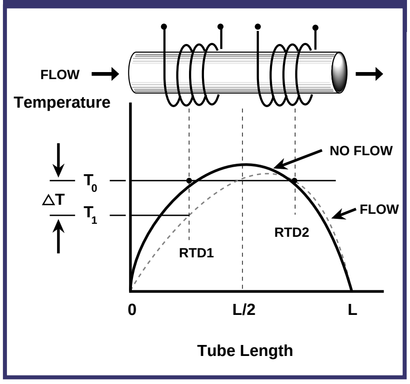
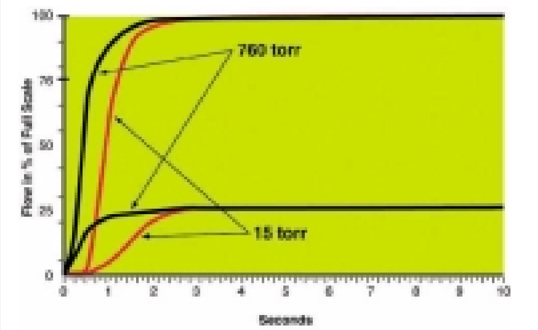
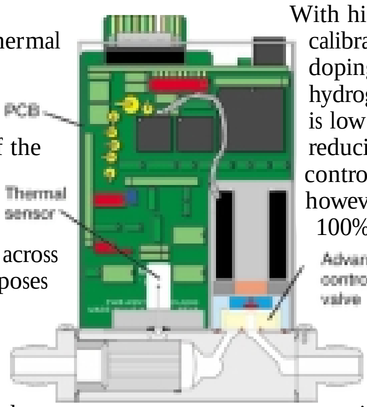


Fig 4: Response at 760 and 15 Torr.



the gradient of the tube (figure 3). The primary mechanism creating the temperature difference is the mass transport of the gas carrying the thermal energy gained in contact with the heated element by virtue of its heat capacity. For a given amount of heat, the temperature change of the gas is a function of mass flow.



• Increasing stability

The changing pressure differential across the MFC in SDS gas applications poses a challenge for sensor and valve tuning. This differential is continually changing, and the sensor and valve have to be tuned to deliver stable, linear flow across the operating pressure range that implanters require.

Coupling the thermal sensor with a magnetic solenoid proportional control valve provides infinite resolution, so that gas flow remains stable at both extreme high and low pressures. The matched and tuned electronic circuitry compensates for the thermal lag time of the sensor to changes in flow. The reduction in internal flow volumes also improves response time.

Improvements in the valve and reductions in dead space volumes enable SDS MFCs to provide the same performance stability at 15 torr as at 760 torr (figure 4). Stabilising the flow also eliminates the need to retune the MFC across the pressure range.

• Calibration

With high-pressure gas sources, calibration is not an issue: where doping gases are diluted with hydrogen, doping concentration is low and flow rates higher, reducing the need for flow control accuracy. With SDS, however, the dopant gas is at 100% concentration, placing far greater constraints on accuracy and flow repeatability on the MFC.

Understanding gas flow in the rarefied flow region has helped develop a technique called gas-specific calibration. Calibration accuracy is highly dependent on the gas's physical properties. Calibration with nitrogen is not accurate enough for gases that have very different physical properties, such as specific heat and molecular weight. The gas-specific method uses surrogate (non-toxic and non-corrosive) gases that have similar properties to the actual process gases and that are non-corrosive and non-toxic to optimise the sensor, bypass and valve to take advantage of the fluid properties of the specific gas, and results in a lower pressure drop across the MFC.

THE PAYBACK

The effect of the specially developed sensor and improved flow through the valve is an MFC with the ability to flow 10 sccm of dopant below 8 torr, enabling users to extract more than 90% of the SDS cylinder contents.

By converting to SDS, production safety in the supply of highly toxic dopant gas is immediately improved. By also converting to thermal-based MFC delivery, the full benefits of SDS can be realised - both high- and medium-beam current implanters can increase efficiency and maximise savings. Gas wastage can be minimised, flow stability is consistent, and up-time increased.

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SDS IN ION IMPLANT

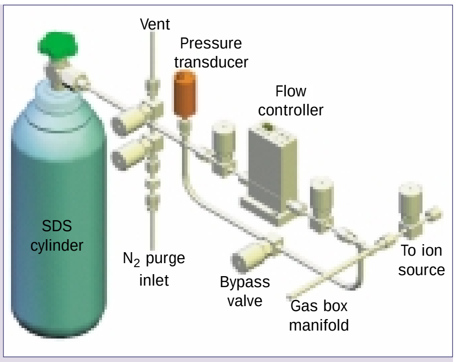
Sub-atmospheric SDS gas sources became commercially available in 1995 as a safer and more productive alternative to either high pressure gases or solid sources. SDS is now being sold as the standard configuration on more than 80% of new implanters shipped around the world. Although ion implant is the main application (figure), SDS is also being adopted by several HDP-CVD OEMs.

Ultimately a gas or vapour is introduced into the arc chamber where the plasma is created. Originally source materials for implant were chosen based upon availability with little concern for safety or the environment. Common atoms such as arsenic, phosphorous, and boron were available as compounds with either hydrogen or fluorine as pressurised gases. More exotic feed materials were available only as solids. The vaporiser for solid feed materials was introduced around 1980 as a safe alternative to the highly toxic, highly pressurised, gaseous sources of the concentrated or dilute mixtures of arsine and phosphine. The oven provided the heat needed to increase the vapour pressure of the feed material so that the vapour could be ionised. However, the time needed for heating the solid and then producing a stable flow drastically reduced productivity.

The SDS gas source derives its safety advantage because it is maintained below atmosphere. Without pressure favouring cylinder discharge, gas releases are governed by diffusion, a process many orders of magnitude slower. Static and dynamic studies were conducted to measure the gas release rates and changes in internal cylinder temperatures that occur when an SDS cylinder is rapidly opened to atmosphere. The release events were monitored over one to two hours to obtain time-weighted averages. The tested cylinders averaged exposure concentrations significantly below TLV.

The SDS gas source consists of a standard compressed gas cylinder filled with an adsorbent media and the adsorbed gas, and a cylinder valve. The technology is based upon the physisorption of a molecule onto a solid microporous adsorbent. Physisorption results from the forces between the individual molecules of gas and the atoms or molecules comprising the adsorbent. These forces are relatively small (5-25 kcals/mole), explaining why adsorption is reversible but strong enough to limit mobility of the adsorbed gas. Common microporous solids include zeolites, silica gels, and activated carbon. Of these, activated carbon yields the most favourable characteristics because of its very large micropore volume and idealised pore-size distribution.

Since the adsorption is reversible, the usable amount of gas is approximately the quantity that can be extracted by the differential pressure of the ion implanter and the cylinder, minus the pressure drop of the delivery system. This is commonly referred to as vacuum desorption. Because the SDS is sub-atmospheric, special consideration must



be given to delivery. High-conductance components and plumbing must be used to deliver up to 10 sccm, with pressure differentials as low as 10 torr to achieve maximum cylinder use.

The International Technology Roadmap for Semiconductors (ITRS 1999), states that "the potential physical and chemical hazards of alternate technologies need to be evaluated and mitigated. Sub-atmospheric delivery systems should be developed (and used) for a wider variety of dopant materials." SDS gas source feed materials are offered in 100% arsine and phosphine, and isotopically enriched $^{11}BF_3$, for doping of Si and SiGe-based integrated circuits and GeF_4 and SiF_4 for pre-amorphisation. Work is underway to develop sources of isotopically enriched $^{72}GeF_4$, used for enhanced productivity of pre-amorphisation implants and of fluorinated arsenic and phosphorous for use in RF-microwave ion sources.