

300mm fabs and the role of bulk specialty gas supply

OVERVIEW

300mm wafer processing brings with it a proportionate increase in specialty gas consumption with associated handling concerns. For many of these situations, a bulk specialty gas system will help meet the demands associated with the higher volume and flow requirements of 300mm fabs. Today, no one would conceptualize dealing with cylinder quantities of atmospheric gases that a cryogenic back pad system now provides. So, why dispense specialty process gas with large numbers of cylinders with added risk, inventory, handling, and quality issues?

The volumes of gases required for 300mm fabs are difficult to predict without detailed knowledge of a specific manufacturer's fabrication processes and tool recipes. However, one estimate of gas flow requirements may be based on process chamber size and geometry. We would expect a gas requirement increase of 2.25× to 3.4×, depending on whether one assumed a cylindrical or spherical chamber model. These multipliers would apply to both total gas volume and peak instantaneous gas flow rate.

The volumetric increase in certain specialty gas requirements for 300mm fabs may be better approximated by the increase in wafer surface area rather than process chamber volume. A general rule of thumb for scaling specialty gas requirements for a 300mm fab would be to simply multiply the requirement of a 200mm fab by 2.25 on a wafer starts/hr (WSPH) basis. This 2.25× increase in specialty gas volumes will translate into a higher frequency of cylinder change outs. Chamber purging gases may require 3× the volume because these requirements are more directly related to tool chamber volume as opposed to wafer surface area. As a result, one can expect an increase in bulk specialty gas system (BSGS, Fig. 1) requests for 300mm fabs.

A potentially greater technical challenge may be the increase in peak instantaneous flow rate requirements for specialty gases. This problem becomes especially difficult with the lower vapor pressure of liquefied specialty gases, for example NH_3 and Cl_2 . In many cases, a dedicated cabinet for each process tool may be required unless a BSGS is used. Due to the larger gas volumes required, "heated" gas supply systems are needed to overcome Joule-Thomson (JT) cooling effects, which will be exacerbated at higher flow rates.

In addition to addressing the difficulties associated with supplying significantly larger quantities of the lower-vapor-pressure

gases, a thorough review of the entire distribution system to tools should also be performed. It is important that the entire bulk supply be taken into consideration as a total system solution to ensure appropriate gas flow to the process tools.

The table lists the number of "typical" 300mm tools that can be supplied from a conventional gas cabinet. Of course, one must bear in mind that such lists can vary significantly depending

on the type of devices being fabricated, device chemistry, design rule, process tool recipe, etc. The last column gives an indication of how many process tools can be supplied by a given gas cabinet in a typical fab. It is important to note that the number of cabinets required are calculated by estimating the 300mm flow rates for various process steps, and could differ significantly in an actual 300mm operating fab.



Figure 1. Scaling of specialty gas requirements associated with 300mm wafer processing may, in some cases, require use of bulk specialty gas systems (BSGS); a typical BSGS is shown.

Specialty gas purity

Gas purities tend to be driven by IC design rules rather than physical wafer size. Historically, industry perception, analytical capabilities, and the operating philosophies have derived many purity requirements. In the past, there has been a strong trend of increasingly stringent purity requirements with each reduction in design rules, and the industry is expected to continue to push for higher

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specialty gas purity levels in the future. These requirements will present a challenge in the areas of specialty gas production and purification. The transition to 300mm wafers should improve delivered gas purity, as larger flow rates tend to dilute contaminant contributions from piping and components of gas delivery systems. Also, bulk containers should contribute fewer impurities to the gas due to the larger volume to internal cylinder surface area ratio.

One approach to further improving specialty gas purity is the use of purifiers either near the source or at the point of use (POU). Unfortunately, the purity performance of on-site purifiers is rarely verified with the actual source gas once installed or tracked over time. For BSGS, there are few specialty gas purifiers that are capable of handling larger average and peak flow rates. A recent advance is the addition of built-in-purifiers (MegaBIP, Fig. 2) inside the source cylinders, which is revolutionizing specialty gas purity specifications. Demonstrating the actual output of MegaBIP gases as part of the product certificate of analysis should better ensure purity at the source. This technology should also neutralize any impact from the cylinder package on gas purity over time, increasing the shelf life of the gas. MegaBIP packages are being developed for bulk containers to be available for 300mm fabs.

Safety, health, environment

A major issue for semiconductor manufacturers concerning BSGS systems is the potential consequence of having larger specialty gas source containers at the site. It is important that any BSGS offering is approached as a total “system” supply, not just a sale of equipment and gas. Site considerations should be part of the offering to provide an optimum and safe installation. Although the piping system’s total length is not expected to increase significantly, the diameter for specialty gases in BSGS service will typically require 1/2-in. lines rather than the 1/4-in. delivery lines used in cylinder gas cabinet supply.

Many semiconductor manufacturers, indeed even some bulk specialty gas equipment suppliers, have little experience in facilitating and operating BSGS. Equipment and gas suppliers should provide written guidelines of relevant code requirements, provide product and project consulting, and be capable of installing an entire system for the fab. The BSGS supplier should have start-up, operating, and maintenance experience that can be passed on to equipment operators, if not actually providing these services.



Figure 2. A specialty gas cylinder with a built-in purifier (i.e., MegaBIP).

The BSGS should be installed with the same containment, ventilation, and monitoring protocols common in gas cabinet installations. Bulk specialty gas systems should be capable of being placed in an outdoor environment, allowing utilization of less expensive space versus traditional gas rooms. Outdoor conditions require cabinets to be more “weather proof” and monitor-and-control electronics to be conditioned for temperature and humidity; a roof should provide protection from snow, rain, and sun, all of which can influence system performance.

For example, snow can affect scale readings, and sunlight on the source cylinders can greatly increase product temperature and hence the gas pressure. The higher input pressure increases the amount of JT cooling upon regulating the gas down to house line set points. This increased cooling can frost up or even freeze a regulator, impacting its capability and reliability due to thermal cycling. Also the gas could liquefy, causing a two-phase gas-liquid combination downstream from the regulator, with large swings in delivery pressure. It is imperative that BSGS come equipped

with JT heaters prior to the regulator, to preclude this occurrence. This is important with indoor installations too, since the higher flow rates for 300mm fabs increase the JT effect.

Liquefied compressed gases have a limited vapor pressure at ambient temperature conditions. The liquid portion of the contained product must evaporate to allow continual vapor withdrawal from the cylinder. Under higher flow conditions, the contained product will cool, since the heat transfer through the wall of the cylinder is insufficient to provide the heat of vaporization.

The result is that the product vapor pressure drops, limiting the maximum achievable steady-state flow rate. The addition of heat prevents gas pressure collapse and sub-cooling of the cylinder wall to the point of potential carbon steel embrittlement. A bulk container heater (Fig. 3) for high-pressure cylinders, which are ~8 ft long by 2 ft dia., compensates for the energy loss during vapor withdrawal. This extends the deliverable flow rate from cylinders of CHF₃, Cl₂, CO₂, HCl, N₂O, SF₆, and NH₃.

Emergency response (ER) capabilities of a site, in conjunction with a gas and equipment supplier’s ability to train and respond to incidents, are critical. Recent regulations by the US Occupational Safety and Health Administration (OSHA) under process safety man-

Number of tools/cabinet for potential specialty gases

| Specialty gas | Formula | No. of tools/cabinet (max.) |
|-----------------------|----------------------------------|-----------------------------|
| Ammonia | NH ₃ | 6 |
| Boron trichloride | BCl ₃ | 5 |
| Chlorine | Cl ₂ | 1 |
| Dichlorosilane | SiH ₂ Cl ₂ | 2 |
| Hexafluoroethane | C ₂ F ₆ | 1 |
| Tetrafluoromethane | CF ₄ | 8 |
| Hydrogen bromide | HBr | 5 |
| Hydrogen chloride | HCl | 5 |
| Methylsilane | CH ₃ SiH ₃ | 6 |
| Nitrogen trifluoride | NF ₃ | 6 |
| Nitrous oxide | N ₂ O | 1 |
| Silane | SiH ₄ | 6 |
| Sulfur hexafluoride | SF ₆ | 1 |
| Trifluoromethane | CHF ₃ | 4 |
| Tungsten hexafluoride | WF ₆ | 1 |

agement (PSM), and the US Environmental Protection Agency's (EPA) risk management plan (RMP) need to be considered.

OSHA PSM (1910.119) and EPA RMP (112r) are specific requirements upon reaching the threshold quantities of certain gases, which are deemed to be risks to people, property, and the environment. ER is one of the facets of these regulations. A BSGS supplier should be capable of providing the required information to semiconductor manufacturers so they can abide by these regulations.

Reliability

As the industry progresses toward 300mm wafer fabs, one can expect to see an increased focus on equipment reliability. A single batch of 300mm wafers in a furnace could potentially represent an end-user value in excess of \$10 million. Because of the high economic risk associated with a process upset, additional redundancy and reliability safeguards will be required



Figure 3. A BSGS fitted with a bulk container heater.

on 300mm equipment. I300I set an aggressive reliability target of 90,000 hrs mean time between failures (MTBF) for process tools. Additionally, it set equipment availability targets of 90% for process equipment and 95% for metrology equipment. These targets are to be calculated based on the SEMI E10 standard for equipment uptime. In addition, I300I specified that embedded controllers used in 300mm equipment must also support availability, reliability, and maintainability statistics per SEMI E10 and SEMI E58.

Clearly BSGS must support these reliability goals as well. The best way to enhance reliability is with vast experience in operating these systems, and feedback of improvements to the product line support team.

Factory automation

Many industry standards organizations have focused their 300mm efforts on the area of factory automation. "Fab modularity" and interoperability are considered to be some of the benefits of developing a new grass roots tool set and the associated support equipment. The increased level of automation in 300mm fabs will affect fab communication technologies. Future fabs are expected to continue the migration toward paperless tracking as a means to reduce material handling errors.

To increase equipment utilization, much of the workflow development and tool automation software will focus on reducing wafer queuing and increasing tool utilization. Higher utilization translates into increased gas usage. All of the process tools

and wafer management systems will be expected to have a standard interface with the fab management system's host computer. Such requirements could potentially have a large effect on BSGS offerings' data systems. Future 300mm fabs are expected to be highly automated, not only for ergonomics, but also for asset management.

Cost-of-ownership targets

Unlike previous moves to larger wafer sizes, the 300mm-transition effort is being accompanied by a strong focus on standardization. To date, most standardization efforts have been developed within the I300I initiative and at International SEMATECH. SEMI has also set up standards committees, which are focused on 300mm fabs. European standards are also being incorporated into 300mm design guidelines as the industry attempts to make the 300mm transition a truly global effort. I300I made the incorporation of EU directives and the CE mark a requirement for all 300mm equipment.

The goal of this increased level of global standardization is to avoid some of the costly pitfalls of previous wafer size transitions. The industry paid dearly for poor standardization during the 200mm transition.

BSGS should be "same as" or "copy exact" from previous systems, which allows the experience gained from prior operations to translate into the same, if not improved, on-stream time at 300mm fabs. Having standardized BSGS product lines that have proven performance will be most important, versus engineered-to-order systems that are effectively serial prototypes.

In addition to developing a set of global engineering design standards, I300I also set some ambitious economic cost targets. For decades, the industry as a whole has subscribed to Moore's Law as a formula for economic success in each new technology transition. In order to continue to reduce the cost/device function in accordance with Moore's Law, an overall capital equipment cost multiplier of 1.3 \times was targeted by I300I.

Use of standardized BSGS product lines eliminates the need for increased engineering development costs that would be included in the price tag. A properly designed BSGS used for 200mm fabs will be approximately the same cost as the 300mm version.

Another challenging target developed by I300I relates to equipment footprint size. With the price tag for a 300mm fab approaching \$3 billion, there has been an increased sensitivity to equipment footprint and fab real estate. I300I set a target that 300mm tools be no larger than their 200mm counterparts. In addition, they stated that support equipment in the subfab (e.g., gas cabinets, gas supply systems, and gas recovery systems) must have a footprint of <1.0 \times that of a 200mm fab on a WSPH basis. Essentially they were asking that gas deliveries at 2.5–3.5 \times be achieved with a smaller equipment footprint.

The Japanese consortium, Selete, has provided less aggressive targets for the space required by process tools and support equipment. Selete targeted a 1.25 \times multiplier on process tool footprint and a 1.2 \times multiplier on the footprint of support equipment. BSGS has an equal footprint for 300mm and 200mm fabs, which

is much smaller than an equivalent number of gas cabinets. If installed outdoors, the impact is even less given the cost of expensive gas rooms.

One trend, which can be expected to continue, is the shift in process engineering and process responsibility from "tool owners" to the equipment, gas, and chemical suppliers. The bulk specialty gas equipment supplier would not only install a "turnkey" delivery system and supply the gas, but also own, operate, and maintain the system.

BSGS and the 300mm fab

Today, the industry is moving to 300mm production factories. Cost benefits of BSGS systems to high-volume specialty gas users include:

- savings of up to 50% on bulk purchases compared to cylinder gas cost;
- less total capital outlay versus multiple gas cabinets;
- minimized labor associated with gas cabinet maintenance, cylinder handing, and change out;
- a substantial reduction in scrap costs due to more consistent product; and
- easy expansion of the customer's tool set by just connecting to a gas drop in the gas distribution piping, if the system is designed properly.

When does BSGS offer economic advantages over traditional cylinder supply? In general, one can say that BSGS quickly makes economic sense for fabs when three or more gas cabinets are required for a specific gas. However, there are other reasons when bulk sup-

ply makes sense, such as unmanageable cylinder change out frequencies, gas cabinets not being able to maintain peak flows, and limited fab floor space.

A BSGS is especially appropriate for the higher volume and flow requirements of 300mm fabs. Today, no one would conceptualize dealing with cylinder quantities of atmospheric gases that the cryogenic back pad system now provides. Why dispense process gas with large numbers of cylinders supplying specialty gas (with added risk, inventory, handling, and quality issues) when one BSGS can meet that requirement? ■

Acknowledgments

MegaBIP is a trademark of Air Products and Chemicals Inc.

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