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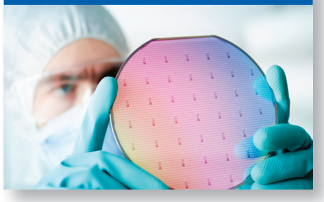
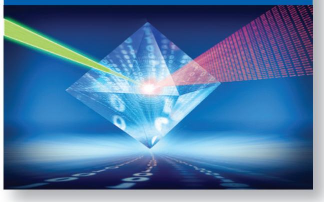
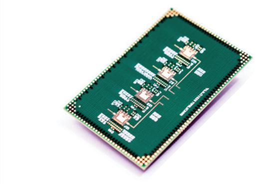
MES applications



Quantum computing



Futuristic radar chip



Conductivity measurements

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AN ANGEL BUSINESS COMMUNICATIONS PUBLICATION

Critical challenges in gas supply to advanced semiconductor manufacturing fabs

Shrinking device geometries challenge manufacturers to more precisely manage gases and other critical materials. Dr. Anish Tolia, Ph.D., Head of Global Marketing, Linde Electronics, explains why scale, quality, supply chain, and sustainability should dominate production planning.

RAPID CHANGES in the technical and business environment of semiconductor manufacturing have intensified challenges throughout the supply chain. Semiconductor manufacturers are pushing the limits of physics and driving a constant need for new materials. Semiconductor companies and materials suppliers must formulate mutually profitable models for developing new products to achieve continued success.

At the same time, process control and purity demands are reaching unprecedented levels due to increasing complexity of the processes and related yield challenges. Tighter production process control and advanced metrology solutions (aka 'fingerprinting') are key to addressing these issues.

On the business side, industry consolidation continues and fewer customers are building ever larger fabs, which presents materials delivery and environmental challenges. The materials supply chain is increasingly globalized; managing risk and delivering uninterrupted product is critical. Larger scale and more on-site gas generation and delivery schemes are cogent approaches to solve the problems.

Finally, as the global semiconductor industry grows, environmental concerns and limited natural resources, which include rare gases like helium, krypton, and neon become an area of increasing focus. Innovative solutions like materials recycling can be a useful tool in reducing environmental impact.

This article explores the four key factors in gas supply to advanced semiconductor manufacturing fabs – Scale, Quality, Supply Chain, and Sustainability – as well as the drivers and solutions for each factor.

SCALE - Larger fabs + more complex and smaller devices = more gases

Consumers want ever more technologically sophisticated smartphones, tablets, smart watches and other wearables, not to mention automotive, household, and medical electronics. Semiconductor companies are increasing capacity to meet this demand – a 10 percent integrated circuits upsurge worldwide in 2014.

This increase has also predicated a move from MiniFabs (monthly production of 10-30,000 wafers) to MegaFabs (30-80,000 wafers a month) to now GigaFabs (80-100,000 wafers a month). A typical logic foundry is now at 80,000 WSPM (wafer starts per month); a typical memory fab now exceeds 120,000 WSPM. Additionally, many large fabs are now concentrated in clusters (science parks).

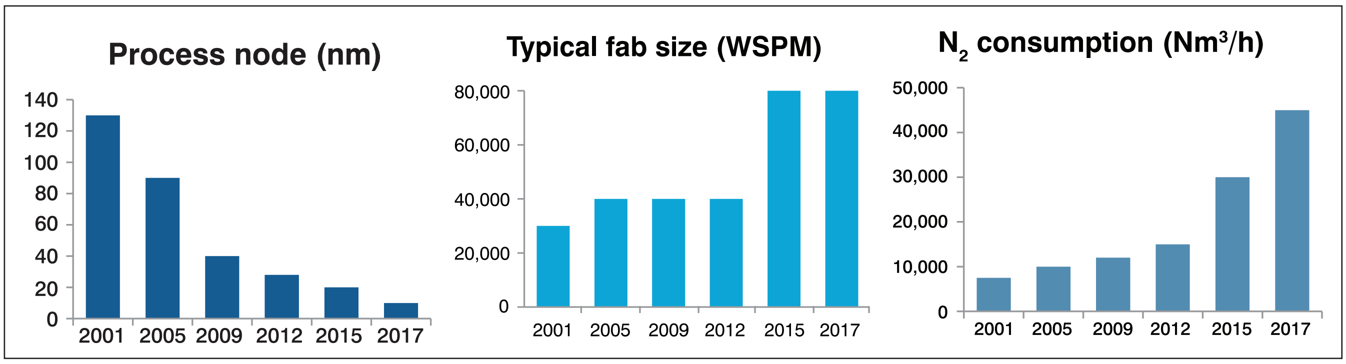
The highly competitive mobile devices market is forcing fabs to ramp to higher volumes faster than ever before. Additionally, development costs for new technology can exceed $2B (USD). In such an environment, economies of scale are essential for profitable operation.

In order to meet the demand and technological challenges, a larger volume and variety of gases is needed. These gases are used in multiple process steps such as etching/cleaning, deposition, doping, purging, and lithography/patterning in the manufacture of semiconductors.

Not only is the increased size of fabs contributing to the need for more gases, the move from single patterning to multi-patterning requires more gases for the production of each wafer.

As feature sizes are driven downward, new challenges emerge in maintaining the cost and performance gains. Until about 2006 at the 65 nm node, gains were obtained by shrinking physical devices using direct optical lithography. After that, more benefits were derived by introducing new materials into the process; for example, germanium in the transistor. By 20 nm, the minimal feature size became smaller than the wavelength of light and necessitated workarounds like multi-patterning to overcome physical limitations. All these factors have increased the consumption of gases per wafer.

Because of the need for low power and high performance, which 2D devices cannot handle, the industry is moving to 3D devices, which increases circuit density. This move to 3D FinFET and 3D NAND and the corresponding move to



increased transistor processing – epitaxy, etch, and ALD (atomic layer deposition) – drive the need for new and increased materials to construct more complex devices.

The gas most consumed in the production of electronics is nitrogen (N$_2$). Nitrogen is used for purging vacuum pumps, in abatement systems, and as a process gas. As process nodes have been driven down and the typical fab size has increased, nitrogen consumption has grown substantially. In large advanced fabs, there can be as much as 50,000 cubic meters per hour of nitrogen consumed, which compounds the need for cost-effective, low-energy, on-site nitrogen generators.

Another electronics manufacturing gas that is seeing an increase due to larger fabs and increased capacity is hydrogen. Hydrogen is utilized during epitaxial deposition of silicon (Si) and silicon germanium (SiGe), as well as for surface preparation. Significant volumes of hydrogen are also anticipated to be used in extreme ultra violet (EUV) in the future as 450mm wafers enter production streams. Hydrogen can be delivered economically as compressed gaseous hydrogen (CGH$_2$) or liquid hydrogen (LH$_2$) for smaller amounts and distances. However, due to the growing need for hydrogen, more fabs are now demanding on-site production through steam reforming or electrolysis. There is also an upswing in the need for rare gases such as neon, krypton, xenon, argon, and helium. This increased usage of gases that are not as readily available as nitrogen has driven sporadic temporary worldwide shortages, particularly helium and neon. Rare gases are also used for wafer cooling (helium), as source gases in lasers (neon), and as sputtering gases (argon and krypton).

So what are the critical challenges for fabs when the volume and type of gases multiplies due to added processes and more complex technology?

QUALITY - Changing needs due to complex technology

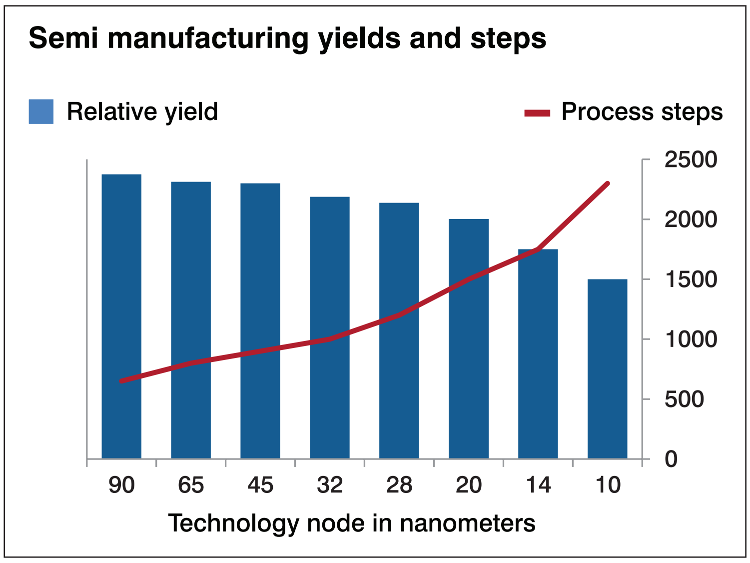
The first consideration for fabs is maintaining quality. Typically as the technology node gets smaller, the number of processes goes up and yield potentially goes down with each added process step. Manufacturers are diligently trying to overcome limits to stay on track with Moore's Law; doing so requires more stringent controls.

Critical process steps in high-volume semiconductor device manufacturing at aggressive feature sizes require stringent control of variability. For a silicon wafer with 100 or more advanced logic chips, each with up to 4 billion transistors and billions of connections, it is critical to remember:

- Essentially all the transistors and connections have to work as intended on each chip.
- The process has to be repeatable from wafer to wafer while chip production proceeds at rates of up to 80,000 wafer starts or more per month through a fab.

Variation among transistors on a chip leads to poorer overall chip performance and must be minimized. Even trace contaminants – including those that are not specified on a standard Certificate of Analysis – can cause measurable shifts in semiconductor processes and affect chip performance in advanced devices. Given that process materials are a critical input in wafer processing, it is easy to see how the quality of electronic materials (EM) products becomes increasingly important for chip manufacturers at leading technology nodes.

Another important consideration is the challenge of the unknown: engineers don't know how a specific impurity might impact performance. This can lead to needing additional processes and controls, which can mean higher operational costs and more risk from higher investments. Any misstep along the way –



an impurity in a gas, for example, might interact in the process in unknown ways. Such a misstep can cost thousands or even millions of dollars per month.

Ensuring consistent product requires a holistic approach to quality. Instead of limiting responsibility to a quality department, it must be a priority that runs through the entire organization. As is seen in this wheel, a comprehensive quality strategy cuts across all functions that touch a product.

To meet the demands for rigorous quality control, organizations may need to hire materials scientists, chemists, and process engineers and change the culture of their organization so that every department has a strategy and plan that contributes to the overall quality vision.

Process stability across the supply chain is made possible through SPC (Statistical Process Control), SQC (Statistical Quality Control), MSA (Measurement System Analysis), and BCP (Business Continuity Planning) systems. Fingerprinting furnishes the means for rigorous measurement, reducing variability, and tightening controls. Gas purity, consistency, and reliability are then delivered as an integral part of the final product.

SUPPLY CHAIN – Drivers reflect complexity

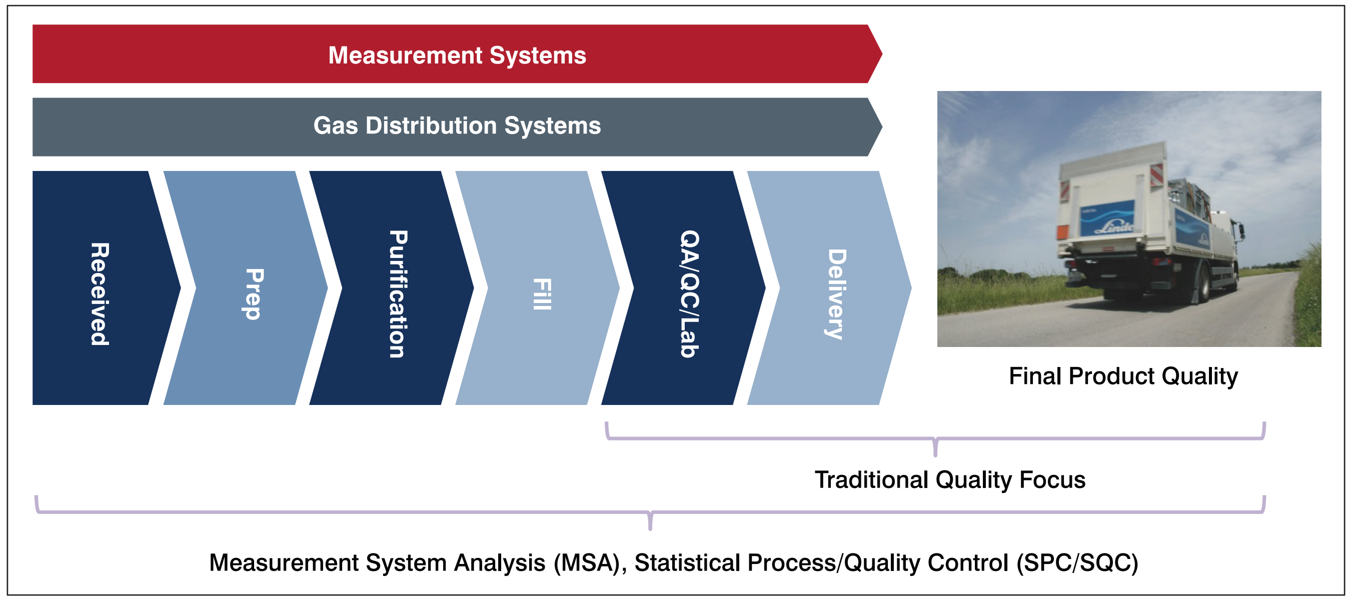
The increased demand and complexity of gases used in electronics manufacturing not only impacts quality, but also the supply chain. Many external factors can affect the supply chain including transportation or labor strikes and natural disasters. For example, after a magnitude 9.0 earthquake and subsequent tsunami hit Japan on March 11, 2011, all shipments coming in and out of Japan had to be checked for radiation.

A change in government regulations can also affect the supply chain, with an example being the 2008 Olympics. During the Beijing Summer Games, the Chinese government blocked hazardous materials from coming into multiple ports, including chemicals such as sulfuric acid, which is used in semiconductor manufacturing. Materials had to be trucked in, which required a lot of extra planning and two months extra time to deliver.

Limited raw material suppliers can impact availability for manufacturers. In order to secure supply, there is a move toward local and regional suppliers. Semiconductor manufacturers must partner with electronic materials suppliers and allow visibility into ramp demand of materials for new technologies and to do capacity planning so that together they can determine usage volumes for specialty gases.

To successfully maneuver all the complexities and potential pitfalls, it is crucial to cultivate an interlinked, comprehensive, customer-focused supply chain. Manufacturers can address these issues through Business Continuity Planning (BCP). They can start by assessing where and how to invest to diversify their supply chain on multiple continents. This includes doing procurement forecasting and planning with customers and suppliers to meet demand and identifying potential supply gaps by plotting product-source mapping.

It is essential to have at least two sources for raw materials and to have customers qualify both sources. Fabs should create raw materials, manufacturing, transportation, and labor shortage contingency plans and develop supply gap mitigation and implementation plans. Bringing materials closer to customers through localization and on-site plants cuts down on logistics complications and makes materials more readily available. It is essential to coach suppliers along the whole chain on Statistical Quality Control (SQC), Statistical Process Control (SPC), and customer requirements to show them why and how things that they do can help customers avert disaster at multiple points in the supply chain.



Water
10 cubic meters used per wafer at 14 nm node x 80,000 wafers per month x 12 months =
9,600,000 cubic meters of water used per year (enough for 39,506 people in U.S.)

Electricity
1220 kilowatt per hour used per wafer at 14 nm node x 80,000 wafers per month x 12 months =
1,152,000,000 kilowatt – hours or 1,152,000 megawatt – hours electricity used per year (enough for 94,846 people) in U.S.)

Natural Gas
61 cubic meters used per wafer at 14 nm node x 80,000 wafers per month x 12 months =
58,560,000 cubic meters of natural gas used per year (enough for 26,899 people in U.S.)

Greenhouse Gases
8 greenhouse gases used, which if unabated, are the equivalent of 4.2 tons of CO_2 per wafer. After 90% abatement at 14 nm node x 80,000 wafers per month x 12 months =
400,000 tons CO_2 equivalents used per year

SUSTAINABILITY – Reduce environmental impact

With complex supply chains, a scarcity of key materials, increasing environmental focus, and the need to reduce operating costs, the ability to ensure a secure and reliable supply of materials is intrinsic to staying competitive.

Fabs face several obstacles to being leaders in environmentally sustainable manufacturing, which is being mandated by an increasing environmental focus and concerns of customers as well as heightened governmental regulations. Semiconductor manufacturing is a highly complex energy and resource intensive process. Consequently, fabs are huge users of resources. Electronics manufacturing plants are not always located in the optimum position for materials deliveries, making it vital to think about how materials could potentially be recovered, purified, and re-used on-site, saving shipping costs, reducing logistical risks, and decreasing carbon footprints.

Materials such as helium and argon can be recovered on-site, purified, and returned for re-use in the manufacturing process. Materials such as sulfuric acid can be recovered on-site and be made available for use in other applications. And high-cost materials such as xenon can be recovered, shipped off-site, purified at an external facility, and then made available for reuse.

An industry success story illustrates how it is possible to eliminate tens of millions of tons of carbon dioxide (CO_2) emission equivalents per year through the use of fluorine (F_2), with zero GWP (global warming potential), in place of nitrogen trifluoride (NF_3), with a GWP of 17,200 and sulfur hexafluoride (SF_6) with a GWP of 22,800. This case involves a major memory fab, which uses on-site fluorine plants as a safer and more cost-effective alternative to cylinder fluorine for cleaning Chemical Vapor Deposition (CVD) chambers in its manufacturing process. It also uses fluorine to replace other fluorinated cleaning gases such as NF_3 following tests that demonstrated up to 40 percent reductions in cleaning time and a 35 percent decrease in the mass of gas used.

Conclusion

So what are the implications for manufacturers of the following four key factors in gas supply: Scale, Quality, Supply Chain, and Sustainability? They must proactively plan around both short and long-term needs. This requires longer term planning to include CAPEX investments and building on-site gas production and recovery when justified by size and growth expectations.

It is imperative that fabs do long-term planning in partnership with suppliers who commit to their needs – suppliers who value and implement process control and measurement and provide security and diversity of supply. It is only through this type of partnership that mutual needs can be truly understood and that the ever-evolving demands of consumers and the needs of manufacturers can be continually met.