Shrinking Devices, Growing Demand

Meeting the Electronics Gas Challenge

By Dr. Anish Tolia

Demand for consumer electronics devices is still strong. Smartphone sales will approach 1.5 billion units in 2015. These smart devices require an increasing number of ever more complex and smaller semiconductors. Manufacturing fabs are challenged to meet more complex technology nodes. That impacts the entire supply chain, in which gases play a critical role. This article discusses the impact of customer demand for smart and small devices on the requirements for gases needed to produce these products.

Semiconductor Market

As the semiconductor market matures, its growth depends on global GDP performance. Last year was a strong year with nine percent growth; 2015 started out strong, but analysts expect a slowing in the second half. However, long term drivers remain robust. The main drivers are still mobile and PCs, but other smaller segments such as automotive, game consoles, medical, digital TVs, set-top boxes, wireless networks, wearable devices, and the Internet of Things (IoT) are showing high growth. The year 2014 saw an upsurge worldwide of 10 percent in integrated circuits and semiconductor companies are increasing capacity to meet this demand.

Gases Used in the Semiconductor Industry

According to analysts, the 2014 electronic specialty gas market was over $2.1 billion and the 2014 electronic bulk gas market was an additional $1.9 billion, which together comprised a total electronic gas market of $4.1 billion.

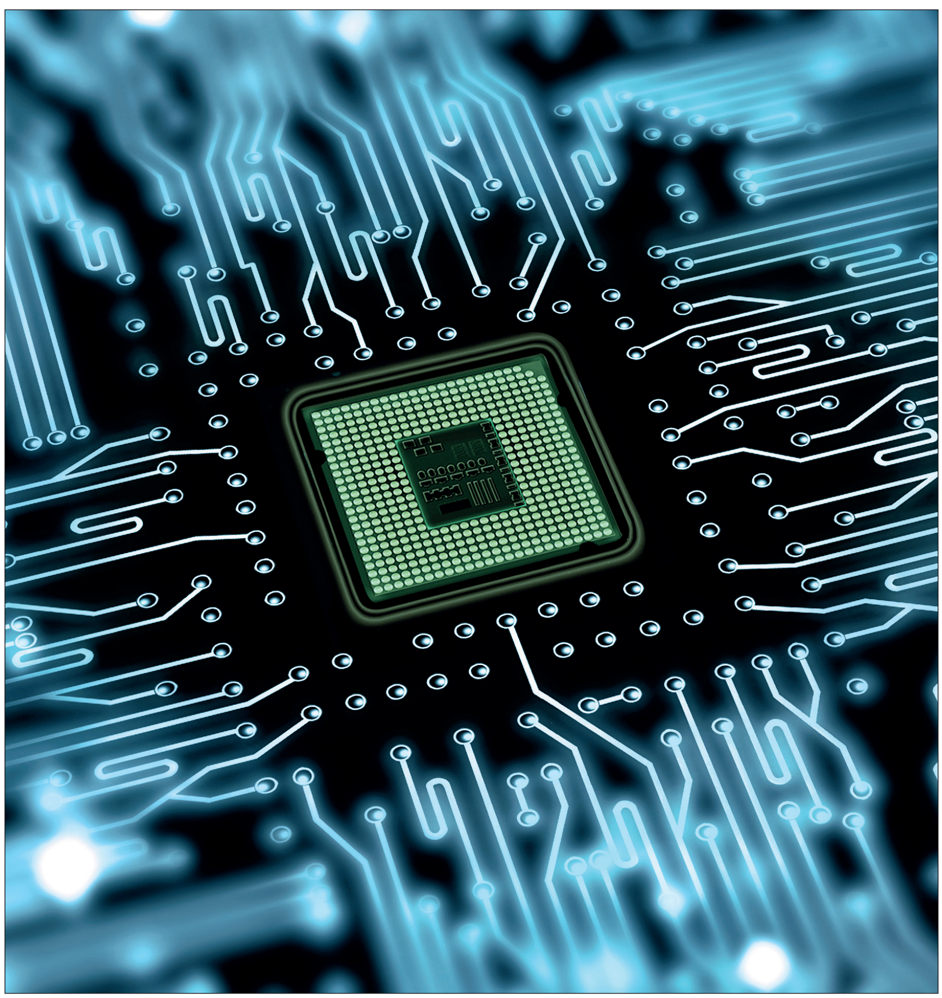
Due to the complexity of semiconductor manufacturing, there are hundreds of gases and chemicals used in several hundred process steps in the manufacturing of semiconductors.

Gases are used in a variety of ways in semiconductor manufacturing. For example, gases are used in plasma chamber cleaning of CVD (chemical vapor deposition) reactors. There are two categories of deposition gases: silicon precursors, which are used in CVD of silicon containing layers, and reactant gases, which are used in the deposition of silicon nitride and metal nitride layers. Some gases are used for doping, which introduces an impurity into a semiconductor to improve its conductivity. In etching (removal), gases are used to strip away undesired layers. This includes wet or dry and blanketed or patterned etch and CMP (chemical mechanical polishing). Gases also are used in heating to elevate the temperature of the wafer and drive chemical reactions to modify the properties of deposited material. In lithography, gases are used to support high-precision excimer laser processes and patterning. The circuit design layouts are transferred to the photoresist on the wafer surface. And in purging, atmospheric gases are used to purge process systems to prevent back contamination.

Electronic Bulk Gases

The major bulk gases used in the manufacture of semiconductors are nitrogen (N_2), hydrogen (H_2), argon (Ar), oxygen (O_2), and helium (He).

Nitrogen is by far the most used gas in semiconductor manufacturing. It is used for purging vacuum pumps, in abatement



systems, and as a process gas. At more advanced process nodes, nitrogen consumption has increased substantially.

In large, advanced fabs, consumption of nitrogen can reach 50,000 cubic meters per hour, which makes the case for cost-effective, low-energy, on-site nitrogen generators. Ultra-pure gaseous and liquid nitrogen can be provided on-site with less than one part per billion (ppb) impurities without the need for an external purifier.

Hydrogen is also increasing in usage due to larger fabs and enlarged capacity. It is used during epitaxial deposition of silicon and silicon germanium and for surface preparation. With the move to EUV (Extreme Ultra Violet) in the future, hydrogen use will see an even bigger spike. Hydrogen can be delivered as compressed gas or in liquid form (only in US and Europe), but due to the growing need, more fabs are installing on-site production through steam reforming or electrolysis.

Argon is used in various applications including the deep UV lithography lasers used to pattern the smallest features in semiconductor chips and plasma deposition and etching processes. In the manufacture of silicon wafers, large amounts of argon are used to protect the silicon crystal from reactions with oxygen and nitrogen while it is being grown at temperatures change to greater than 1400ºC. And increasingly, tools using small droplets of liquid argon are employed to clean debris from the smallest, most fragile chip structures.

Oxygen is used for purging, growing oxide layers, and in etching polymer materials. Ultra-pure liquid oxygen (LOX) can be provided on-site with less than 10 ppb impurities without the need for an external purifier.

Helium is used in electronics manufacturing at hundreds of points in the fab for cooling, plasma processing, and leak detection.

Electronic Specialty Gases

There are hundreds of electronic specialty gases used in the manufacture of semiconductors. Some of the most common are:

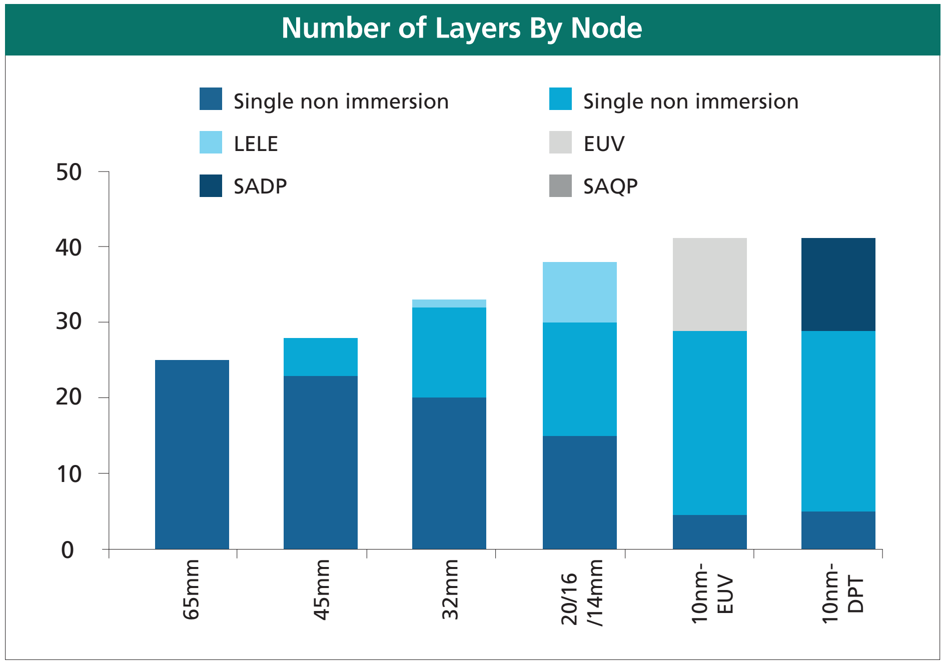


Figure 1 Source: Linde Electronics

Silane (SiH_4) is the primary Si source for deposition of Si-based thin films such as SiO_2 and SiN.

Nitrogen trifluoride (NF_3) is used in the cleaning of silicon wafers and is also an etchant.

Tungsten hexafluoride (WF_6) is used in low pressure or plasma-enhanced CVD of tungsten or tungsten silicides.

Hydrogen chloride (HCl) is used to clean and to etch semiconductor crystals.

Ammonia (NH_3) is used as nitrogen source in the chemical vapor deposition process of nitride films.

Disilane (Si_2H_6) is increasing in semiconductor memory (DRAM and NAND flash) for lower-temperature silicon deposition for making high-quality ultra-thin epitaxial films in advanced technology nodes and is a preferred alternative to silane.

Germane (GeH_4) is a silicon precursor used to form and deposit the SiGe (silicon-germanium) layer on silicon wafers. The use of germane in the semiconductor industry is increasing due to the move to smaller transistors with higher switching speeds.

High-purity carbon dioxide (CO_2) is being increasingly used to replace air in the liquid immersion systems of high-end lithography systems.

New Semiconductor Technologies

Mobile devices are now the primary drivers of Moore's Law and the move to more advanced technology nodes to meet consumer wants. These wants and drivers of new technology include lower power, longer battery life, increased storage capacity, and higher performance. What are some of the new semiconductor technologies and their implications for gases?

Multi-patterning

Due to ever smaller devices, the feature size is now smaller than the wavelength of light. Multi-patterning is a way to get around that.

Multi-patterning requires significantly more process steps and more deposition and etch tools and thereby drives increased consumption of both bulk gases and ESGs. For example, multiple lithography steps means more laser gases and deposition and etch materials, especially low-temperature deposition and highly selective etch materials. At the same time, an increased number of process chambers drives larger nitrogen consumption.

3D Devices

Because of the need for lower power and higher performance in more complex and miniscule devices, which 2D devices cannot handle, there is a move in the industry to 3D devices such as 3D FinFET and 3D NAND and the resulting increase in circuit density.

The 3D structured semiconductor devices era started when Intel produced Trigate, a FinFET transistor, in 2011 as its 22 nm logic chip. Si FinFET transistors become the mainstream logic transistor of choice at 16/14 nm.

With FinFET 3D CMOS transistors, the industry should continue the scaling roadmap for performance, power, and area (PPA) into 7 nm technology nodes.

NAND flash memory has the highest transistor density of all semiconductor products and is moving to the 3D era to increase gate density and to reduce cost per bit of storage. Another motivation of 3D NAND is scaling challenges in lithography.

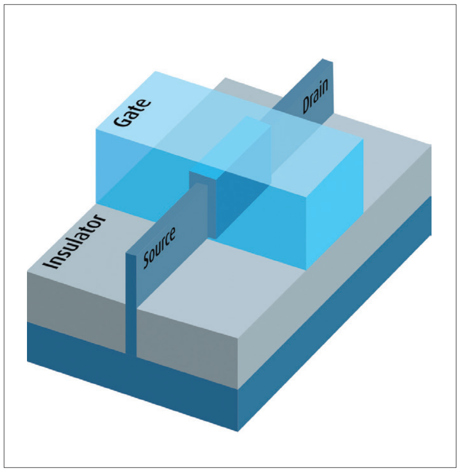
With FinFET technology, there is an increase in transistor processing such as epitaxy and ALD (atomic layer deposition). This drives the need for more epitaxial materials such as trichlorosilane, HCl, and germane as well as ALD precursors.

3D NAND requires less lithography patterning materials, but needs more deposition and etch of dielectrics.

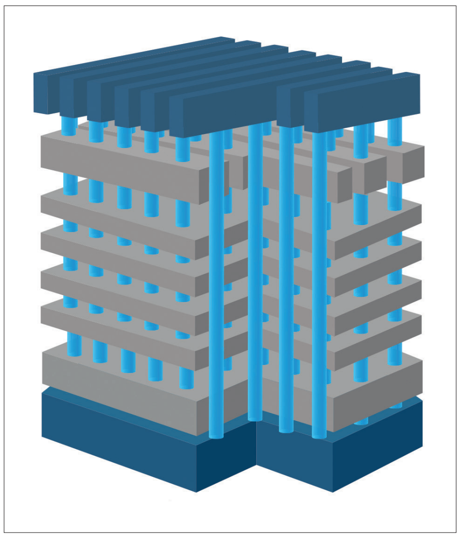
Lithography

Smaller feature sizes require a better optical resolution. As the resolution depends on the wavelength of the light, illuminating systems with increasingly smaller wavelengths had to be developed. The light sources used to produce the desired wavelengths are excimer gas lasers and are fed with gas mixtures containing halogens and noble gases. Krypton-fluorine excimer lasers emit light with 248 nm, while argon-fluorine lasers generate photons at 193 nm. Both belong to the Deep Ultra Violet part of the spectrum and are therefore called DUV lasers (in contrast to EUV, which is Extreme Ultra Violet light).

Meeting the stringent requirements for mixture accuracy and gas purity are crucial for a high-quality light generation process.



3D FinFET



3D NAND

As the requirements on the precision of the lithography process are getting higher, equally precise quality control of the laser gas source material is mandatory. Meeting the stringent requirements for mixture accuracy and gas purity are crucial for a high-quality light generation process. Gas contaminations as well as non-precise gas mixtures affect critical laser parameters like power output, target wavelengths, and lifetime.

The development and introduction of EUV as a next-generation lithography technology is proceeding. The small wavelength of 13.5 nm will enable fabs to process wafers for 10 nm, 7 nm, and smaller nodes. The continuous delay in EUV is shifting its introduction to smaller nodes. While predictions about EUV adoption have seen many delays, it is now predicted to be in production at 7 nm in logic (around 2018).

Immersion lithography creates a strong demand for precise laser gas mixes of inert gases (Kr/Ne/Ar) mixed with N_2 or H_2 and additional bumps of ultra-high purity (UHP) CO_2 for immersion lithography.

While EUV tools use different gases from traditional and immersion lithography, EUV is expected to be used for only the most critical layers; less critical layers will still use ArFi (immersion) and multi-patterning.

For EUV, CO_2 is used as a laser gas. The new source architecture is changing the light generation concept, switching from a direct light source (excimer lasers) to an indirect light generation (a CO_2 laser beam hitting a tin droplet, leading to the generation of EUV light).

These tin droplets can cause tin depositions on the reflecting optics, leading to a reduction in light power. To prevent this, hydrogen is used to form volatile tin compounds, which can be pumped away, preventing a reduction in the amount of photons available for illumination. Compared to other gases like nitrogen, hydrogen has a low absorbance for EUV light, making it the gas of choice wherever a EUV light beam is passing through a chamber.

Conclusion

The ever-increasing consumer demand for higher performing, low power, and smarter mobile devices requires ever more complex semiconductor manufacturing technology. Semiconductor manufacturers depend on a complex supply chain of equipment and materials, which must keep up with their complex technical requirements. The gas industry must also keep pace with these changes and offer the right gases with the right specifications and a robust supply chain. ■

For a list of gases used in the manufacture of semiconductors, go to **www.linde.com/electronics.**

Dr. Anish Tolia is Head of Global Marketing, Linde Electronics. For more information on Linde Electronics visit www.linde.com/electronics.