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Connectivity lifts chip outlook

Semiconductor sales returned to growth last year, having shrugged off a lengthened smartphone replacement cycle with strong DRAM and flash memory demand. Looking ahead, the Internet of Things (IoT) is creating mammoth volume of opportunity for chipmakers and their suppliers, but both will have to push hard to solve the technological challenges of the next node.

Rebecca Coons

The global semiconductor market grew 2% in 2016, after declining in 2015, according to IHS Markit. Key drivers were DRAM and NAND flash memory, which grew 30% in the latter half of last year. Semiconductors for automotive applications were also a key driver of 2016 growth, with a 9.7% expansion by year end, IHS Markit says.

"From a materials perspective, it's a great time to be in this industry," says Guillermo Novo, president and CEO of Versum Materials (Tempe, Arizona). "Few specialty materials markets have as many underlying growth drivers as we do, where the IoT and technology shifts are contributing to growth forecasts at multiples of GDP."

Key end market drivers include IoT, automotive, data centers for the cloud, and 3D memory, suppliers say.

"We're in the midst of the strongest cycle that the electronics industry has had in recent years, certainly on a dollar basis," says Paul Stockman, Linde Electronics' head of market development. "This is being driven by large increases in memory prices for DRAM and flash memory, but also on the basis of chip units and silicon surface area."

Smartphone demand—once a driver of double-digit annual growth for suppliers—has slowed, but the market is not necessarily saturated.

"The replacement cycle for smartphones is lengthening, but at the same time you have market expansion in parts of the world that didn't use smartphones in the past, particularly in India and Africa," says Stuart Tison, v.p./specialty chemicals and engineered materials at Entegris. "They may be lower-end smartphones, but they still require advanced logic."

Demand drivers are now becoming more broad-based, rather than being dominated by PCs or mobility. Craig Borkowski, general manager, global electronic and industrial materials at Momentive Performance Materials Korea, says the automotive market has been the biggest growth driver for the company's electronics product line, which include thermal materials and optically clear adhesives. "If you look at overall automotive growth, it's only a couple of percent. But if you look at the sheer number of sensors being put into cars, it's a very different story."

According to IHS Markit, the number of connected IoT devices globally will jump 15% YOY, to 20 billion, in 2017. The industrial sector will account for nearly half of new connected devices between 2015 and 2025. Suppliers point out that, in addition to the connected devices themselves, the IoT will generate massive amounts of data that will need to be stored and analyzed—creating an additional layer of growth as connectivity advances into all corners of life.

Stockman says that there were "lots of hyperbolic statements made about IoT without drilling down to what the actual applications are. That said, it is a very important driver. It's made of up of two distinct markets. First, the Things—the billions of smart sensors, most of which are very small and cheap—but all generate lots of data. The other side is the Internet, the growing cloud that tracks all of these sensors and the remote server farms that are collecting, processing and storing all of this data."

IoT is also creating opportunities for fabs to extend the life of legacy nodes. "In the past, before IoT became a prevalent market, companies would actually retool their fabs, upgrading their toolsets to move from a legacy node to producing the latest IC chip," Tison says. "Now, a lot of these fabs will keep running the old legacy node and use those tools for IoT-type applications. In order to serve the leading nodes, you have to build new fabs. You're seeing a lot of new announcements about plans for new builds."

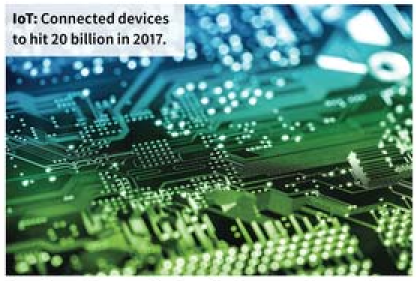
Jeff Handelman, senior vice president/ electronic chemicals at KMG, notes that the IoT, despite still being in its infancy, is driving higher usage of high-purity process chemicals to meet demand for logic and memory chips. KMG is a leading provider of high-purity process chemicals including acids, solvents, and customized etchant blends.

New architectures

At the most advanced nodes, chipmakers are looking to chemistries to solve cost and technical challenges associated with fabricating these devices. The most advanced logic devices require more process steps, increasing the amount and value of chemicals and materials used in the fabrication process.

"Today, the advanced nodes and 3D architectures require more than just purity," says Jay Henderson, marketing manager at Huntsman Performance Products. "There are technical challenges that require new chemistry to solve in order to support the smaller feature sizes and to make the manufacturing process as efficient as possible."

Tison says there are multiplier effects



IoT: Connected devices to hit 20 billion in 2017.

keeping electronic chemicals growth at or above the rate of semiconductor growth. "Deposition materials will grow much faster due to the expansion of 3D NAND architectures—as much as four times as the number of layers increase. Depending on the fab, there are 32 layers or 64 layers today, and they are going to 96 and then 128 layers over the next two to three years."

Because newer nodes are more complex, they use more gas, Stockman says. "By their very nature, a chip made using the latest technology node requires much more gas and chemicals than those at the older nodes." Linde supplies onsite plants for nitrogen, hydrogen, and fluorine, as well as bulk atmospheric gases and specialty gases. It also operates a wet chemicals business for etchants and cleaning.

Advanced logic challenges are mainly in

Annual silicon industry trend

Source: IHS Chemical. © 2017 IHS Markit

shrinking dimensions and new materials necessary for the new structures, Tison says. "Cobalt is slowly replacing a number of the legacy materials, like copper, on the front end. Some processes are being used more abundantly, such as ALD, not only in the front end but also in the back end. Ruthenium, a new material for the industry, is needed as we go down to 7 nm and below." Most of the new materials on the front end are being integrated to increase transistor speed and reduce the power required per transistor, he says. "On the back end, it's to reduce wiring signal delay."

There are also more stringent requirements for existing materials, Tison says. Tungsten is commonly used around the transistor, but its usual delivery method—tungsten hexafluoride—needed to be revisited at the most advanced node. "It turns out fluorine can damage the structure of the chip, so there is a need to move to fluorine-free tungsten. Most of these precursors are actually difficult because they may be a chlorinated form, which is a solid. So delivery can pose a challenge."

The unprecedented amount of chemical innovation required to realize advanced nodes and more complex chip architectures is driving increased collaboration with customers.

"Each of the large, integrated IC manufacturers actually develop their own design and integration schemes, which use different materials and require different cleaning chemistries, for example," Tison says. "Suppliers need to work closely with customers in developing very specific and tailored solutions."

Semiconductor manufacturing is also a very concentrated business, so the relationships and the access that you have with customers is absolutely critical, Novo says. Versum Materials is a pure-play supplier to the semiconductor industry after being spun out of Air Products in October last year. "At the end of the day, materials are a critical part of the innovation requirement to enable these technologies. Without these new materials, the roadmap will be unable to advance to 5 nm. And, if you look at how quickly this industry moves to the next node, they are on a very tight timeline and the value of yield and productivity are much greater than the material itself."

The need for ever-higher purity at smaller nodes adds yet another challenge for chemicals and materials suppliers. "What was acceptable purity at 28 nm is unacceptable at 7 nm," Novo says. "For us, this is an opportunity for differentiation. The molecules might not change that much but we put a lot of effort into technology and analytical science."

Handelman says that providing consistency helps customers optimize their manufacturing yields. "Particle control has become equally important for our customers as smaller manufacturing genometrics cannot tolerate particles that can block or inhibit electrical connections from layer to layer in the semiconductor device. Because line widths in integrated circuits are so small now, particle filtration and process management have become critical considerations in chemical performance." In many cases, KMG raw materials are purchased from large industrial chemical manufacturers whose

SMARTPHONE: Replacement cycle is lengthening.

quality focus is not as demanding as that of semiconductor industry. "In many cases, [high-purity process chemicals] represents an insignificant portion of their business," Handelman says. "[S]o our ability to engage and expect similar data and process control from these suppliers hasn't matured yet, or comes at a significant cost." KMG has invested in metrology and purification technologies to control potential sources of contamination. Though the resources needed to manage the entire chemical ecosystem is significant, "semiconductor customers expect us to prevent material excursions, not react to them."

Stockman points out that the individual parts of the transistors are shrinking to atomic dimensions. "At these scales, a single atom impurity begins to make a difference. Even isotopes behave differently both chemically and physically. Using an isotopically pure material can improve both device function and lifetime." For example, deuterium is not subject to the same device-damaging hot electron effect as hydrogen. Linde also supplies a heavy isotope of boron, which is resistant to thermal neutron absorption damage.

Henderson says purity is one of Huntsman Performance Products' most critical concerns. "Our customers are continuously pushing us to go beyond what we used to think was possible."

Newer nodes are also lithographically intensive, suppliers say. Extreme ultraviolet (EUV), the most advanced—but still prohibitively expensive—lithographic method, has been slow to gain adoption in the industry technology roadmaps beyond the most advanced nodes.

"Industry has been stretching the current deep UV (DUV) [lithography] technology for around 15 years," Stockman says. "This means there are multiple patterning steps needed to create one feature. Linde is a major supplier of the gases that these lithographic tools use, so this is very favorable."

Nevertheless, several leading players at the logic and foundry have publicly committed to having EUV on their roadmap. "We fully anticipate EUV will be embraced by the leading manufacturers," Stockman says. "But even so, EUV does not take the place of all lithographic steps at the leading edge, and it will likely be introduced gradually. And there will still be quite a bit of lithography done by the current DUV lithographic technology in the technology nodes to come."

China pours billions into chips

China plays a large role in any chemical supply and demand conversation, but the government's "Made in China 2025" plan, which earmarks up to $150 billion to increase semiconductor production capacity, could significantly redirect trade flows in semiconductors and semiconductor materials. According to Semi, 14 fabs are under construction in China this year alone.

"China is already a big factor, both as a consumer of semiconductors for the local market and as a major producer of electronics that get exported," Novo says. So far, most local production has been by multinationals and a couple of China's largest chip makers, but this is set to change as government pushes to develop its own industry. Chinese producers will most likely carve out their position in the market toward the older nodes, but move into newer nodes over time, he adds.

Stockman says Linde has already signed a number of contracts for bulk gas installations, he says, adding that Chinese fabs will produce both high-end chips and legacy nodes. "Particularly on the foundry side, there is plenty of space in technology that is over 20 years old to enter and have a healthy business. If you look at the entirety of the announcements in China in the foundry space, they really cover almost all of the technology nodes. So there are some leading-edge announcements by Chinese companies, as well as many others in older technology nodes."

Rethinking the roadmap

Suppliers say that as the semiconductor industry moves to new architectures, Moore's Law—Intel founder Gordon Moore's observation that the number of transistors on ICs doubles approximately every two years—should not be the only yardstick to measure industry's pace of innovation.

"Moore's Law, and the reliance on it, really drove investment cycles," Stockman says. "It was clockwork. Every two years, there were new fabs being built. I think as applications have multiplied, as the technologies have gotten more diverse, there's still improvement, but it is happening on many different dimensions. For one application, faster speed may still be required, but for others, low power or low thermal degradation is key."

Novo notes that the shrinkage and scaling that allowed industry to double the capacity of wafers every two years had hit a technological wall, but says it is back on track. "[N]ow and now we're at 10 nm, with 7 nm soon to come on, and there are roadmaps for 5 nm and 3 nm. What's changed is that there are other vectors of innovation that previously did not exist. Transistors are shrinking not only by way of dimensional scaling, but through structural scaling. For example, vertical structures are driving storage capacity." Another area of innovation is packaging, Novo says. "A lot of the semi players are looking at how they structure their chips to increase computing power and reduce energy usage."

Smartphones, for example, integrate an increasing number of functionalities in a space that is increasingly smaller and thinner, says Thierry Perchet, marketing director at Huntsman Advanced Materials. This requires materials to be able to resist higher temperature while offering the same dimensional stabilities, he adds.

Looking ahead, Stockman believes that instead of the discrete steps along Moore's Law, "we should be looking at many different dimensions, and pay attention to continuous improvement." This is already evident in 3D NAND, where instead of building new fabs, operators are adding more layers as soon as the prior process is mastered, he adds. ■