ElectronicsIQ.

Information Quarterly from Linde Electronics.

THE LINDE GROUP

Summer 2014

Welcome to ElectronicsIQ, the quarterly update from Linde Electronics. In this issue, we will explore the evolution of electronic materials. The market expectations of modern electronics technology are changing the landscape in terms of performance and power consumption and new innovations are putting unprecedented demands on semiconductor devices. This issue will look at the revolution ahead in microchip design and manufacturing and the new materials required to ensure innovators have everything they need.

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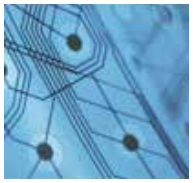
New Approaches to Small Problems

The continued shrinkage of semiconductor dimensions and the matching decreases in microchip size have corresponded to the principles of Moore's Law with an uncanny reliability since the idea's coining in 1965. However, the curtain is now closing on the era of predictable / conventional size reduction due to physical and material limitations.

Read more…



Future Requirements for Electronic Materials Suppliers in the Semiconductor Industry

The semiconductor industry is undergoing a period of unprecedented change. Change is being seen in both the architectures of current devices as well as in the substitution of new materials in advanced devices, including high mobility channel materials, and finally into the introduction of novel non-volatile memory devices such as MRAM and RRAM.

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A Strategic Approach to Quality

The electronics business is a challenging one, requiring constant evolution to adapt to the ever changing environment. Technology nodes are continuously reducing, requiring novel technologies and more sophisticated processes. Furthermore, these advances elevate the expectation of quality from the viewpoint of the customer, driving the need for more internal and external collaboration.

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With the growing variety of specialty gases and chemicals used in semiconductor manufacturing at advanced technology nodes, the stability of supply and consistency in supply quality are essential factors to customers, given the sensitivity of their manufacturing processes.

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The variety and nature of electronics being produced has changed, and with it the requirements of electronics manufacturers have become increasingly unique. This has meant that customers are increasingly asking for products created and tailored for them. In order to fulfil that need we have to predict what our customers are going to need next, a challenge in itself.

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My Life at Linde

We speak to Greg Shuttleworth, Global Product Manager at Linde Electronics, about what motivates him to get out of bed in the morning and his proudest moment at Linde.

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Greg Shuttleworth, Global Product Manager at Linde Electronics

New Approaches to Small Problems

The market expectations of modern electronics technology are changing the landscape in terms of performance and, in particular, power consumption, and new innovations are putting unprecedented demands on semiconductor devices. Internet of Things devices, for example, largely depend on a range of different sensors, and will require new architectures to handle the unprecedented levels of data and operations running through their slight form factors.

The continued shrinkage of semiconductor dimensions and the matching decreases in microchip size have corresponded to the principles of Moore's Law with an uncanny reliability since the idea's coining in 1965. However, the curtain is now closing on the era of predictable / conventional size reduction due to physical and material limitations.

Thus, in order to continue to deliver increased performance at lower costs and with a smaller footprint, different approaches are being explored. Companies can already combine multiple functions on a single chip —memory and logic devices, for example—or an Internet of Things device running multiple types of sensor through a single chip.

We've always known that we'd reach a point where conventional shrinking of semiconductor dimensions would begin to lose its effect, but 2014 is the year when we'll start to tackle it head on. A leading US semiconductor manufacturer got the ball rolling with their FinFET (or tri-gate) design in 2012 with its 3D transistors allowing designs that minimise current leakage; other companies look set to bring their own 3D chips to market within this year. At the same time, there's a great deal of experimentation with a range of other approaches to semiconductor redesign. Memory device manufacturers, for instance, are looking to stack memory cells vertically on top of each other in order to make the most of a microchip's limited space. Others, meanwhile, are examining the materials in the hope of using new, more efficient silicon-like materials in their chips.

Regardless of the approach taken, however, this step change in microchip creation means new material demands from chip makers and new manufacturing techniques to go with them.

The semiconductor industry has traditionally had to add new materials and process techniques to enhance the performance of the basic silicon building blocks with tungsten plugs, copper wiring / CMP, high-k metal gates, for example. Now, however, it is beginning to become impossible to extend conventional materials to meet the performance requirements. Germanium is already added to Si to introduce strain, but its high electron mobility means Germanium is also likely to become the material of the Fin itself and will be complemented by a corresponding Fin made of III-V material, in effect integrating three semiconductor materials into a single device.

Further innovation is required in the areas of lithography and etch. This is due to the delay in production suitability of the EUV lithography system proposed to print the very fine structures required for future technology nodes. Complex multi-patterning schemes using conventional lithography are already underway to compensate for this technology delay, requiring the use of carbon hard masks and the introduction of gases such as acetylene, propylene and carbonyl sulphide to the semiconductor fab. Printing the features is only half of the challenge; the structures also need to be etched. The introduction of new materials always presents some etch challenges as all materials etch at slightly different rates and the move to 3D structures, where very deep and narrow features need to be defined through a stack of different materials, will be a particularly difficult challenge to meet.

The microchip industry has continuously evolved to deliver amazing technological advances, but 2014 will see the start of a revolution in microchip design and manufacturing. The revolution will be slow but steady. Such is the pattern of the microchip industry, but it will need a succession of new materials at the ready, and, at Linde, we're prepared to make sure the innovators have everything they need.

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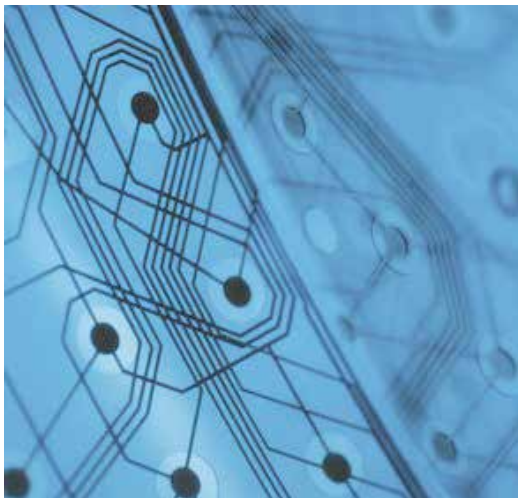
Mike Corbett, Managing Partner at Linx Consulting

Future Requirements for Electronic Materials Suppliers in the Semiconductor Industry

The semiconductor industry is undergoing a period of unprecedented change. Change is being seen in both the architectures of current devices—such as in the transition from planar to non-planar transitions and planar NAND to 3D NAND—as well as in the substitution of new materials in advanced devices. This includes high mobility channel materials and the introduction of novel, non-volatile memory devices such as MRAM and RRAM.

In addition, the end of traditional lithography-based scaling and the beginning of materials-based scaling with increasing levels of process complexity has led to the introduction of many new materials, such as high-k gate dielectrics. It has also impacted the requirements for many suppliers of electronic chemicals and materials in the global semiconductor industry.

One significant consequence of this change is that the number of new materials used in wafer fab operations is being rapidly increased; in the past, there were relatively few materials used and integrated. Now, as the number of devices grows and as materials are increasingly being used for scaling purposes, the sheer volume of new materials has grown at almost an exponential rate over the last decade.



In addition, the profile of materials consumption is also evolving due to differing integration requirements. We see fewer high volume materials such as TEOS or silane being introduced, as there are more specialty materials in use. The key difference between high volume and specialty materials can be seen in volume and price curves. The volumes of new materials are typically on the order of tens of metric tonnes and the price points are in the $ per gram range. Compare this to silane, which is consumed at roughly a thousand tons per year at prices well less than $0.05 per gram.

In response to the growing number of materials being used and the need to develop a greater number of products, chemical and material suppliers are adopting their capabilities to be able to:

- Bring in new materials from new suppliers and value chains
- Invest more in the critical materials the industry will require to ensure that there is adequate production
- Enhance the quality of incoming materials to minimise excursions and ensure adequate protection for the fab
- Serve the unique needs of the semiconductor industry

At the same time, the barrier to entry for direct material suppliers is increasing in the semiconductor industry. This is based partially on end-user (fab level) consolidation and the difficulty for materials suppliers in accessing and interfacing with a concentrated group of customers who all have a lot of buying power. There is also a requirement to possess detailed knowledge of the semiconductor industry and understand its various processes and particularities. An example of this is the need to respond when something goes wrong, which requires quality skill sets, troubleshooting capabilities (which is much more than ISO certification), and the ability to do root-cause analysis.

Suppliers need to increase their investments in quality operating systems and supply chain management capabilities, including change control and supply chain management. The demand for Enhanced Quality Operating Systems is being driven increasingly by end users who want to push supplier quality into the supply chain in order to avoid costly firefighting by pre-emptively qualifying the supply chain. Over time, this will play an increasingly important role in the selection of primary and secondary suppliers. These systems will be critical for new materials, which are often required for the most challenging applications. The new materials typically have new value chains, from new sources, which usually have not been qualified by the industry.

To meet new quality requirements, some end users are demanding more information with an expectation of supplier transparency for the whole supply chain. As a result, the major primary suppliers need to set up effective audit trails for all secondary sub suppliers. Whereas, this may lie within the capability of large suppliers, the small and medium size suppliers may not have the expertise to develop acceptable supply change qualification systems and will likely remain reliant upon the primary supplier as a market channel.

In conclusion, the role of the chemicals and materials supplier in the semiconductor industry is expanding. Suppliers are adding more capabilities as customers are relying on the suppliers to meet more stringent quality requirements, manage more supply chains and sub-suppliers, provide unique trouble-shooting capabilities and invest in the products that keep the industry going down the path of Moore's Law.

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Jody Alt, Global Head of Quality at Linde Electronics

A Strategic Approach to Quality

The electronics business is a challenging one, requiring constant evolution to adapt to the ever changing environment. Technology nodes are continuously reducing, requiring novel technologies and more sophisticated processes. Furthermore, these advances elevate the expectation of quality from the viewpoint of the customer, driving the need for more internal and external collaboration.

On 18-19 February 2014, various countries and departments from Linde Electronics joined together in Shanghai, China to discuss how we can leverage our talent and resources to support quality and business growth in electronics.

Many quality committees fail to look beyond their own scope of responsibility when prioritizing their programs. This hinders the identification of best possible solutions for the business, and the team struggles to drive ownership throughout the organization. Our major stakeholders played an essential role in the Shanghai workshop, utilizing the strategy wheel concept to identify priority areas and critical links. From metrology development to packaging performance, our programs are owned and steered by the various departments across the business.

Quality in Linde Electronics is just one unit within our business; the success of quality for our electronic customers will be heavily driven by cross-functional collaboration.

At the core of the quality programs supporting the overall business strategy is **customer experience and technology**. A few of the programs underway are listed below.

Metrology Development
The Linde board has recently approved a state-of-the-art analytical facility, known internally as the Analytical Center of Excellence (ACE). The center will include the latest in ICP-Mass Spectrometer and Residual Gas Analyzer technologies which will enable us to meet our customers' analytical requirements for the latest manufacturing nodes.

Advanced Process Technology
Technology, commercial and quality teams continue to collaborate with our customers to assess the resources and update our quality systems to meet <20 nm technologies.

Packaging Performance
Reducing errors is essential, and we are increasing our efforts to improve packaging performance. The global and regional engineering teams will harness Six Sigma methodologies to reduce the number of overall package defects.

Our customers face the challenge of higher complexity, yield impacts and uncertainties; all of our departments have crucial roles to play in helping the industry meet future technology and quality requirements.

For any questions regarding these quality programs, email jody.alt@linde.com.

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Cheryl Chan, Head of Global EM Supply Chain at Linde Electronics

Diversifying and Reinforcing the Supply Chain

The electronics market is a dynamic industry with relatively short production cycles. As the technology in semiconductor manufacturing gains complexity, customers have an increasing expectation for critical suppliers to manage and adapt to the changes accordingly in their global supply chain. With the growing variety of specialty gases and chemicals used in semiconductor manufacturing at advanced technology nodes, the stability of supply and consistency in supply quality are essential to customers, given the sensitivity of their manufacturing processes.

Looking at the types of elements that go into an electronic device, it is not difficult to imagine the set of challenges that exist in a complete supply chain. Some critical raw materials like germane, noble metals, silicon-based and fluorinated gases suited for electronics usage have rather limited sources available.

In addition, the sources are located at more remote areas globally, require stringent logistics and safety handling, and the raw materials have to be treated and processed before specialty gases or chemicals can be suitably used for different semiconductor manufacturing purposes.

Linde is amongst the gas companies that synthesises, purifies, blends and bulk breaks these raw materials from prime manufacturers. We often provide materials, which are created in these processes, that only a handful of other providers can produce. However, at times, material sources are unavailable for short periods due to unforeseen circumstances; this can cause many supply chains to be thrown into chaos. Hence, there is a need for us to diversify and ensure greater flexibility in every supply chain to ensure that our customers receive reliable, secure delivery.

Over the past few years, our production footprints have been strengthened by localising some of our supply chains. In line with customers' requirements, we have moved segments of the supply close to where our customers are based. This increases the confidence of our customers, but more importantly spreads supply lines across the world. For instance, we have increased our pool of suppliers in Asia and U.S. In recent years, Linde has expanded and invested in two Nitrous Oxide (purity 5N, i.e. 99.999%) plants in Korea and China, adding to the existing facility in Taiwan. Linde has also added local blending of high purity Germane (GeH4/H2) in Taiwan and an Ammonia (7N) plant in China.

As a result of these efforts, should access to a supplier in one country be lost, access to other sources within the same region is still possible. If for any reason a supply disruption affects an entire region, Linde has the option to switch sources to other continents.

Linde's procurement processes have also undergone improved optimization as a result of learning from market dynamics and customers' requests for enhanced business continuity plans. There is added focus to diversify and mitigate risks, which are unexpected and beyond reasonable control of nature. We have concentrated our efforts on adding more suppliers with geographical spread to our supply chain and creating robust vetting procedures to ensure consistency of suppliers and their materials newly added to the supply chain.

Incrementally, more rigorous reviews are placed on the quality of supply and technology capabilities of new suppliers. In order for Linde to always meet our customer demands consistently, we have in place reliable operations planning for our internal facilities and we partner with other specialty gas and chemical providers as required to ensure that our supply chain is robust and reliable at all times. For example, we began partnering in April 2013 with flurochemicals specialist Pelchem to distribute Xenon Diflouride (XeF2) following a noticeable increase in demand for Micro-Electro-Mechanical Systems (MEMS).

In picking any supplier, we undertake comprehensive due diligence to ensure reliability. When considering a raw material source, Linde audits the company's supply to ensure the product quality to our customers. Whilst trading for processed materials, the prospective supplier's technical and operational capabilities are evaluated, followed by processes being implemented to ensure sustainability of

supply and consistent quality. Once these relationships with raw materials' suppliers are established, a continuous engagement and improvement programme is maintained with our suppliers, keeping them updated on industry trends and the changing needs from our customers through channels such as newsletters and supplier workshops. By keeping our suppliers engaged with our end customers' needs, we are more certain that they are ready to meet ours.

By taking these steps, Linde has created a robust, diversified supply chain which sees us working with more than 50 electronic material suppliers to meet our global demand. If, for any reason, anywhere in the world, the supply of a raw material is interrupted, we are in a stronger position to limit the long-term business effects. By working more closely with our suppliers, we can deliver on our customers' new requirements faster and more reliably than ever before.

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Paul Mittonette, Business Manager, Linde Group

How to Predict the Future

Across the electronics industry, we've seen a huge change in the past five years. The variety and nature of electronics being produced has changed, and with it, the requirements of electronics manufacturers have become increasingly unique.

For Linde, this means that customers are increasingly asking for products created and tailored for them. In order to fulfill that need, we have to predict what our customers are going to need next, a challenge in itself. We try to do this with two strands of new product development:

- Establishing and understanding existing products that will fit new solutions
- Creating new products

Striking a balance between what customers want and what customers' real needs are is a constant challenge with many needs being satisfied by product solutions that are different from the initial customer request. This process of really establishing what will satisfy a customer's needs requires a dialogue and intimacy that is based on a mutual trust that is built up over a long period of time

Our work comprises two distinct facets of the innovation spectrum: that of a sustaining nature where existing products are adapted or developed to satisfy new customer needs and that of a more disruptive nature that changes the way we do business and enables us to both deliver against future industry needs, but also remain competitive over time. Internal experts and external partners and stakeholders across the industry play a critical role in looking ahead to the challenges that they expect the industry to face in the coming years. From there, we are able to map conceptual solutions to future issues and then push a rigorous development process that ensures an effective solution to an industry problem that is delivered from a solid infrastructure and enabled with a robust business model.

Particular attention is paid to initial screening, where we need to answer the basic question of whether we fully understand a customer's needs and whether we have a realistic vision of what a solution would look like. If we propose a development solution to an independently recognised need, but we find that there isn't an audience, then we're probably fixing a problem that doesn't exist or alternatively, we are simply anticipating a need well in advance.

The challenge and the opportunities that we face are significant. Back in the 1980s, there was a handful of elements from the periodic table that comprised a modern chip; today there are over 45. The different combinations and applications of compounds synthesised from these 45 elements is significantly bigger than 30 years ago. This further supports the need to be deeply embedded in what need we are addressing and what the optimal solution for the customer is.

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My Life at Linde

We speak to Greg Shuttleworth, Global Product Manager at Linde Electronics, about what motivates him to get out of bed in the morning and his proudest moment at Linde.

How would you describe your role in 5 words?
Interesting, challenging, inspiring, motivating, rewarding.

What motivates you to get out of bed in the morning?
I love developing creative solutions to customer technical or commercial issues, for example, or how best to effectively communicate advanced technical concepts in a customer presentation.

Describe your colleagues in three words.
Dynamic, motivated, enthusiastic.

Tell us a little about your background – university, degree qualification etc.
I read Metallurgy and Science of Materials at Oxford University, where I developed a strong interest in electronic materials. This led to a graduate position as a semiconductor process engineer responsible for thin film deposition processes for the then very advanced sub-micron technology. It is amazing to see how the technology has shrunk by two orders of magnitude since that time! The opportunity for travel was enthusiastically taken and led to a position as field process engineering manager for a CVD equipment company and living in Silicon Valley. From there, I moved to BOC Edwards as an Applications Manager and was lucky to live in Tokyo for six fascinating years supporting semiconductor and FPD pump applications there. On return to the UK, I joined the Fluorine team, which has transitioned now to a broader product management role, and then had another international posting in Singapore.

What was it about Linde that made you join the company?
Previous roles had been quite specific either to a technology or customer and I wanted the opportunity to develop a wider range of skills and experiences by working for a truly global company with a diverse range of products and customers. The people were also fantastic, making me feel at home from the very first minutes of the interview process.

How long have you been a part of the Linde team?
I joined BOC Edwards in 1997, and after a brief break in 2005, rejoined in 2006.

What does your role entail?
My role is centred on developing product strategies that help meet or exceed the company targets. There is a global aspect for certain products and a regional support requirement for all, which in my case, means China. We also help with the introduction of new products, working closely with the technology team.

What has been your proudest achievement during your time at Linde?
Every purchase order feels special! If forced to pick one, then it would probably be the first fluorine system sale to Russia after making trips to Vladivostok in December and February.

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