ElectronicsIQ.

Information Quarterly from Linde Electronics.

THE LINDE GROUP

Autumn 2013

Welcome to ElectronicsIQ, the quarterly update from Linde Electronics. In this issue, we will explore the rapid rate of innovation we've seen in the electronics industry in the last 50 years, and look at what the future might hold as carbon nanotube development ramps up. We will also provide a peek behind the scenes at Hsinchu Science Park, one of the biggest semiconductor manufacturing clusters in the world. Dr Sian Fogden will talk about her life at Linde and what inspires her in the fast-moving world of electronics. And finally, we will share details of two landmark agreements we have made with Samsung and Pelchem to support the future growth of the global electronics industry.

Innovation, partnership, commitment – underpinning Linde's role in the global electronics industry

It's quite incredible that it has only been 50 years since semiconductor-based ICs were developed by RCA, Bell Labs and Fairchild Semiconductor. As today's smartphone, tablet and laptop manufacturers seek to meet the needs of their increasingly discerning customers with sleeker and more capable devices, IC manufacturers are under pressure to produce higher performance, lower power and reduced cost chips in smaller geometries. The latest ICs have reached a point where some of their functional layers are only a few atoms thick, making it harder for chip makers to shrink device structures any further. Consequently, material suppliers – such as Linde – need to provide solutions for IC manufacturers to enable the industry to continue to push the boundaries of innovation.

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Innovation: Linde and University College London collaborate on carbon nano-tubes

By Dr Christopher Howard, University College London

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Commitment: My life at Linde

We speak to Sian Fogden at Linde nanomaterials about what inspires her; the fastmoving world of electronics; and how she ended up at Linde.

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Partnership: Linde gases supply for Samsung display plant underway

In May last year, Linde announced a long-term deal with Samsung Electronics to supply gases for its latest 8.5 generation display manufacturing plant in Suzhou Industrial Park. This is one of the largest 8.5 Generation display projects undertaken in China, under which Linde is to provide Samsung with a turnkey installation of the display plant's bulk gases supply systems.

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Partnership: Linde and Pelchem join forces to fuel M2M innovation

Earlier this year, Linde strengthened its material support for electronics manufacturing by announcing a strategic partnership with Pelchem, the global fluorochemicals specialist, to accelerate the development of MEMS. MEMS are seen as key building blocks for M2M communications which will drive the next semiconductor growth wave.

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Innovation

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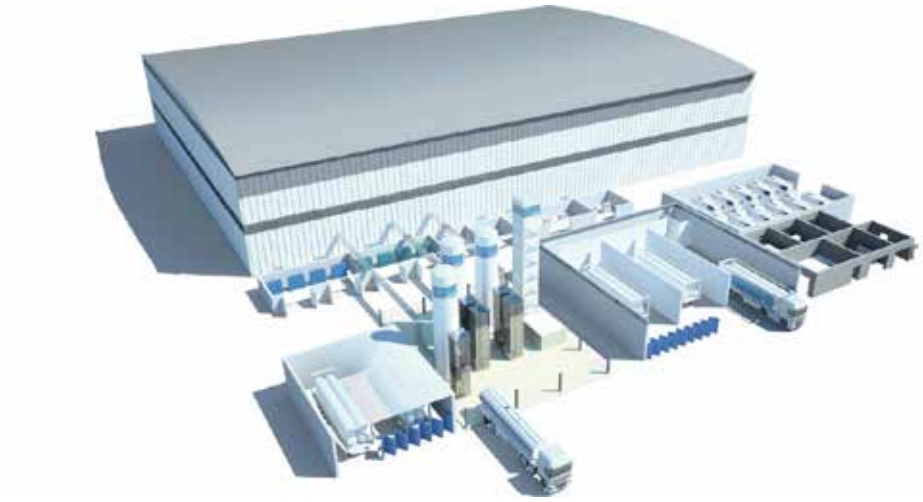

Linde turnkey gas and chemical solutions

As today's smartphone, tablet and laptop manufacturers seek to meet the needs of their increasingly discerning customers with sleeker and more capable devices, IC manufacturers are under pressure to produce higher performance, lower power and reduced cost chips in smaller geometries. The latest ICs have reached a point where some of their functional layers are only a few atoms thick, making it harder for chip makers to shrink device structures any further. Consequently, material suppliers – such as Linde – need to provide solutions for IC manufacturers to enable the industry to continue to push the boundaries of innovation.

To overcome the limitations, chip makers require new deposition materials. This applies both for FEOL (e.g. high-k, gate electrode, channels) and BEOL (e.g. low-k, diffusion barrier, seed layers), as well as new device architectures such as FinFET or 3D memory. The number of chemical elements needed for the manufacture of ICs has grown from five in the early days of Fairchild, to no less than fifteen in the last decade. In the coming years this number will increase further in order to enable technology nodes of ten nanometres and below.

It would be unfair to compare Fairchild's first ICs to today's latest and greatest microchips, but it goes without saying that we've seen huge technological advancements in this space since the 1960s and 1970s. At Linde, we've facilitated innovation in the industry for the past 40 years, and we are excited about what the future holds.

Partnerships

Due to the need for increasingly complex chip technologies, we're seeing more and more IC manufacturers, equipment manufacturers and materials suppliers join forces to facilitate the fast pace of innovation in the industry. Joint development projects enable the pooling of resources and minimise the risk for all participants.

We're also witnessing a shift in focus towards the fast growing mobile devices market. This highly competitive space is characterised by the need for manufacturers to constantly innovate, as new smartphones and tablets must hit the shelves before the end of year shopping season.

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Andreas Weisheit, Linde

To meet demands of this 12-month cycle, chip manufacturers need to build and ramp up new fabs much faster than before. Material suppliers are closely involved, enabling fast track projects. To illustrate, on-site air separation plants are built and brought on-stream in record time to help the industry cope with ever shorter development times, and to bring consumers the sleeker and faster devices they crave.

Commitment

Given the fast rate of technology development in the semiconductor industry and the demand for more innovative products, there's a need for materials suppliers with a global presence and a strong footprint in the electronics industry hubs, especially in Asia. At Linde, we are committed to developing new solutions for our customers, and we are investing ahead of the curve in new electronics materials and bulk gas infrastructure globally.

A great example of this is Taiwan Hsinchu Science Park, one of the biggest semiconductor clusters in the world and home to approximately 10% of the global wafer fab capacity. We've been an integral part of Hsinchu Science Park since day one, supplying nitrogen through an extensive 30km underground pipeline network to multiple customers in the park. We continuously explore new technologies to support the growth of the industry in Hsinchu and beyond, enabling our customers to continue on this path of rapid innovation that we've seen in the semiconductor industry for the last 50 years.

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By Dr Christopher Howard, University College London

Innovation: Linde and University College London collaborate on carbon nanotubes

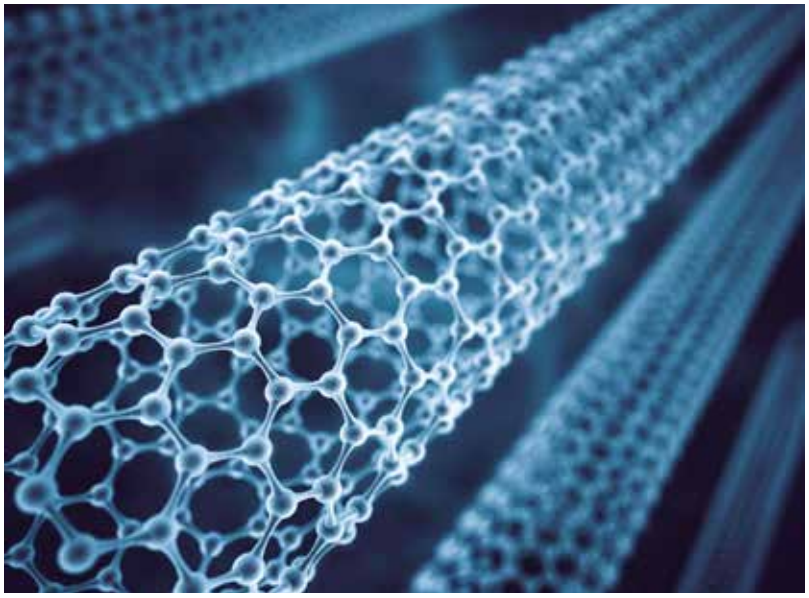
Last month Linde Electronics launched SEERe- ink, a revolutionary liquid containing single-walled carbon nanotubes (SWNTs) which can be used to make thin conductive films for flat screen TVs and lightweight strong composite materials.

The technology upon which SEERe- ink is based was invented by myself and Professor Neal Skipper at University College London, and Dr Sian Fogden and Professor Milo Shaffer at Imperial College London. Since the invention of the technology a couple of years ago, Dr Sian Fogden has become part of the Linde nanomaterials team at Linde Electronics.

At the start of the research, we were investigating the fundamental solution physics of another carbon-nanoparticle, Fullerene (C_{60}). By applying the knowledge gained from this to SWNTs, we discovered that by negatively charging SWNTs in ammonia-based solvents we could overcome the forces binding the SWNTs together in bundles, and lead to their dissolution. It is this complete 'debundling' into solution, without damaging or shortening the SWNTs, that drastically improves the performance of the resulting films and composites. For example, being able to dissolve longer SWNTs reduces the number of junctions in resulting films and this can significantly improve the film's conductivity.

Single wall carbon nanotubes SWNTs are tiny tubes of carbon that have an array of outstanding physical properties: they are stronger than steel, more conductive than copper, and being made exclusively from carbon, they are lightweight. Despite their enormous potential, their adoption in real technological applications has, to date,
been limited. The most significant challenge facing those hoping to harness the properties of SWNTs is how to dissolve them to form solutions, while maintaining their pristine structure and outstanding properties. SEERe- ink overcomes this challenge and has already been used to fabricate 'best in class' performing transparent conductive films.

Throughout the development of our methods, we have maintained a close working relationship with Linde. The company has supported our work over a number of years, from letters of support to help us win research council grants, to directly funding development of the technology. This relationship coupled with Linde's expertise in gas handling, which is crucial to the technology, meant they were the ideal licensee for our product.



Single wall carbon nanotubes

Since licensing the IP from us, Dr Sian Fogden and the rest of the Linde nanomaterials team have demonstrated the potential of the method by fabricating world-leading transparent conductive films, and we are now excited about the launch of SEERe-ink. This advancement has the potential to unlock further development of SWNTs in thin conductive films, thin film transistors, solar cells, sensors and the next generation of composite materials, which makes it a product whose impact could be extremely far reaching.

Short Bio: Dr Christopher Howard is a lecturer at University College London. Following his thesis work on the solution physics C60 he has predominantly worked on manipulating the properties of carbon nanostructures.

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Commitment: Greetings from Hsinchu Science Park in Taiwan

Taiwan's Hsinchu Science Park is one of the biggest semiconductor manufacturing clusters in the world and home to approximately 10% of the global wafer fab capacity. Through its joint venture partner Linde LienHwa, Linde has been an integral part of the park since its phase one development began in the late 1980s, supplying nitrogen to numerous customers via an underground pipeline system which has grown to more than 30 km in length.

The backbone of this system is a series of eight SPECTRA-N™ plants at multiple sites, which supply ultra-pure nitrogen across the whole park. The plants feed a unique looped pipeline system; this ensures maximum reliability and security to the world's leading chip makers, as gas supply can continue uninterrupted even if one section of the system experiences a fault.

UIGC is a Linde LienHwa Joint Venture with Electronics customers in the park

Linde works closely with its customers in Hsinchu Science Park to ensure that this critical infrastructure meets semiconductor manufacturers' needs today and in the future. The company is currently in the process of introducing a brand new SPECTRA-N™ 50K nitrogen plant at Hsinchu. This next-generation system will safeguard supply as demand for nitrogen from semiconductor makers continues to grow.

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Commitment: My life at Linde by Dr Sian Fogden

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

What motivates you to get out of bed in the morning?
My fundamental belief in the potential of the technology that Linde nanomaterials is based upon.

Describe your colleagues in three words?
Intelligent, motivated, dedicated

Tell us a little about your background – university, degree qualification etc.
I completed my MChem at Oxford University where I had my first experience of the new field of carbon nanotubes. Following a brief stint working in quality control for a company that made rattlesnake anti venom I went back into academia and completed my PhD researching carbon nanotubes at Imperial College in London. It was during this time and through collaboration with other researchers in the field that the technology that Linde nanomaterials is based on was developed. Linde's innovation management department saw the potential of the technology before I started my PhD and sponsored the post-doctoral fellowship following it.

Dr Sian Fogden, Linde

What was it about Linde that made you join the company?
Working in a company trying to commercialise the technology developed during my PhD was basically my dream job, so I was delighted when Linde offered me the role of Market and Technology Development Manager at the newly formed Linde nanomaterials. Taking the job also meant a move from London, England to the Linde Electronics R&D site in San Marcos, California and the potential of lots of travel!

How long have you been a part of the Linde team?
I have been working for Linde for two and a half years.
What does your role entail?
My role is centred on developing our technology so that its potential is realised, and launching our products into the R&D market, as well as promoting its potential to large companies who could use our technology now.

What has been your proudest achievement during your time at Linde?
Launching our first product into the R&D market and receiving the first purchase order!

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Before the start of the implementation, Linde purchased a 30,000m² piece of land next to Samsung's site to house the gases supply systems. The conditions of the site terrain made preparation work for construction work very challenging. There is a public road and canal running in between Linde's piece of land and Samsung's site, blocking access. To enable the team to start the construction of the gases supply systems, the team excavated 14m underneath the road and installed two underground 350-metre pipe tunnels 2.7m in diameter each. Finally, they installed dual pipelines from Linde's site to the Samsung site to ensure 100% redundancy and availability.

Linde Suzhou Samsung gas facility design

The turnkey installation of the display plant's bulk gases supply systems is now underway. Linde will supply several different gases for Samsung, so the implementation is phased. The supply systems that have been completed include purified Nitrogen Argon, Oxygen and Helium. Linde is also the first company to provide Samsung with Compressed Dry Air (CDA), and Linde's team is working closely with Samsung to ensure that the remaining gases go online according to the customer's requirements.

Linde has become the gas supply partner of choice for display manufacturing in China with substantial gas contracts in place with the three largest flat panel display manufacturers. Linde will explore opportunities offered by the region beyond the existing electronics hubs to help its customers discover new areas for growth through innovation and environmentally friendly solutions.

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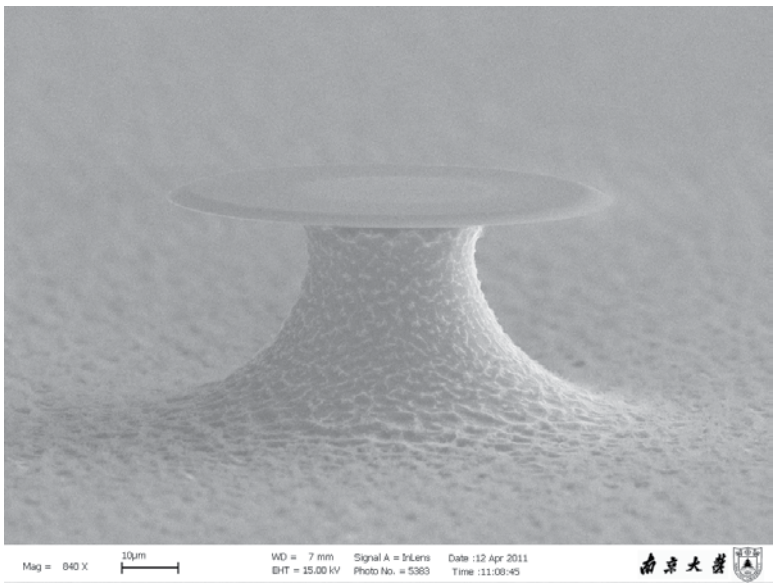
Partnership: Linde and Pelchem join forces to fuel M2M innovation

Earlier this year, Linde strengthened its material support for electronics manufacturing by announcing a strategic partnership with Pelchem, the global fluorochemicals specialist, to accelerate the development of MEMS.

MEMS are seen as key building blocks for M2M communications which will drive the next semiconductor growth wave. To satisfy this increasing demand, Linde and Pelchem have partnered to distribute xenon difluoride (XeF2), a critical material used in the manufacture of MEMS.

The properties of XeF2 make it ideally suited to the etching of MEMS silicon and control of this step becomes more crucial as the patterns etched become smaller and more complex. XeF2 is a highly selective and directional etchant of silicon, which enables complex structures to be created quickly, uniformly and at the small sizes required for integration into almost any device.



A microdisk created using XeF2 etch

With Pelchem having the largest share of the global XeF2 market and Linde's customers including the world's leading device manufacturers, the partnership enables the two companies to take the lead in material supply for the world's MEMS market. Linde and Pelchem have a long standing working relationship further strengthened by this partnership.

Peter Owen, Head of Linde's Global Electronics business and Asia Joint Venture Management described the partnership as "just one component of our continued investment in advanced materials to facilitate the growth of this market. The addition of XeF2 complements our existing portfolio of gases that help electronics manufacturers globally produce more innovative electronic devices more cost effectively. Collaborating with Pelchem enables us to support the manufacture of the latest MEMS devices as the fast growth of this sector continues."

Dr Petro Terblanche, Managing Director of Pelchem said "by joining forces with Linde and tapping into Linde's extensive, world-class distribution network and infrastructure, we are well positioned to be the supplier of choice for XeF2 on a global scale."

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