Europe’s Compound Semiconductor Industry

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Keywords: solar cells, power electronics, lasers, automotive radar, LED light bulbs

Abstract
Europe has a diverse, successful compound semiconductor industry. This is helping to: spur the growth of solar power systems operating at grid parity; trim losses associated with power conversion in power supplies; aid the development of efficient green lasers for pico-projectors; improve the affordability, efficiency and color quality of LED light bulbs; and create affordable automotive radar.

INTRODUCTION

New technologies promise to make the world a better place. They can spur greater generation of energy with renewable sources, leading to a reduction in carbon dioxide emissions, which can be cut further with increased deployment of more efficient electronics and lighting systems. In addition, new technologies can reduce the chances of accidents, by slashing crashing on our roads; and they can also add more attractive features to our mobile devices, such as tiny projection systems for sharing our photos, presentations and movies.

In every one of these areas, compound semiconductors have a major role to play. They lie at the heart of photovoltaic energy generation systems, and are the key ingredient in efficient energy conversion modules, lighting products, automotive radar and laser-based projection systems. Manufacturing of these chips takes place all over the globe, with Europe punching above its weight in several areas.

PHOTOVOLTAICS

Attempts by several nations to limit their carbon dioxide footprint have helped to increase the size of the market for photovoltaic systems. Crystalline silicon dominates this sector, but its grip is weakening, due to rising sales of a handful of thin film technologies, which can be based on a wide range of semiconductors. According to analysis by GTM Research [1], all forms of thin-film device accounted for just 3 percent of the photovoltaic market in 2002, but rocketed to 14 percent by 2008 and could hit up to 29 percent this year. CdTe will take the lion’s share, accounting for 14 percent of the total market in 2012.

The leading manufacturer of CdTe is the US-headquartered firm First Solar, which has manufacturing lines in Europe at Oder, Germany. These lines, plus others at Perrysburg, Ohio, and Kulim, Malaysia, have a combined annual capacity of several gigawatts and rapidly churn out panels with an average efficiency of about 12 percent at a very low manufacturing cost – this is significantly below $1-per-Watt.

The primary reasons why First Solar can outperform its silicon rivals in the highly important cost-per-Watt stakes is that it produces its cells very quickly, using a proprietary process that consumes tiny amounts of materials – the semiconductor films are two orders of magnitude thinner than those in silicon cells. First Solar is unwilling to divulge the details of its process [2], but a report written by its predecessor, SCI, reveals that its manufacturing technology involves elemental vapor deposition onto large glass sheets.

The four-stage manufacturing process begins by placing glass on rollers, which transport these sheets into a chamber heated to 600 °C. The glass is then transferred to a second chamber filled with CdS vapor heated to 700 °C. A film just a few microns thick is deposited onto the sheets in this chamber, and in the next one a CdTe film of similar thickness is added. A gust of nitrogen rapidly cools the panels in a fourth chamber, before a subsequent heating step enhances efficiency, and a laser patterns the sheets into an array of solar cells connected in series.

The performance of these CdTe devices continues to rise, and in summer 2011 First Solar reported a cell with a record-breaking efficiency of 17.3 percent.

Even higher efficiencies are possible with other forms of thin films. For example, the record for copper indium gallium (d)selenide (CIGS) on glass is just over 20 percent. Switch to a plastic substrate, which is cheaper and flexible, and the record falls a little to 18.7 percent. CIGS technology promises to excel in reducing the cost-per-Watt, but developing a reproducible, high-yield manufacturing process is challenging. However, companies are making progress, including solar cell maker Solibro of Bitterfeld-Wolfen, Germany, which announced a record-breaking CIGS module efficiency of 17.4 percent late last year.

More traditional III-Vs are also making an impact on the terrestrial solar cell market, after decades of deployment in space, where they have been used to power satellites. Efficiencies of around 30 percent are possible with conventional triple-junction cells that are grown on germanium, which forms one cell, and have additional cells made from InGaAs and AlGaInP.
If solar systems were built in a conventional manner using these multi-junction cells, costs would be astronomical. But it is possible to produce systems that can compete in unsubsidized markets in sunny climes, such as the south-west US, by building systems that track the position of the sun in the sky and focus its rays onto devices using concentration factors of several hundred. In addition to cutting costs, this approach can boost the efficiency of each solar cell to more than 40 percent.

For chipmakers and developers, success in this market requires the manufacture of highly efficient devices. The record for efficiency has changed hands on many occasions during the last few years, with Europe owning the bragging rights at one point, thanks to the efforts of Fraunhofer ISE. Researchers at this institution pioneered a new triple-junction structure that uses the combination of germanium, InGaAs and GaInP and delivers an efficiency of 41.1 percent [3]. (At the time of writing, the efficiency record rests with Stanford University spin-off Solar Junction, which has developed a 43.5 percent efficient photovoltaic that features a dilute nitride section for the low-energy cell).

Europe has also pioneered the development of novel III-V cells that promise to deliver even higher efficiencies. Quantasol, a spin-off from Imperial University, London, developed cells incorporating a stack of quantum wells, which enable absorption of light with longer wavelengths (see Figure 2). The US firm JDSU was particularly impressed with this technology, and in July 2011 it announced that it had acquired the critical assets of the UK solar start-up, including product design and patented intellectual property.

POWER ELECTRONICS

All types of solar cell generate a DC output, which must be transformed into an AC form before it can be fed into the grid. Silicon power electronics can be used in this power conversion process, but far higher efficiencies are possible using devices made from wide bandgap semiconductors, such as SiC. Such devices can also improve the efficiency of switch-mode power supplies, and they promise to revolutionize the electronics in hybrid electric vehicles: Thanks to their higher operating temperatures, it is possible to eliminate a separate cooling system currently used to prevent overheating of silicon electronics.

Europe has led the commercialization of SiC devices. Infineon, which is head-quartered in Germany, launched the first commercial diode in 2001, and STMicroelectronics of Geneva, Switzerland, has also had significant commercial success with this class of product.

In many applications, diodes have to be paired with transistors that produce a switching function. However, making a SiC transistor is far more tricky than producing a diode, with products only coming onto the market in the last few years. Firms in the US have led the way, with SemiSouth
of Starkville, Mississippi, launching a SiC JFET in 2008 and Cree of Durham, North Carolina, launching a MOSFET in early 2011. In Europe another form of SiC transistor, a BJT, was launched in 2008 by TranSiC. However, like Quantasol, this university spin-off has been snapped up by a US firm, in this case Fairchild Semiconductor.

LED LIGHTING

Increases in the efficiency and brightness of LEDs have enabled the manufacturers of this device to target new applications. Backlighting handset displays and illuminating their keypads was the first multi-billion dollar market for the LED, which now generates similar sales from the backlighting of larger screens, such as those found in netbooks, laptops and TVs. The next big market for chipmakers everywhere is general lighting.

LED light bulbs are already available around the globe, but prices are very high. According to the market analyst IMS Research, the average selling price in November 2011 was $28 [4]. To slash the retail price to a level that is viewed as affordable by many potential customers, chips costs must plummet, because they account for more than half of the total bill of materials [5].

One way to reduce the costs associated with a white, GaN-based LED is to switch the substrate material from either sapphire or SiC to silicon. Lattice Power, an LED manufacturer based in Nanchang, China, has been one of the leaders in this regard, and can produce high-power devices on silicon with a peak external quantum efficiency of 60 percent [6].

Lattice Power produced its first devices on 2-inch substrates, but is working on scaling its process to larger sizes, because this can help to drive down LED chip costs. The US firm Bridgelux has made major strides in this direction, producing prototype warm-white and cool-white LEDs on 200 mm silicon with efficacies of 125 lm/W and 160 lm/W, respectively [7]. These wafers are flat enough for processing in under-utilized 200 mm silicon fabs that are dotted around the globe, with production of chips on this platform promising to unlock the door to $5 LED bulbs. Europe is active in this area, with Osram Opto Semiconductors recently reporting pilot production of LEDs on 150 mm silicon, and Plessey of Plymouth, UK, planning to manufacture LEDs using the same sized silicon substrates by the end of this year.

Another weakness of the white LED is its decline in efficiency when the emission is adjusted to produce a warmer hue, which is better at replicating the palette of an incandescent bulb. White LEDs contain a blue-emitting chip coated in a yellowish phosphor, with color mixing responsible for the broad spectral output. To make the emission warmer, the phosphor must emit at a longer wavelength, making the process less efficient. One way to address this issue is to use red LEDs to provide the long wavelength content. Osram is leading manufacturer of this class of LED, and in October 2011 it claimed to have broken the efficiency record with an LED that could deliver more than 200 lm/W.

LASER-BASED DISPLAYS

The next few years will witness a growing number of tiny projection systems, known as pico-projectors, fitted to cameras, handsets and other devices. Many of these pico-projectors will use red, blue and green lasers to form color
images. The red and blue lasers are already well established, and are descendants of the light engines used in DVD and Blu-Ray players. Developing a green laser chip has proved far more tricky, because it is very difficult to form a high-quality InGaN layer with enough indium content to emit beyond 500 nm. In addition, the strong internal electric fields in conventional nitride layers pull apart the electrons and holes in the light-generating quantum well layer, hampering emission efficiency.

To overcome this issue, some researchers, such as those at Rohm, UCSB and Sumitomo, started to develop visible lasers grown on different polar planes with weaker internal electric fields, or none at all (see Figure 3) [8]. A race to make the first green laser followed, which spurred further progress in conventional long-wavelength nitride lasers. Osram has played a major role in advancing green laser performance, with the world’s first lasers operating beyond 500 nm. It plans to launch commercial green-emitting lasers in 2012.

**AUTOMOTIVE RADAR**

One RF application where Europe has been a leading player for many years is the production of chips for automotive radar. A significant share of the market is held by United Monolithic Semiconductors, which has manufacturing facilities in France and Germany. Infineon is also active in this area. It made its first autoradar chips from GaAs and related materials, but sold this business unit to TriQuint in 2002. Soon after this, the company signed up to a European automotive radar project, and started making chips again. But it switched materials, using silicon transistors with a SiGe base layer that drives up the operating speed of the chip, so that it can emit at 77 GHz. This approach cuts the number of chips needed to build an automotive radar system from a handful to just two, which in turn helps to trim the cost of automotive systems. According to UK market research firm Strategy Analytics, sales of automotive radar systems based on silicon – which hit the market in 2009 due to the launch of a Bosch system incorporating a pair of Infineon chips – will overtake those based on GaAs within two years. In other words, Europe could be the dominant force in automotive radar chips for several years to come.

**CONCLUSIONS**

Europe may not have any of the world’s biggest GaAs foundries or the vast number of LED chipmaking fabs found in Asia, but it does play a significant role in many, many parts of the III-V industry. It’s a leading light in the development of various forms of solar cell, LEDs for general illumination, green lasers, SiC power electronics and forms of automotive radar.

**ACKNOWLEDGEMENTS**

The author would like to thank the CS-Mantech committee for the invitation to present this paper.

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