It has been more than a year since we looked at the markets for III-Vs devices in space. Since then, Iridium - one of many space-based telecom systems that rely almost entirely on solar cells for power - has been up and running, then down, and now (after acquisition by Iridium Satellite LLC of Iridium LLC in December 2000 and the launch of commercial services at the end of March) it is up and running again. Although the overall prognosis for the optoelectronics industry has not been good recently, some sectors - such as solar cells - have been affected less than others.

Roy Szweda
Associate Editor

Compounds vs silicon for solar cells: less is more

Solar cells can be divided into various categories according to the semiconductor material from which they are made:

- Amorphous silicon (a-Si) and monocrystalline silicon;
- III-V compound semiconductors (e.g. GaAs and InP);
- Copper indium diselenide (CulnSe₂, or CIS);
- Others (e.g. II-VI semiconductors, plastic/organic materials).

This is also the order of their relative importance. Silicon is the clear market leader in terms of volume of devices shipped, but compounds are very important in terms of market value (e.g. the GaAs solar cells used on the Iridium satellite system - see Figure 1). CIS is the newcomer and on the initial part of its growth curve.

In terms of wafer area, solar cells are still one of the biggest consumers of wafers in terms of area (millions of square inches per annum).

Solar cell markets

According to the second edition of the forthcoming market report: 'A Strategic Study of the Worldwide Semiconductor Optoelectronic Component Industry to 2005' by Reed Electronics Research, the total market for semiconductor solar cells will grow from US$649m in 2000 to US$1.032bn by 2005 (see Figure 2).
Figure 2. (a) The breakdown of the solar cell market by application will remain largely unchanged from 2000 to 2005, but (b) the total market will grow from US$649m to US$1.032bn.

Like many other opto device markets, in 2000-1 this sector suffered one of the first reversals of fortune in its history. The reasons were complex but had much to do with a lack of confidence in the telecoms sector, for which the higher-value solar cell market segment has so much to contribute. There has also been a general decline in manufacturing worldwide which shaved a few more points off the growth of opto and other devices. Continuing downward unit price pressure is also affecting the market.

However, the strength of the solar cells market derives from several factors such as:

- General expansion of terrestrial applications;
- Good growth in space applications;
- Impact of new markets such as battery-powered remote equipment (e.g. signage);
- Improvements in alternative energy sources.

The dominant application sector is the "consumer" sector (which includes energy generation as well as smaller applications such as toys). Next is telecoms (which includes all satellite systems).

Automotive is also proving to be an interesting market, with use of panels for electric vehicles as well as traffic signage and management.

The market is essentially split into two main application sectors:

1. Terrestrial - high volume but low unit price;
2. Spacecraft - high value but low volume.

The first sector is dominated by silicon-based photovoltaic units. These are the lowest cost and are made by the hundred thousands of square inches per annum.

**Importance of germanium**

To gain insight into the role of germanium in the solar cell industry, III-Vs Review spoke to Ignace de Ruijter, Business Line Manager Substrates at UM Electro-Optic Materials. "The germanium wafer market is presently 95% dedicated to space solar cells; the balance is for photodetectors and some development work," he says. "However, with the advent of GaAs-on-Ge concentrator cells, there is great potential for terrestrial applications," he adds. "Ge is also poised to become important for other opto applications, notably red LEDs. UM and IMEC have demonstrated red cavity LEDs, as well as production of Ge as a substrate for transistor manufacture."

The standard germanium wafer size today is 4" (see Figure 3). Demand for all types is about 4 million square inches per annum, leading to a vast share of the MOCVD market. LED applications will likely generate additional demand for 2" and 3" wafers. Germanium wafers can, however, be grown up to 8" in diameter dislocation-free, triggering its use for new electronic applications.

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Ignace de Ruijter,
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UM Electro-Optic Materials
"ISE has developed novel [monolithic tandem] solar cells [based on GaInP and GaInAs] that yielded 28% efficiency for terrestrial and 24.5% for space applications...

This is a single-stage process and so is less costly compared to two separately-made cells mechanically stacked... For terrestrial use we have added a Fresnel lens to concentrate the sunlight by a factor of 100-500... ISE has recently achieved a world record efficiency of 32%.”

Dr Andreas Bett, Fraunhofer Institute of Solar Energy Systems

Meanwhile, in Germany the Fraunhofer Institute of Solar Energy Systems (FhG-ISE) has developed very interesting solar cells which have set new records for efficiency (see Figure 4).

The driving force behind this work is Dr Andreas Bett. “For the first time in Europe ISE has developed novel solar cells that yielded 28% efficiency for terrestrial and 24.5% for space applications,” he says. The technology is a monolithic tandem solar cell based on GaInP and GaInAs. “This is a single-stage process and so is less costly compared to two separately-made cells mechanically stacked. The different materials provide different absorption characteristics which yield a more efficient sunlight conversion.”

For terrestrial use we have added a Fresnel lens to concentrate the sunlight by a factor of 100-500. With such a device ISE has recently achieved a world record efficiency of 32%.

To commercialize these developments a company in Heilbronn and ISE are planning industrial production of the tandem cells. ISE also plans to exploit the concept of diversified III-V material systems to produce even higher efficiencies, as...
shown by simulations. In this case a conventional tandem solar cell will be mechanically stacked on top of a low-bandgap GaSb based device. Efficiencies of 34% have already been measured under concentration.

**II-VIs - targeting costs**

In the UK, the Sheffield Hallam University is also focused on improving efficiencies of solar cells and reducing costs. "These objectives can be achieved by reduction of expensive semiconductors and use of lower-cost process techniques", says Dr I M Dharmadasa. Sheffield's cells are only 2 μm thick compared to 200 μm used for crystalline silicon cells (see Figure 5). Also lowering cost is an electro-chemical method. "In 8 years of research we have shown that these electro-deposited materials produced under the right conditions are as good, if not superior, to those made by the expensive growth methods."

Proving very interesting are the II-VIs such as CdS, ZnSe as window materials and CdTe or CuInSe₂, for example, as absorbers.

"We are most excited by our latest material CuInGaSe₃ [CIGS]. Our first structure is based on glass/FTO/n-ZnSe/p-CuInGaSe₃/Au. It has shown 15% efficiency - to our knowledge this is the best so far for one-step electro-deposited semiconductors". Moreover, it is not far from the 18.8% measured for cells made by costly vacuum growth by NREL. "We are presently directing our research to see if we can match such efficiencies with our low-cost electro-deposited materials."

**Solar futures**

From this quick survey of some of the key developments it is obvious that we have not seen the end of solar cell development. The field becomes ever more interesting not only because of the continual breaking of records but also the strong efforts to bring costs down.

The solar cell field is also interesting simply because of the use of a broad range of semiconductor materials. Workers around the world are striving to use less materials and more efficient fabrication processes. Through these means, solar cells will continue to play a key role in the provision of clean, renewable and efficient energy sources to meet future needs in a diversifying market place.

"Our first structure is based on glass/FTO/n-ZnSe/p-CuInGaSe₃/Au. It has shown 15% efficiency... the best so far for one-step electro-deposited semiconductors... Moreover, it is not far from the 18.8% measured for cells made by costly vacuum growth."

Dr I M Dharmadasa, Sheffield Hallam University