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Interview inside

**A PRACTICAL GUIDE FOR IMPROVING
CRYSTALLINE SOLAR CELL EFFICIENCIES
THROUGH FIRING PROCESS OPTIMIZATION**

SMART PACKAGES FOR CPV CELL DEVICES

**ACHIEVING THERMAL UNIFORMITY IN
PHOTOVOLTAIC APPLICATIONS**

**INCREASING SOLAR PANEL PRODUCTION
EFFICIENCIES WITH ACRYLIC FOAM TAPE**

NEW PRODUCTS

INDUSTRY NEWS

INTERNATIONAL DIARY



Smart packages for CPV cell devices

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Without doubt, the future of renewable energy systems that utilise concentrator photovoltaic (CPV) principles depend absolutely upon the capability to build cost effective CPV cell modules. The system energy cost is continually being driven down, and new CPV systems have to be ahead of the game both in terms of providing efficient light to energy conversion and low "dollar per watt" electricity generation.

The big advantage for CPV modules is that they use relatively small, photosensing diode devices. These are virtually the opposite of light emitting diodes (LED) and can, with some smart design, be developed to utilise much of the manufacturing technologies that have recently mushroomed for the fast growing LED industry. The small compound semiconductor solar cells can be manufactured by using optoelectronic semiconductor assembly techniques (wire bonding, dicing, pick and place, etc.) for cost effective assembly and encapsulation. In particular, CPV does mirror the latest HB LED technologies which use semiconductor assembly processes with new technology developments to achieve low cost, high volume production.

Development of concentrator PV

Optical diodes convert light and energy in two basic formats. As light emitters, they output light when energised, or as photosensors they emit an electric current when exposed to photons of light. Much work has been done in recent years, and continues on, to utilise new technologies for making photodiode devices more efficient. LEDs in particular are today a very high profile industry as the efficiencies improve and the usage of LEDs for lighting has created a very high demand for high brightness devices. Conversely, the solar power industry is seeing the uptake of photosensing devices to convert the energy of sunlight into electricity. With the use of lenses, as we all know, sunlight can be focussed to a very small point of high intensity light. This intense, concentrated light can be converted by high efficiency photodiodes into significant amounts of energy.

In 2003, a European Funded, Framework 6 project entitled "FULLSPECTRUM" (see www.fullspectrum-eu.org) set out to develop this light concentrator technology (Figure 1).

The overall goal of the project was the better exploitation of the solar spectrum in the photovoltaic (PV) conversion of the solar energy. The conventional, single semiconductor, solar cells only convert the

photons of energy close to the semiconductor bandgap effectively. Photons with less energy are not absorbed and their energy is totally wasted whilst photons with too high energy only use a fraction of it. This project looked at the use of compound semiconductor materials, the "III-V" multijunction (MJ) cells, along with manufacturing technologies for novel concepts including assembling. The results did lead to a major development programme to industrialise the concepts and produce high performance CPV modules.

The United States National Renewable Energy Laboratory (NREL) continues to be the arbiter for the development of efficient PV cell devices utilising MJ devices and regularly publish data covering the developments of high efficiency cells. NREL are working with a number of R&D projects in concentrating solar power, focussing on parabolic trough solar technology and advanced concentrating solar power technologies to support the U.S. Department of Energy in its concentrating solar power deployment efforts.

These CPV systems use lenses or mirrors to concentrate sunlight onto high-efficiency solar cells. Although typically more expensive than conventional cells used for flat-plate (typically Silicon) photovoltaic systems, these solar cells utilise the light

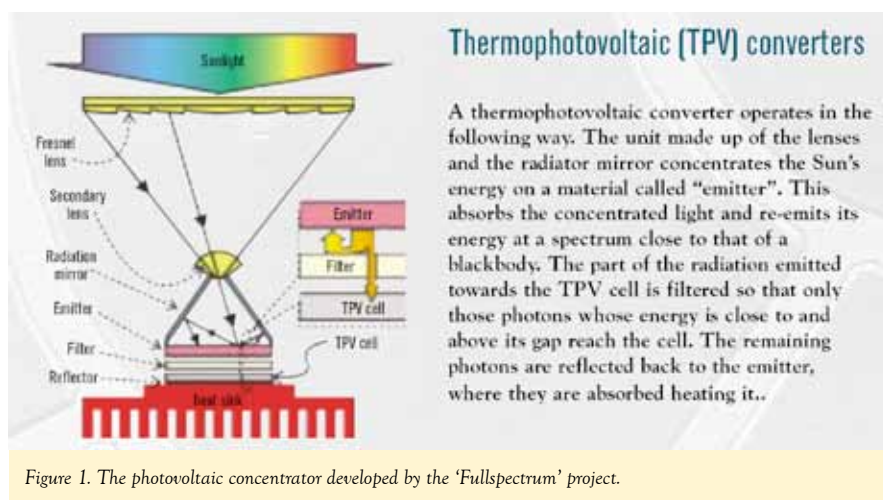


Figure 1. The photovoltaic concentrator developed by the 'Fullspectrum' project.

concentration to decrease the required cell area while also increasing the cell efficiency. NREL state that CPV technology offers the following advantages:

- Potential for solar cell efficiencies greater than 40%
- No moving parts
- No intervening heat transfer surface
- Near-ambient temperature operation
- No thermal mass; fast response
- Reduction in costs of cells relative to optics
- Scalable to a range of sizes.

However the high cost of advanced, high-efficiency solar cells must utilise cost-effective concentrator optics and cell assemblies to enable concentrated sunlight systems to achieve a comparison with other solar power options.

CPV cells

Solar cell size is a key aspect in concentration applications. The optimum size for a GaAs solar cell operating at 1000 suns is about 1 mm². (Operation at 1000 suns means a light power density of 1 MW/m².) A small size cell maximises the efficiency and if a 1 mm x 1 mm size is chosen, this is very close to that of a LED device (Figure 2). Yet because III-V multijunction solar cells operate at lower photocurrent than single junction, a triple junction (3J) with a size of 1 mm² requires a high light intensity in order to provide a good conversion. However, operating at 1000 suns means that the light power received by the solar cell is 1 watt. Assuming an efficiency of 35%, then 350 mW of this energy is converted into electricity, while 650 mW is transformed into heat. Although a heat intensity of 650 mW/mm² does not require active cooling, and heat extraction of several hundred of mW is well developed for high power LEDs, the CPV devices do need good thermal management built into the system to ensure long term reliability.

The MJ CPV cell device is a semiconductor device that needs to be interfaced and mounted onto a base that can provide an electrical interconnection as well as some form of thermal dissipation. In semiconductor terms, the cell devices are quite large as typically the industry is moving towards the 5 mm x 5 mm size rather than the smaller 1 mm x 1 mm. Some applications are using even larger 10 mm x 10 mm devices. Even so, all semiconductor devices need to be protected from damage caused by handling, mounting into systems, ambient conditions and moisture. Hence, these devices need some form of circuit board,

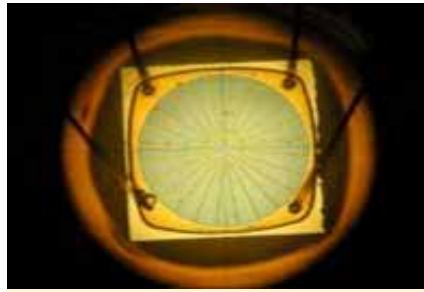


Figure 2. A typical GaAs 1 mm x 1 mm CPV cell units. (Courtesy of Isofoton)

substrate or package to allow the connections between one another and the outside world. This is course similar to the needs of the LED devices. LEDs and high brightness (HB)LEDs in particular, are mounted in small surface mount housings (packages) that have integral heatsinks and are sealed with a silicone optical gel (Figure 3).

In the CPV world, most cell modules also incorporate bypass diodes as protection from “dark current.” This is a potential problem when one of the cells in the system is damaged, weak or (most likely) in shade. Then there is the risk that full current from the rest of the cells could pass through the shaded device and cause overcurrent damage.

Essentially, concentrator cells must therefore comprise a small, high efficient, multijunction cell, together with a bypass diode, suitably housed in a robust package that will provide thermal management, protection of the device from ambient dust, dirt and moisture, and an optical interface (support and alignment) with the light gathering structures (lenses). This package must also ensure long term reliability and be low cost...definitely a “smart package.”

Comparison to HB-LED technology

Typically there are 4 main parts required for a HB LED or a CPV cell package, as shown in Figure 3.

- A housing (package body)
- Interconnection terminals (leads)
- Thermal management (heatsink)
- Optics support.

These elements do not necessarily have to be individual items and for cost advantages. The LED industry has developed a number of packages that combine most of these elements together. In terms of the manufacturing processes, LED fabrication yields of 95-98% are standard while silicon PV is in a lower range of 90-95%.

If the HB-LED is considered, the

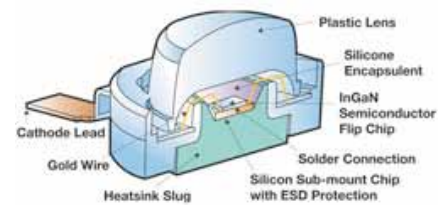


Figure 3. Structure of a high-brightness LED. (Source: Lumileds™)

packages are also developed to be suitable for assembly on high throughput assembly equipment as used by semiconductor chip assembly companies. The package is typically on a carrier, or lead frame, that can work with automated pick and place ‘die attach,’ wirebond, sealing and testing machinery. The assembly equipment ensures that the chips are accurately located (within microns) to provide exact optical alignment with the seal or lens focal planes. Devices are then singulated and packed into tubes or carrier tapes to enable handling, storage and ease of use for insertion and assembly into the application requiring the LED. The application subsystem will also provide additional thermal management (heat sinking), electrical connections and probably additional optical alignment.

A CPV solar application has identical assembly requirements and the use of pre-packaged cell units is now becoming the optimum solution to ensure high quality and long term reliability of CPV modules.

CPV cell packages

Thermoplastic injection molding technologies used to provide cavity chip package solutions is one the key emerging technologies for the electronics industry. A chip package is just a box with connectors, and plastic molded connectors are in themselves part of a fast moving industry high technology, high volume industry. Molding high performance engineering plastics, such as liquid crystal polymers (LCP), to pre-formed copper leadframes, is the choice for packages for sensors, MEMs, LEDs and other electronic devices. This technology is now the cost effective choice for “smart” CPV packages.

As discussed, there are a number of crucial factors that must be combined into the design of a CPV cell package. As volumes develop, it would seem prudent to ensure that such devices incorporate the use of low cost Assembly capabilities and adoption of “standard” semiconductor ‘back-end’ assembly processes is the only



Figure 4. A CPV package unit on leadframe carrier.

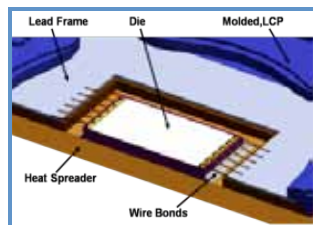


Figure 5. The assembly of a basic CPV package unit.

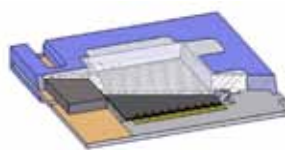


Figure 6. Cross section of a basic CPV package unit.

way to go for this. The package must therefore take into account the requirements of the manufacturing systems: small sizes, carrier frames, die attach, wirebond, pick and place, etc.

Optical alignment is also a crucial part of the solar cell unit. Chip packaging is, in general, a proven technology for ensuring alignment of devices in the 'X' and 'Y' planes but a CPV cell is actually a "3D" device. There has to be a focus of light onto the chip, and therefore, depending upon optics, the package has to be aligned to the "Z" plane to ensure optical conversion efficiency. It is feasible, as with LED packages to build some form of X, Y and Z alignment into the packages and this is easily done utilising plastic injection mold capabilities. However, as there is no "standard" optical design, the package design is then really a match for the "unique" optics that may be used. It may be more effective to use an available "standard" low cost package, always a smart choice, and utilise a separate "lens holder" to customise the system.

Power dissipation needs are foremost, to ensure efficiency and reliability of the cell. Utilising a leadframe technology as opposed to a ceramic or organic substrate allows for a substantial metal mass to be utilised as a die pad. This pad also acts as a heat-sink and enables much simpler thermal management within applications. Interplex Engineered Products have developed a number of unique injection molding systems that allow two separate leadframe formats to be molded together at the same time, and by incorporating this technology into the designs, they have produced a package technology that allows the interconnection leadframe to be electrically isolated from the die pad/heatsink frame. Using frame technologies, rather than "drop in" metal slugs is a much lower cost process and is much more applicable to high volume applications.

The design of a simple looking chip housing, the molded plastic part, is really the 'smart' part of the package. It provides protection for the metalwork, insulation

for the system components, a methodology for optical alignment and connection apertures for electrical interconnection to the rest of the system.

SMART packages

The package design in *Figure 4* incorporates the Interplex unique, patented, dual lead-frame design, integrating a thick copper base die pad as a heatsink, with a standard lead-frame structure in a high temperature LCP thermoplastic enclosure. This ensures excellent heat transfer from cell to heat sink via the copper lead-frame ensuring increased cell efficiency. The design of the package molding allows for flexible secondary optics mounting, suiting the varied and different module designs that CPV system manufacturers are now considering. It is also designed to have inexpensive interconnect spade terminals for low cost integration of cell systems enabling a lower total cost of assembled receiver due to simplified assembly operations.

These packages offer significant advantages compared to the alternative methods of component assembly utilizing metallised circuit boards such as ceramic substrates or mounted onto direct bond copper (DBC) or insulated metal substrates (IMS). Thermal management is built in, secondary optics are easily mounted, and isolation between cell and system housing can be achieved very simply with a variety of materials. Furthermore, a packaged cell device allows easier and safer handling, quicker assembly and test of the system as well as simpler repair and replacement, making the designs more future proof as better 'III-V' cell designs and efficiencies are developed.

This design of package will also easily lend itself to customisation or scaling to suit different size cell devices and different interconnection needs. Examples of such designs are shown in *Figure 5* and *6*. One is for surface mount and the other is designed for interconnection wires (cables) to be soldered to the packages.

Conclusion

Interplex have taken the lead in developing a range of 'smart' package options for the developing CPV solar energy market. They have developed a range of package designs offering a user friendly solution for the component user as well as the device supplier (*Figure 7*). To ensure that cost effective devices will become available they have produced a package that enables the CPV technology industry to adopt manufacturing skills already developed for the Semiconductor, particularly the LED, industry. The "standard" semiconductor assembly processes offer proven technology, with efficiency and automation to meet low cost assembly needs of the CPV industry. The designs to match these processes utilise readily available low cost materials, to provide a package solution that is the ideal option for both sample testing and production applications.

These "smart package" developments now offer the manufacturers and users of photosensing power LED and CPV devices a robust, thermally enhanced housing coupled with simple interface connectivity.

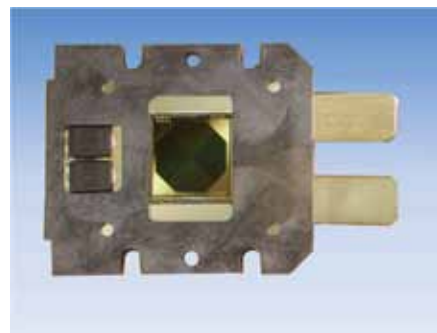


Figure 7. A CPV cell fully assembled. (Courtesy of Spire)

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