PACKAGING III-V TANDEM SOLAR CELLS FOR PRACTICAL TERRESTRIAL APPLICATIONS ACHIEVABLE TO 28 % OF MODULE EFFICIENCY BY CONVENTIONAL MACHINE ASSEMBLE TECHNOLOGY AND POSSIBILITY OF 500 X AND LOW WEIGHT HCPV FOR SPACE

K. Araki, M. Kondo, H. Uozumi, Y. Kemmoku (1), N. J. Ekins-Daukes (2), M.Yamaguchi (2)
Daido Steel Co., Ltd. 2-30 Daido-cho, Minami, Nagoya 457-8545 Japan
(1) Toyohashi Sozo College 20-1 Matsushita, Ushikawa, Toyohashi, Aichi 440-8511 Japan
(2) Toyota Technological Institute 2-12-1 Hisakata, Tempaku, Nagoya 468-8511 Japan

ABSTRACT: A new concentrator receiver containing a 7 mm X 7 mm 3J concentrator solar cell with a 37.4 % peak efficiency was developed. The receiver design includes a homogenizer, heat handling (epoxy lamination) technologies and a low resistance soldered connection and can be applied to various concentrator optics, including dish systems. The outdoor efficiency with a combination of a plastic Fresnel lens, made by low-cost injection molding, reached 27 % on a hot summer day under 35.0 C ambient temperature without additional cooling. With this newly-developed receiver, mechanical engineers will be able to design their own concentrator module suitable for their environment, using their mechanical knowledge and local industrial resources.
Keywords: III-V Semiconductors, Concentrator Cells, Concentrators, Encapsulation, High-Efficiency, Multijunction Solar Cell, PV Module

1 INTRODUCTION

It is expected that concentrator modules with high efficiency multi-junction solar cells will reduce the PV cost significantly [1]. Recently various kinds of concentrator module structure were proposed and tried to 3J monolithic multi-junction solar cells. The back-contact silicon concentrator with its peak efficiency 26 % is now widely used for large scale concentrator solar electricity power generation in Arizona and Australia made by two leading companies Amonix and Solar Systems [2][3]. It was expected by simply replacing the silicon cells with new 3J cells (peak efficiency 37%), the power generation would be 1.4 times more [4]. However, it is not a simple scenario. Both Amonix and Solar Systems expressed a cautious opinions that it will take years until they ensure the new 2J or 3J cells can be properly protected by harsh environment [4][5][6].

One possibility is to provide environment-protected packaged III-V concentrator receivers. This is analogous to circuit engineers who design complicated circuit by using packaged IC devices without paying much attention to semiconductor physics and the reliabilities of semiconductor chips.

2 PACKAGING TECHNOLOGY

A new packaging structure for III-V concentrator solar cells was developed, applicable mainly to Fresnel lens concentrator modules but may also be used in dish concentrator systems. The solar cell used in the new receiver package was III-V 3J concentrator solar cell developed by SHARP. It was grown on a fragile Ge substrate with thickness of only 150 um. The overall size was 7 mm X 9 mm with 7 mm square aperture area (see Fig. 1).

The 1st step was to solder tab sheets to the cell chip. It is common to use soldering technologies to connect the concentrator solar cells to the back electrodes.

The key technology we introduced was soldering the front tab directly to the fragile cell chip. The commonly adapted technology is wire-bonding or silver-epoxy bonding. These are convenient for avoiding damage to the fragile concentrator cells. However both of them have higher contact resistance and may not be scaled to higher concentration ratio. The wire bonding technology has a problem of re-crystallization of the wires at high current density. The silver-epoxy bonding showed decrease of the contact points and increase of the series resistance after heat cycling.

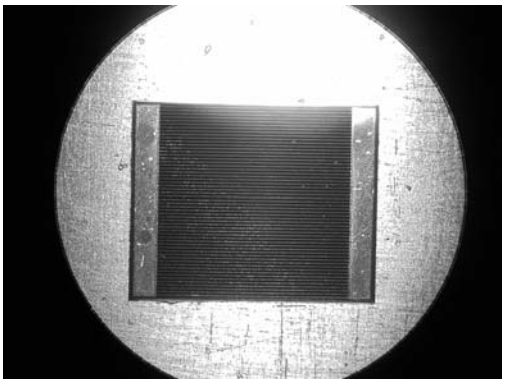

Figure 1: Bare III-V 3J concentrator chip.

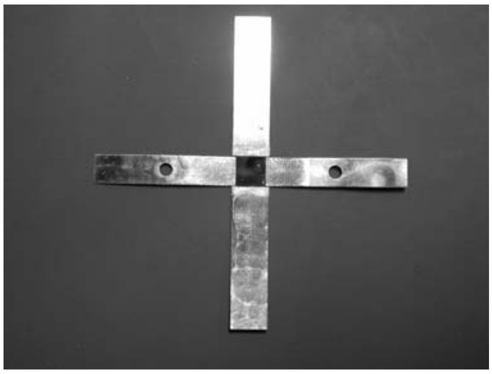

Figure 2: Step 1, Soldering tab sheets

The 2nd step was the lamination of the solar cell to the aluminium base plate (see Fig 2). The material for laminating the solar cell to the base plate was heat conductive epoxy. It contained a heat conductive medium uniformly dispersed to the epoxy. One of the difficulties of this process was heat conductive epoxy required an extremely high pressure to bond the solar cell. Since the solar cell was fragile 150 um thin germanium, it cracked or became damaged only by handling with a stainless steel tweezers. Precise control of pressure and temperature was essential.

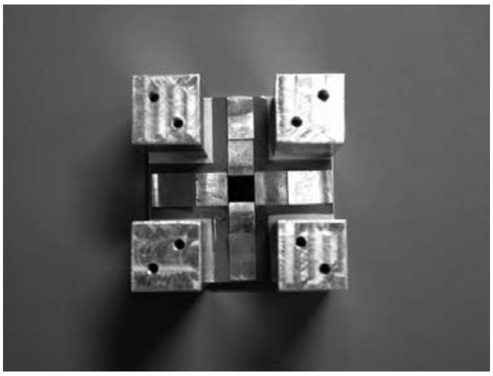

Figure 3: Step 2, Lamination to aluminum base-plate

Thanks to the well-controlled process, the temperature rise on the cell surface remained 6 K with current 400 X (geometrical concentration ratio) application with yet maintaining good electrical insulation. The insulation capability is minimum 2.0 kVp. Various environment test, including hot-wet, heat cycling and freezing cycling test described in IEEE Standard 1513-2001 did not decrease endurance voltage less than 2.0 kVp.

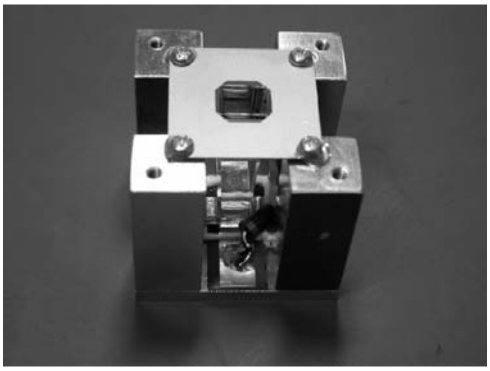

Figure 4: Step 3, Assembly of a homogenizer and etc.,

Finally, some components were assembled depending on the applications (see Fig. 4).

For HCPV applications more than 200 X geometrical concentration ratio, a homogenizer is strongly recommended. The homogenizer is an optical kaleidoscope optics that mixes the concentrated rays into well-defined square and uniform concentrated flux [7]. This is an essential optical device for III-V multi-junction solar cells whose efficiency drops sharply by chromatic aberrations of the lens or excessively concentrated flux. Another advantage of the homogenizer was the enlarged mechanical assemble tolerance (see Fig. 5). Common technologies optical alignment procedure in fabrication of concentrator module, so that the concentrated spot is well-aligned to the cell centre and will collect all concentrated flux. The new technology with the homogenizer allowed normal assemble technology common to various machines and did not require optical alignment technique.

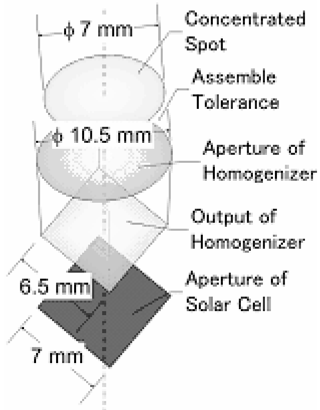

Figure 5: Assemble tolerance with the homogenizer

Another important component was the sealing polymer for the solar cell. A special material with examined treatment was chosen to completely isolate the environmentally sensitive III-V solar cells from moisture. The endurance against concentrated flux or UV as well as compound stress with water condensation is now being examined.

Finally, a bypass diode was added to avoid hot-spot degradation as well as electro-static damage.

The new receiver also took care of cooling the solar cells. The common technologies for mounting concentrator solar cells is to place the cell onto a ceramic substrate with a DBC (Direct Bond Copper) pad and the ceramic substrate bonds to the module body. This structure, however, has two insulation layers, one for ceramic substrate and another for glue, before spreading concentrated heat flux. The heat resistance from the solar cell to the heat spreader will be inevitably high. The new structure used only a single layer of insulator, namely heat conductive epoxy, doing both electrical insulation and bonding, kept heat resistance substantially lower than the conventional structure.

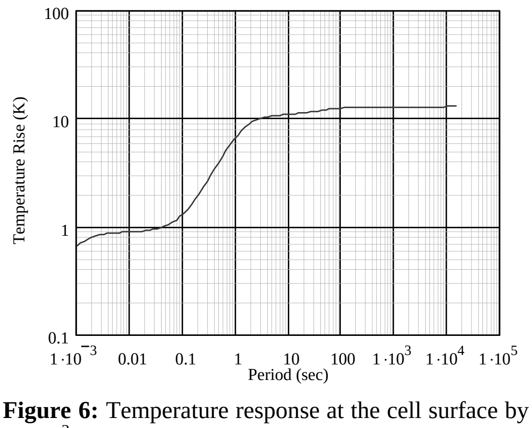

Figure 6: Temperature response at the cell surface by 50 W/cm^2 step irradiance

This simple structure had the advantage not only as steady-state heat conduction but also transient heat conduction. The concentrated heat flux dissipated in about 1 second (see Fig. 6). This rapid response was fast enough to handle the concentrated heat step result from movement of clouds around the solar disk.

The power output of the receiver was evaluated outside (see Fig. 7). The efficiency was 27 % without cooling in a hot summer day.

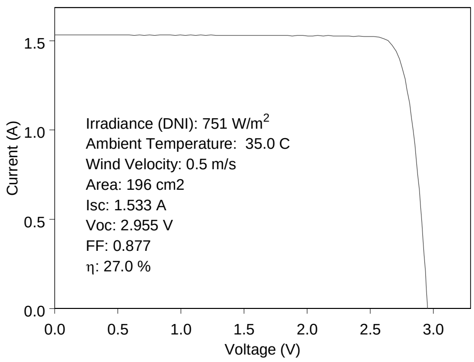

Figure 7: Outdoor evaluation of the receiver in a hot summer day

3 TERRESTRIAL APPLICATION

With these concentrator receivers, various concentrator modules were easily designed and fabricated including 200 Wp module connecting all 36 receivers in series and demonstrated small mismatching losses (see Fig. 8)

Figure 8: 200Wp concentrator module

A total of 6 modules were fabricated and tested in two sites, Inuyama and Toyohashi. Thanks to the high-efficiency concentrator receivers, the new module exhibited high efficiency during clear sky day. Both Inuyama and Toyohashi site recorded 28.1 % (after temperature correction to 25 C). Considering the uncertainty of measurement of direct normal irradiance, the peak efficiency will be 26.8 plus or minus 1.5 % (see Fig. 9).

Measurement error in DNI is a well-known problem for scientists measuring solar irradiance. Since the module efficiency is high, a ten percent measurement error of DNI moves as much as three points of the efficiency value. In order to avoid DNI problems and make a fair comparison among the current available technologies, daily power output was compared with that of a commercial multi-crystalline silicon module (see Fig. 10). The power output on Oct 15 by the concentrator module was 1.79 kWh/m2, whereas the power output from the commercial M-Si solar panel was 0.62 kWh/m2. The power generation per area was about three times of the commercial flat-plate module.

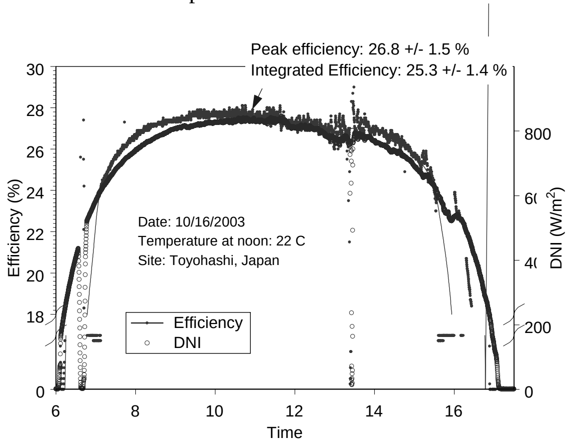

Figure 9: Typical power output in a clear sky day

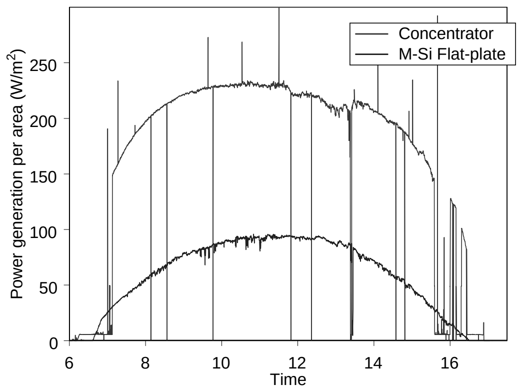

Figure 10: Typical power output in a clear sky day

One of the promising applications for this type of the module is apartment rooftop. The module covers about a third of the rooftop area that a flat-plate module would need to provide the same energy. The apartment rooftop market, becomes one in which the limited rooftop area and higher occupancy are constraints that this concentrator module can meet.

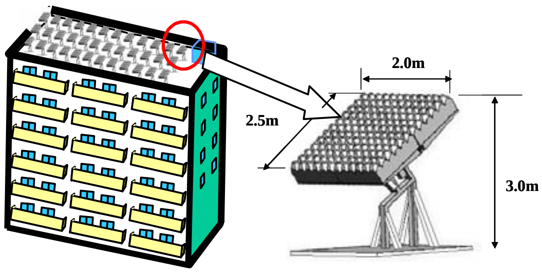

Figure 11: Rooftop application on apartment houses

The new concentrator receiver will be able to be applied to a dish system beside the above-mentioned Fresnel lens system by laminating many cells with small spaces and expanding its aperture by homogenizers (see Fig. 12)

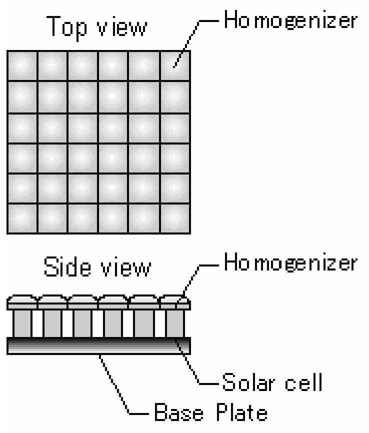

Figure 12: Dense array for a dish system

4 SPACE APPLICATION

These technologies will be able to be applied to high concentration PV in space. Fig. 13 shows rough design of low-weight receiver structure with a homogenizer and heat dissipation structure. 1 mm thick two-layer graphite is sufficient to diffuse the concentrated heat as 15 K temperature peak (see Fig. 14).

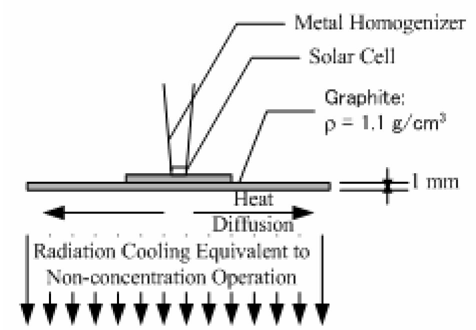

Figure 13: Design for space 500X concentrator receiver – low weight and sufficient heat dissipation

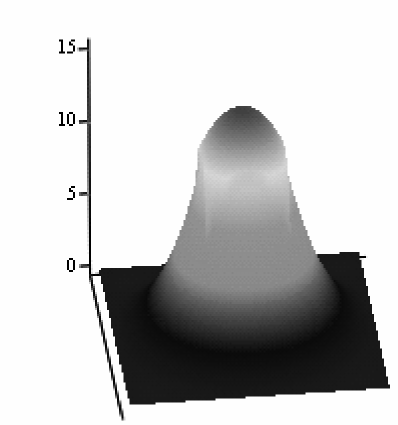

Figure 14: Temperature diffusion in the base plate made by low-density graphite. The maximum temperature rise to the reference was calculated as 15 K.

5 CONCLUSION

A new concentrator packaging technology was developed. With this newly-developed receiver, mechanical engineers will be able to design their own concentrator module by their mechanical knowledge suitable to their local industrial resources and environment. This technology is expected to open a door to new local mechanical industries. The situation is similar to the computer assemble industries and automobile assemble industries where key components are imported and main bodies are assembled using local technologies.

6 ACKNOWLEDGEMENT

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Daido Steel Co., Ltd.
attn. Kenji Araki
Tel. +81-52-611-9426, Fax + +81-52-611-2199
E-mail: k-araki@ac.daido.co.jp