

Comparison Of GaAs (III-Vsemiconductors) And Si Vertical Multijunction Solar Cells, As The Converters In The Power Beaming Systems

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Abstract: In electricity transmission systems by the laser radiation, the GaAs photovoltaic converters with more than 50% efficiency are used. Recently the VMJ also has been studied for the monochromatic light conversion into the electricity. Here, these technologies and their application in electricity transmission systems, have been studied and evaluated. The processing method, structure and conversion efficiency have been compared. Results prove that VMJ silicon solar cells along with concentrator have the high conversion efficiency equal to 43% for the monochromatic light with 975 nm wavelength. Although the GaAs cells along with concentrator have the 58.3% conversion efficiency. Considering the complexity and processing costs the silicon cells have the better situation, however if the concentrator is presented in production process, there is not considerable difference between them.

Keywords: Optical Power Transmission, GaAs, Vertical Multijunction, Diode Laser

I. Introduction

Optical power transmission (OPT) is a suitable method that the Copper wiring can be replaced by the optical fiber or even the air as the medium. This replacement is justifiable because of the reasons such as short circuit danger and sparkle of power transmission lines by the copper wires or the thunderbolt clash to the power lines (Oliva, 2008). Also this replacement allows to transmit the information and energy via one signal simultaneously. The OPT system consists of 3 parts as it can be seen in figure 1.

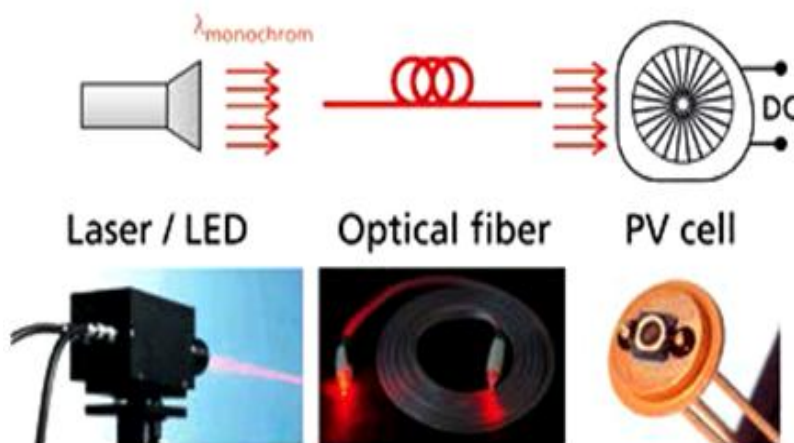


Fig1. The OPT system structure (Helmers, 2014)

The electricity can be transmitted as photons and via the optical fiber or the air. For this aim a Monochromatic light source is needed such as laser. Because the bandgap of photovoltaic converters can be set with an especial wave length, the Monochromatic light can be converted to the electricity by a solar cell with higher conversion efficiency than the solar radiation. Especially the GaAs in this domain is highly regarded by the researchers. The III-V Semiconductor's bandgap can be changed well by the elements compound. In Fraunhofer ISE, the desired wavelength have been achieved for each semiconductor via the III-V elements combining. In table 1 some of these cutoff wavelengths have been shown in 300 °K.

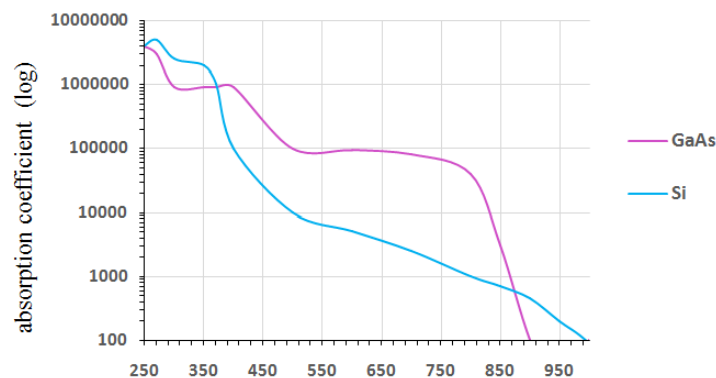
Table1. The III-V elements ratio in corresponding cutoff wavelength and compounds (Helmers, 2014)

The element's ratio	Cutoff wavelength
Ga _{0.51} In _{0.49} P	660 nm
GaAs	870 nm
Ga _{0.83} In _{0.17} As	1050 nm
Ga _{0.16} In _{0.84} As _{0.31} P _{0.69}	1100 nm
Ga _{0.47} In _{0.53} As	1680 nm
GaSb	1700 nm

II. Si And GaAs Comparison, Used In Optsystems

The GaAs mineral structure is similar to diamond cubic crystal structure with zinc blend crystal structure. The lattice constant of GaAs and silicon are equal to 0.565 nm and 0.543 nm and their density are 4.42×10^{22} and 5.0×10^{22} respectively (Smets, 2016).

GaAs is a semiconductor with direct bandgap equals to 1.42 eV while the silicon is a Semiconductor with 1.12 eV indirect bandgap. In optical power transmission systems the most important part is the state of coupling or correlation between the bandgap and laser monochromatic wavelength (Helmers, 2014). According to graph 1, the GaAs absorption coefficient in visible and Infra-red spectrum is not only bigger than silicon but also has a steeper slope. It means that GaAs and other III-V semiconductors will be better coupled with diode laser's monochromatic radiation (790-840 nm).



Graph 1. Comparison of the silicon and GaAs absorption coefficient

III. The GaAs photovoltaic converters

The GaAs photovoltaic converters made of III-V semiconductors will be coupled well with monochromatic laser radiation, because of their bandgap structure and Adjustability. These converters have single-junction structures and especially designed for the better coupling with considered wavelength. Shan (2015) designed an optimum structure that had the 61.8% efficiency in theory at 840 nm wavelength (fig 2).

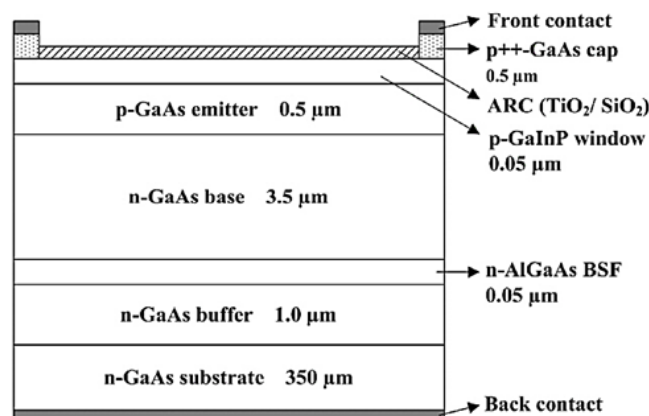
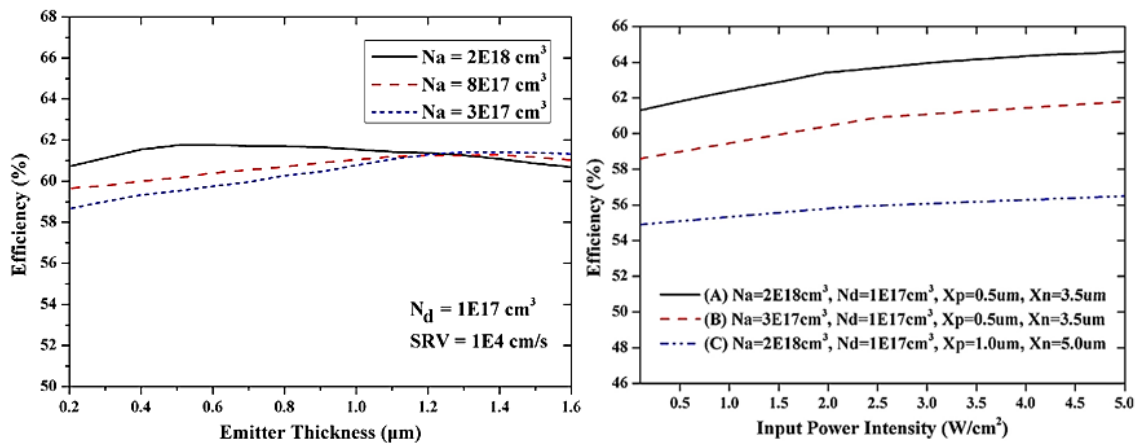


Fig2. The optimized structure of photovoltaic converters with n-AlGaAs BSF layer. (Shan, 2015)

Before the experimental works, Shan simulated an optimized model by a 1-D finite element program (PC-1D) and variable amount such as layer thickness, dopant concentration, wavelength of 790-840 nm and incident radiation equal to 0.1 to 5 wat/cm². They obtained an optimum thickness of 3.5μm for base layer or n-GaAs. Thinner base layer doesn't able to collect enough transmitted photons from the emitter layer and actually

with thicker thickness will rise the resistivity of equivalent circuit series resistivity. Considering the graph 2 and 3, the low doping decreased the open circuit voltage and Conversion efficiency consequently. On the other hand the high doping decreased the generated carrier's distribution and consequently the short circuit current.



Graph2. The efficiency of GaAs photovoltaic converters against the right: laser radiation incident power and left: Emitter thickness in micron (Khostikov et al., 2014 and Khostikov et al., 2015).

The modeling calculations revealed that the most efficiency will be occurred that dopant concentration in emitter and base layers are $2 \times 10^{18} \text{ cm}^{-3}$ and $1 \times 10^{17} \text{ cm}^{-3}$ respectively. Also the emitter and base layer thickness is 0.5 and 3.5 µm respectively. In this situation, surface recombination velocity, SRV, has been obtained equal to $1 \times 10^4 \text{ cm/s}$. finally a prototype has been provided by the MOCVD method. Table 2 shows the converter's electrical operation characteristics. The best wavelength of laser based on simulation, is 840 nm. However in 750 to 855 nm spectrum more than 50% efficiency is still accessible. Mukherjee et al (2013) studied the conversion efficiency by making of an InGaAsP/InP Multi-junction structure.

Table2. Electric properties of made prototype (Shan, 2015)

Pin (W)	ISC (A)	VOC (V)	Imax (A)	Vmax (V)	Fill Factor	(%)η
0.5	0.272	1.122	0.262	0.991	0.851	51.93
3	1.666	1.127	1.594	0.994	0.844	52.81
5	2.793	1.135	2.653	1.001	0.840	53.23

Above values can be extracted from the I-V curve. Khostikov et al (2015) designed a photovoltaic converter as AlGaAs/GaAs and provided it by the Liquid Phase Epitaxy (LPE) method. This converter has been designed and produced for the high radiation power Conversion in wavelength of 809 nm (fig 3).

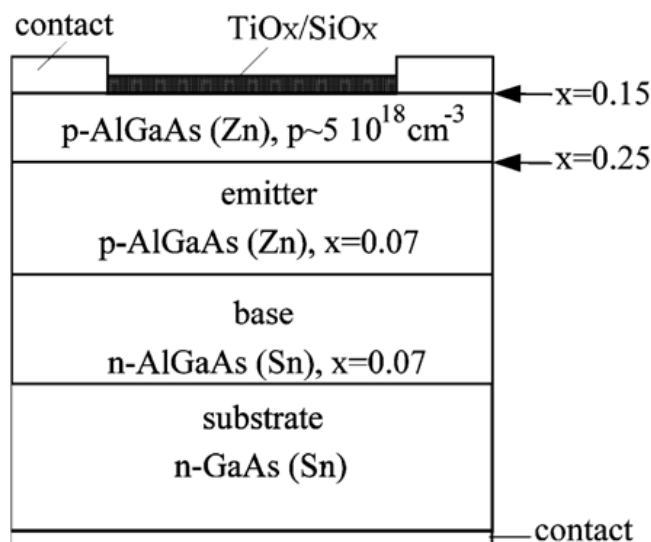
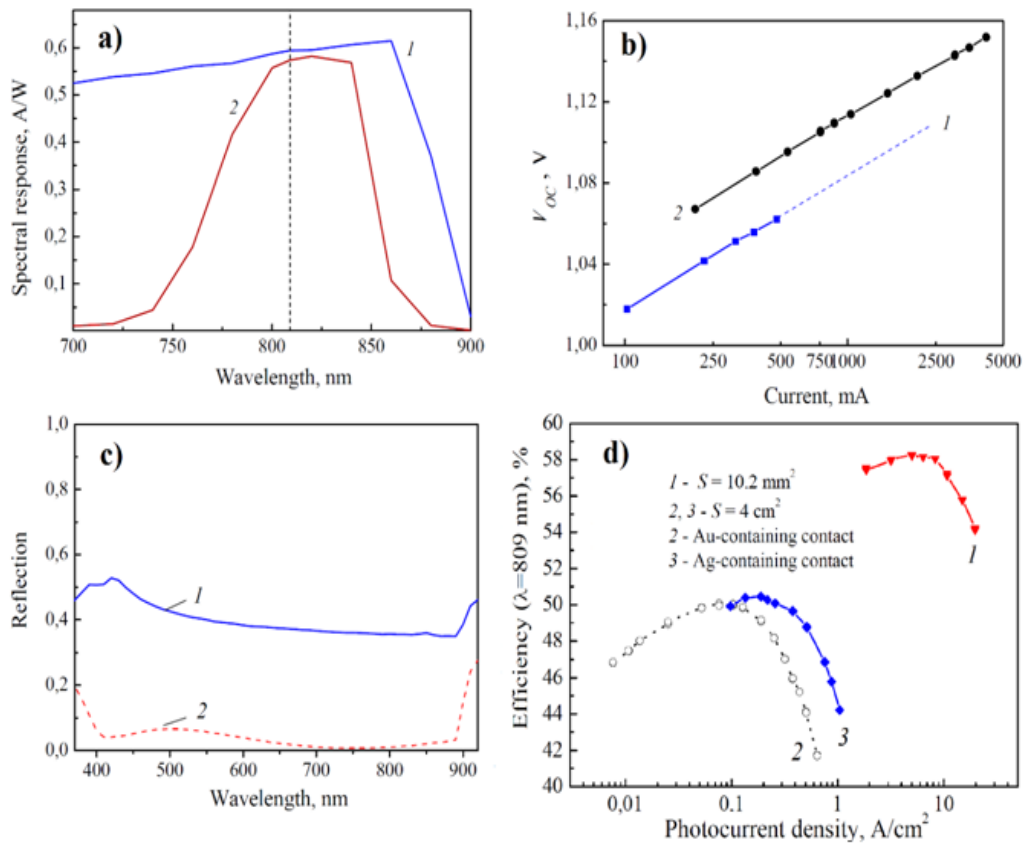


Fig3. Photovoltaic converter's structure for coupling with high power laser with wavelength of 809 nm.

Indeed the main work of Khvostikov et al was determining of photosensitivity in various layers in wavelength of 809 nm. Here the p-n junction is designed as $Al_xGa_{1-x}As$ that x is equal to 0.07. Unlike the conventional multijunction structures, there is no need for the photosensitivity towards the short wavelength in upper cell or window layer. Considering the figure 3 it is obvious that the aluminum density in window layer, which has a good photosensitivity to the short wavelength, is decreased from 0.25 to 0.15 by moving from down to the front contacts.



Graph3. a) Spectral response of conventional PV converters (1) and Laser PV converters (2). b) Comparison of the open circuit voltage in conventional PV converters (1) and Laser PV converters which is made by LPE method (2). c) Reflection coefficient for converters with (2) and without (1) TiO_2/SiO_2 ARC. d) Conversion efficiency for Laser PV converters with, smaller area (1), large surface area and gold contacts (2) large surface area and silver contacts (3). (Khvostikov et al., 2014 and Khvostikov et al., 2015).

One of the Aluminum low density benefits at junctions, shows the junction situation improvement and decreasing the amount of surface recombination (Khvostikov et al., 2014 and Khvostikov et al., 2015). Similar to Shan et al, here the TiO_2/SiO_2 anti-reflection coating (ARC) has been used for the diminishing optical losses. Khvostikov et al investigated performance differences, especially in spectral response and open circuit voltage, between solar cells and laser photovoltaic converters, which is made via LPE method.

Conversion efficiency related to laser photovoltaic converter in graph 3-d shows that depend on cell surface area the efficiency changes from 50% to 58.3%. Decreasing the cell surface area the conversion efficiency has been increased. This efficiency increasing has been attributed to the series resistance decreasing and increasing of cell equivalent shunt resistance and also the heat loss decreasing. Also the Ohmic resistance reduction at metal-semiconductor junction due to material changes and thickness increasing, caused the improvement output properties such as output current density.

IV. The vertical multijunction Si photovoltaic converters for the high intensity radiation

The structure of VMJ silicon photovoltaic converters have the different structure than the conventional structures. These cells have been designed for the intense incident radiation and especially monochromatic ones. As it can be seen in figure 4 the structure consists of many series junctions as it can provide low resistivity. On the other hand the series cell junctions present the high output voltage and low output current that made it suitable for using under concentrated radiations. Indeed one of the most considerable benefits of this technology is the high produced voltage (Nayfeh, 2008).

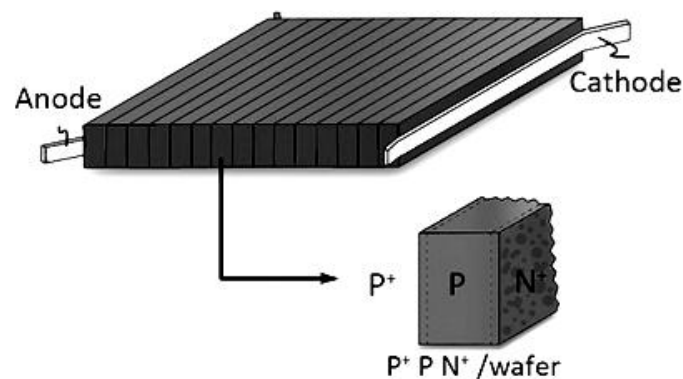


Fig4. VMJ converter structure for the monochromatic and concentrated radiations (Nayfeh, 2008)

Nayfeh et al used these converters for the airplane electric engine. They achieved the conversion efficiency up to 44.39% under the 200 wat radiation and 975nm wavelength. But it can be seen that heat factor has more devastating impact on conversion efficiency. As for each linear 10 °C the conversion efficiency will reduced 2.5 %. This problem will be more critical in intense and concentrated radiation. Therefore wide researches have been done about this problem.

Tung et al suggested a solution for this problem, using two layers of Boron-Nitride and one layer of Aluminum-Nitride between them. This structure as the Thermal Epoxy, upon to figure 5, well conducts the heat from a direction of VMJ silicon cells toward the copper pipe units. This process improves the VMJ cells operation.

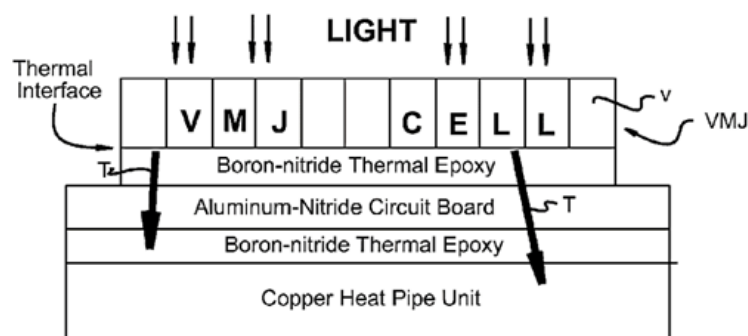
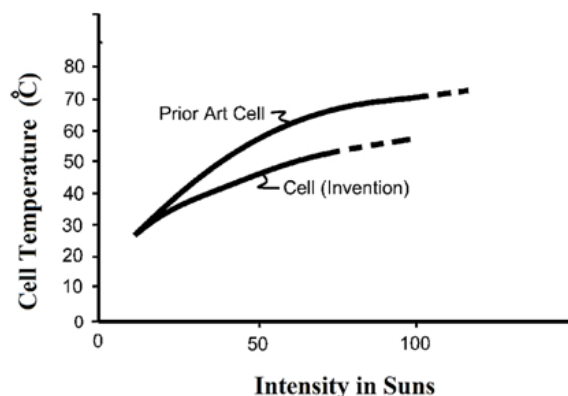


Fig5. The structure of VMJ silicon photovoltaic which is equipped with heat-conducting layers. Arrows show the flow of heat transfer (Tung, 2016).



Graph4. The temperature of VMJ cell operation as a function of incident radiation intensity

As it can be seen in graph 4, in comparing produced prototype with solar cells without this technology, the rising of temperature along with increasing in radiation intensity has a gradual slope (Tung, 2016). Perales et al (2016) designed a setup for the VMJ cells, and achieved to 43% efficiency and 31 volts density per centimeter under the laser radiation equal to 1kWatt with wavelength of 976 nm.

V. Conclusion

The OPT systems generally use of GaAs photovoltaic converters. But recently the VMJ photovoltaic converters also qualified for using in this domain. In all studies about the GaAs converters at first an optimum structure has been designed and simulated and after that it has been made. Most of simulations has been done in one dimension and therefore there are differences in operational results. The GaAs cells have higher conversion efficiency, because of their better coupling with monochromatic radiations and thermal behavior. But in situations that the higher voltage is needed, (more than 20 volts) the cells should be linked as series form. VMJ converters for this aim seems to be suitable but indeed they are suffering from power losses due to the temperature rising, however, Tung et al solved this problem, using the heat transmission copper pipes.

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