Developments in III-V multi conjunctions solar cells at high efficiency and the connection of cost and efficiency of centralized and regular cells

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Abstract: between reincarnations energies such as wind, biomass, see and other, solar energy have been attract much more attention at research institutions. Lower cost of using this energy is possible by reaching high efficiency at centralized systems. This paper discusses research approaches of III-V multi conjunction solar cells for reaching high efficiency. Metamorphic $Ga_{0.44}In_{0.56}P/Ga_{0.92}In_{0.08}As/Ge$ three conjunction cells reached 47.7% efficiency at 240sun under standard spectrum (AMI/5D, low AOD, 24w/cm^2, 25°C) and three conjunctions cells of synchronized lattice reached 40.1% efficiency at 135sun. The 3 conjunction metamorphic device is the first cell with the efficiency higher than 40%, and for any photovoltaic cell till now has the highest solar change efficiency. Many optimal band gaps for maximum energy transformation are possible with metamorphic semiconductor materials. A cost analysis shows that reaching very high efficiency for affordable photovoltaic is vital because of efficiency effect on system costs and module packing.

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1. Introduction

Photovoltaic technique which is created based on chemical elements of III and V group of periodic table shows high exchange efficiency. Understanding of getting high performance for exchange not only in theory but also in practice by developed multi conjunction solar cells caused a revival of research at this area. This work is an investigation about new development at research on multi conjunction metamorphic cells with 40.7% efficiency under central terrestrial spectrum, scientific fundamentals of these cells and also the chance of reaching an affordable point at PV systems by creating centralized III-V cells. [1-9]

2. Metamorphic III-V multi conjunction solar cells

The fundamental and different property of III-V multi conjunction cells is the wide range of bandgaps of the structures and sub cells, which can divide the solar spectrum in an optimized way. Lattice of sub cells synchronization with Ge substrate in centralized multi conjunction cell of GaInP/GaInAs/Ge is not an optimal configuration, because band gap of sub cells are so high and they cannot distribute sun spectrum in an optimal way. An uncoordinated lattice plan or metamorphic or MM is more optimal, because it removes the limitation that all sub lattices had to have the same lattice constant. In this study sub lattice band gap decreased and an optimal spectrum split was created.

In 3 conjunction metamorphic solar cells of GaInP/GaInAs/Ge , sub lattices of GaInP and GaInAs can be grown on a metamorphic buffer. So these sub cells would be matched as far as crystal lattice point is concerned, but both would be unmatched to sub lattice and Ge substrate. Figure 1 shows combination of GaInP and GaInAs sub cell band gap at a lattice constant based on Ge substrate [10]. Diagram of the case with one sub lattice of III group which is irregular at sub cell of GaInP which had a higher band gap at GaInP, and also the diagram of a one sub lattice of II group which is regular at sub cell (low Eg) had been drawn. Metamorphic cells can close the cell plan to the space area of Eg_2, Eg1, which has the highest theoretical performance.

Figure 1 also shows the real effects of decrease at 3 conjunction cell V_{oc} by recombination of Shaklee-Rid-Hall (SRH) in addition to radiation recombination.

At metamorphic cells in addition to radiation recombination, SHR recombination appears because of the disorder density due to lattice imbalance. At past recombination at disorders at MM materials mostly had the promise of higher theoretical performance impossible, but based on recent result of cells with 40.1% performance and metamorphic cells with 40.7% performance of figure 1, disorder density and activation was controlled to improve the performance of MM plan, not only in theory but also in practice.

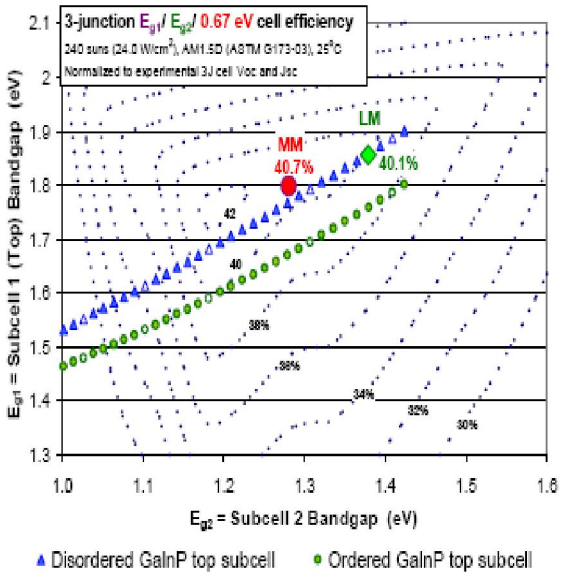

Figure 1. Curves of 3 conjunctions centralized cell as a function of Eg_2, Eg1

Figure 2 shows a schematic diagram of LM and MM cells, which metamorphic buffer used in MM case are for transition from substrate lattice constant to upper sub cells lattice constant.

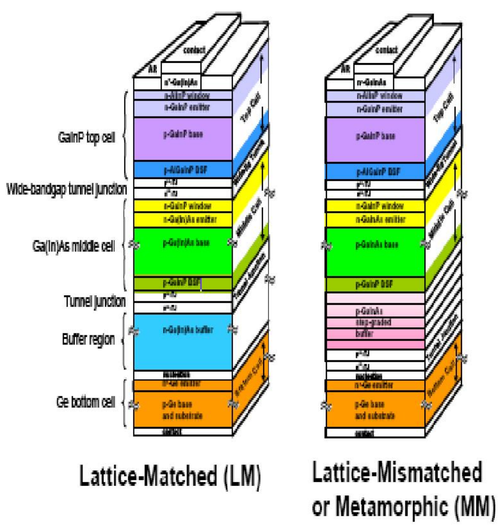

Figure 2. Schematic diagram of LM and MM cells

Figure 3 shows lattice constant and traction at different layers of 3 conjunctions MM cell of $Ga_{0.44}In_{0.56}P/Ga_{0.92}In_{0.08}As/Ge$ at the mutual space map (RSM) of X ray diffraction with high resolution (HRXRD)[11,12].

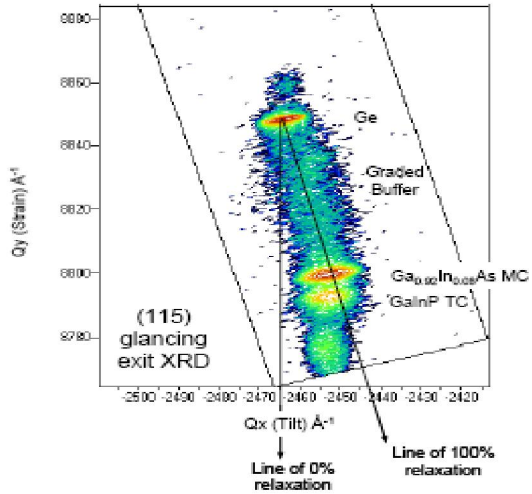

Figure 3. X-ray diffraction space map with high resolution

An imbalance of an indefinite lattice, higher performance in most multi conjunctions cell plans can be reached if the band gap of GaInP upper cell increased. In this was less light is needed to permeate through GaInP to underside GaInAs, and at the higher voltage of upper GaInP cell more transform would be done. Disorder or disassemble of Ga and In atoms on sub lattice of III group, would lead to increase of band gap to about 100 mV at harmonic lattice, this effect would remain at disassemble combination of lattice too. Figure 4 shows the order and disorder GaInP cell [13].

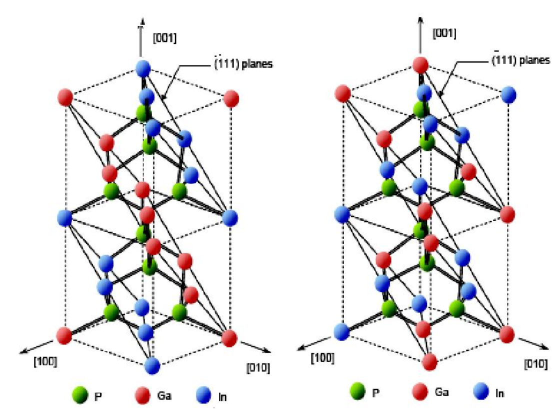

Figure 4. Sub lattice of III group at GaInP a) ordered, b) disordered

Figure 5 shows the changes at quantum performance of 3 sub cells at GalnP/GalnAs/Ge 3 conjunctions cells as a result of a lower band gap of GalnP and GalnAs sub cells of metamorphic plan. So MM cells can keep and save current density otherwise it would have been lost at Ge sub cell at a harmonic plan of lattice. Quantum performance and solar spectrum, low AOD, can cover AMI/5G and AMI/5D to show current densities at response range of sub cells.

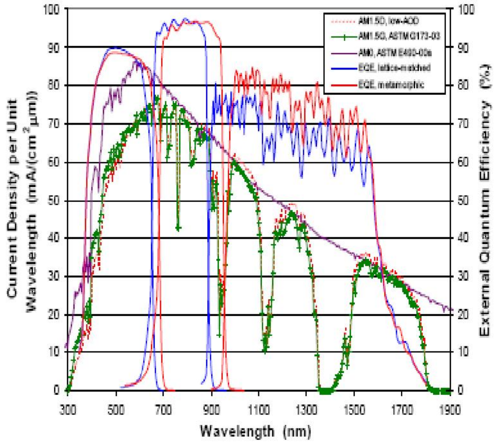

Figure 5. Quantum performance of 3 sub lattice at GalnP/GalnAs/Ge 3 conjunctions cells

Figure 6 shows I-V optical curve which was measured for metamorphic GaInP/GaInAs/Ge 3 conjunctions cell with 40.7% efficiency at 240sun under standard spectrum for centralized solar cell (AMI/5D, low AOD, 24w/cm^2, 25°C). This is the first solar cell with an efficiency more than 40% and higher performance of solar change for any photovoltaic device till now.

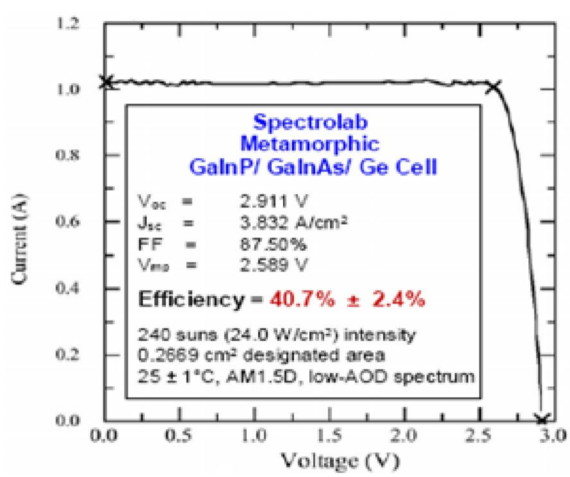

Figure 6. I-V optical curves of metamorphic 3 conjunctions cell with 40.7% efficiency

3. Relation of efficiency and cost at centralized and regular cells

Figure 7 shows the higher cellular performance of some technologies at the years of 1975 to 2000 in a diagram and it shows the recent cellular efficiency of 40.7% [14].

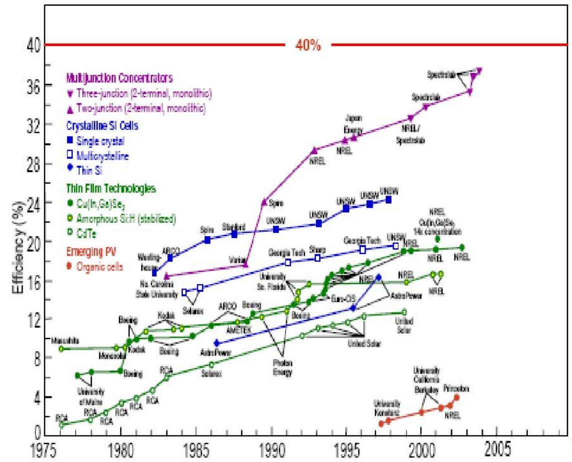

Figure 7. Efficiency for a photovoltaic technology range

Affordable flat page systems are needed at the range of 0.1 10 1 Cent cost cells per any cm^2 for cells with 20% performance, while for centralized systems with 30% performance cells per any cm^2 with the cost of 1to5 Dollar are needed. The best way for an affordable photovoltaic is to pay attention to cell performance at the range of 40% to 50 %, which metamorphic $Ga_{0.44}In_{0.56}P/Ga_{0.92}In_{0.08}As/Ge$ 3conjunctions centralized solar cells with 40.7% efficiency can be the best affordable one.

This high performance is very vital for PV economy, because it decrease all costs related to module level. Tracing, system balance (BOS), module optical performance and cost difference for centralized and flat page systems and cell variable cost are calculated. Figure 8 shows the diagrams of average electricity cost by Dollars per kilowatt per hour ($/kWhr) for 5 years. It shows that both centralized and flat page systems can reach a low cost point of 0.15$/kWhr with some combinations with high performance and low cell cost.

Two categories of curves can be seen at figure8. One category of flat page systems which have very low cellular cost and another category of centralized systems which higher cellular cost is acceptable for them. With lower performance at 12% for flat page systems and 20% for centralized systems, PV system cannot be affordable even with zero cost for cells, which is because of module packing cost, BOS, and same costs.

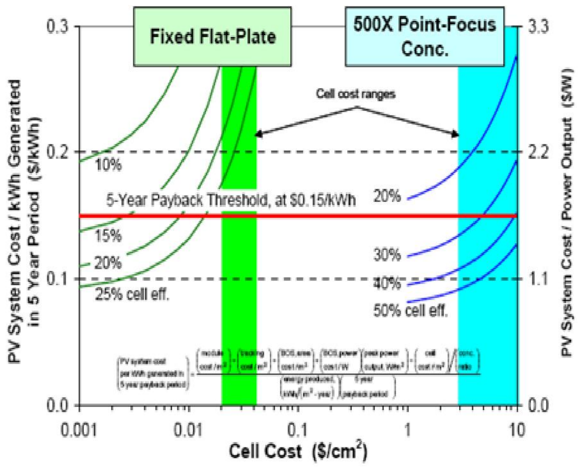

Figure 8. Average electricity cost for 5 years on $/kWhr as a function of cell cost per surface currency.

4. Conclusion

GaInP /GaInAs/Ge multi conjunctions solar cells with 40.7% performance with semiconductor metamorphic technology, and with 40.1% for synchronized lattice cells were determined. These are the first solar cells which go up turning point performance of 40%, and have the higher solar change performance in comparison o other photovoltaic devices which were made till now. These high performances of tentative cells are transferring to solar cells.

Metamorphic materials have more freedom in choosing bond gap. Wide band gap of upper cell which appears due to disorders of III group sub lattice, increase the efficiency of these cells.

Efficiency higher than 40% of III-V multi conjunctions cells can make centralized PV technology very effective at the economy of PV electricity production at near future.

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