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A new structure in Tandem Solar Cells

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ABSTRACT : *In this paper, we introduce a new structure for AlGaAs/GaAs Tandem Solar Cells as AlGaAs/InSb/GaAs. In typical structures, cells build on top of each other from higher to lower energy band gaps, respectively with tunnel junctions between them. Therefore, high energy photons are absorbed in upper layers and lower energy photons in bottom layers. Tunnel junctions guarantee low ohmic resistance. Due to its low ohmic resistance, a thin layer of InSb is proposed here to replace the tunnel junctions. Some disadvantages such as light absorption in these narrow band gap layers and lattice mismatch are present but very low ohmic loss with typical doping, and wide range of short circuit currents that we can choose for these cells are major advantages achieved.*

Keywords**:** *Alga As/GaAs, InSb, MBE, Tandem Solar Cells, Tunnel Junction*

I. INTRODUCTION

Using Tandem solar cells is one of the methods for achieving high efficiency in transforming solar energy into electricity [1]-[8]. Solar cells made from III-V semiconductors can be arranged in a cascade architecture which increases their efficiency [9]-[14]. A tunnel diode structure is thus normally used [9],[10],[12],[13],[14].

The optical and electrical losses of these diodes must be as low as possible in order not to affect the increased efficiency of the cells. A small thickness of cascaded layers and large rates of I_p/V_p can lower the optical and electrical losses, respectively [12],[15].

On the other hand, in the process of tunnel diode production, high density of dopants will result in crystal defects and light absorption. Also unwanted diffusion of impurity atoms may occur when subsequent layers are grown [12].

InSb has a very small band gap resulting in such a large number of intrinsic carriers that diodes built with InSb do not act properly at room temperature unless they are designed under special conditions [16]. These diodes are Appropriate at cryogenic temperature and their PN junction has a very small resistance at room temperature.In the case of producing a triple junction cell, GaInP/GaAs/Ge structure seems appropriate [11]. Ge can be used as a suitable substrate in this formation. Ge has the advantage of providing a PN junction at normal working temperature while its lattice constant matches well with GaAs. InSb is not a good choice as a substrate in such structures and would not work properly because it does not play any role in energy production and also due to its large mismatch will cause many defects in the formation of the upper crystal lattice.

In this research, the first step is considering a double junction Tandem solar cell with AlGaAs/GaAs structure whose efficiency was 28% [12] and simulating its energy bands structure. Then considering the limitation of current density related to the tunnel diode used in this structure, it was replaced with an InSb diode. Finally, this New Formation was simulated. The results are explained in detail in the following sections.

II. OVERALL VIEW OF THE DESIGN

Fig. 1 illustrates the structure of a tandem AlGaAs/GaAs double junction solar cell. The GaAs tunnel diode with a 30 nm thickness provides electrical connection Between AlGaAs and GaAs cells. In order to lower the effect of the p-type region impurities diffusion, C is applied instead of Zn. However in the thermal process of AlGaAs cell production, Current- Voltage behavior of this tunnel diode becomes more non-ideal and current density peak decreases [12]. This fact is shown in Fig. 2.

Previous works on the MBE growth of a PN junction with InSb and corresponding simulations have shown that at 300°K when a small reverse or forward bias is applied, a considerable current density would be achieved. Having noticed these results, the idea of using such a diode instead of a tunnel diode in Tandem solar cells was formed.

In order not to change the overall structure and to compare the results more precisely, the thickness of layers is kept unchanged. The AlGaAs layers with large amount of Al which helps to reduce the undesired diffusion of impurities are used. In addition to different semiconductor types and doping densities, the mentioned diode was applied in a different direction. Since in the typical structure and near zero volts, tunnel diode permeates current in both directions, P^+ layer is placed above P layer of GaAs cell. So PN^+ is not formed in this point and would not obstruct photo current flow of the solar cell.

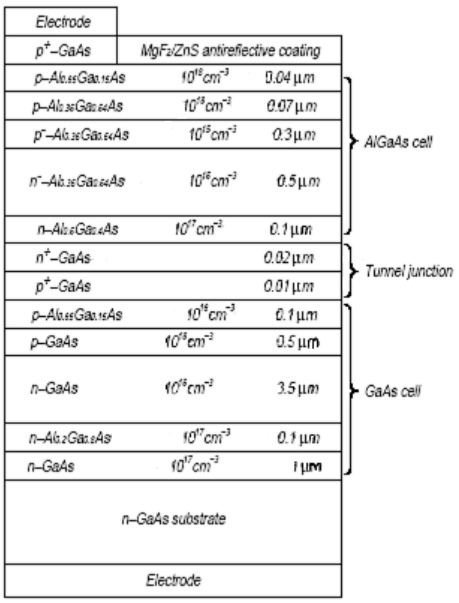


Fig. 1. A double junction AlGaAs/GaAs tandem solar cell with 28% efficiency

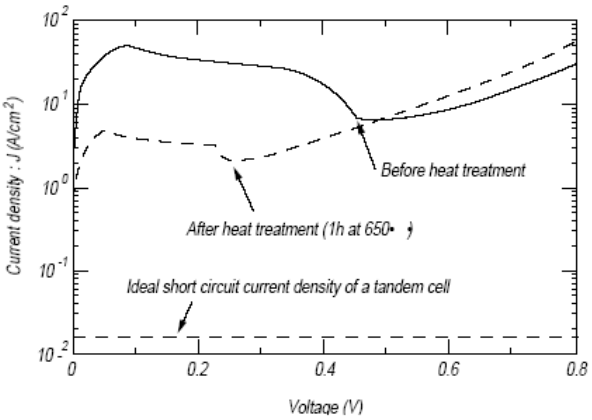


Fig. 2. GaAs tunnel junction I-V characteristics after and before heat treatment

The N^+ region of the tunnel diode is placed under the AlGaAs N layer so P^+N diode is not formed in this point, therefore there will be no problem in solar cell function during light absorption and photo current generation. In fact this is the main advantage in using tunnel diode in Tandem structures.

In our studied structure (Fig. 3), a diode is applied in such a form that the whole design is similar to a Tandem triple junction. Thus if the optical flow was generated in this sector, however slightly, it would not be in the opposite direction to the current in the other sections and would not decrease the solar cell's V_{oc}. Also, no section of this junction forms a diode at room temperature and therefore it doesn't block the photo current.

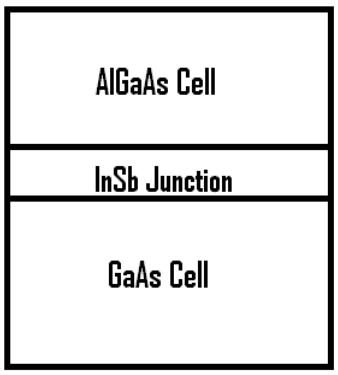
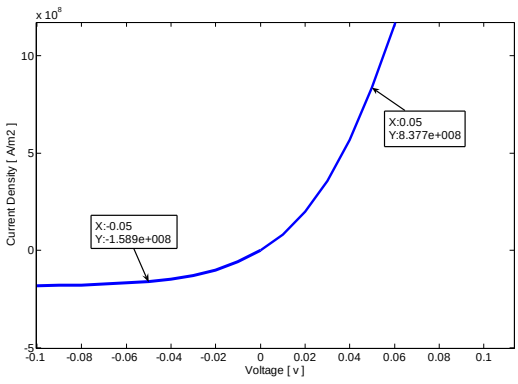
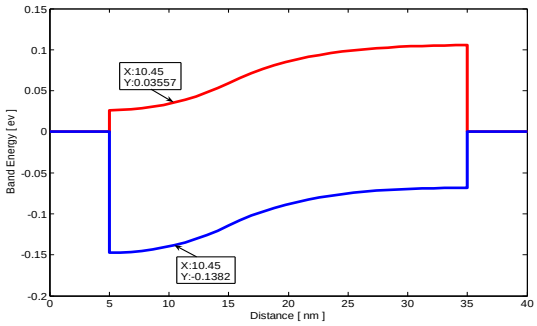


Fig. 3. New structure for tandem solar cell



(a)



(b)

Fig. 4. (a) I-V characteristic and (b) band diagram of InSb PN Junction at 300˚K

Another major advantage here is that there is no need to use very high density of impurities, unlike what is required in the tunnel diode.

Thus the undesired effect of impurity diffusion during the process of producing other sections and thermal procedures is reduced. Fig. 4-a shows part of the current-voltage characteristic obtained from simulating InSb PN junction at 300 degrees Kelvin.

Layer thickness of N and P are 10^{nm} and 20^{nm} respectively. The density of impurities is considered to be $10^{18}/cm^3$ in both sections. Impurities used for the P region are Be atoms with an acceptor band 26^{mev} higher than valance band. For the N region, donor atoms with a donor band very close to conduction band are considered. The energy band structure of the junction is illustrated in Fig. 4-b. As can be seen in this figure, the band gap of InSb has a small value of 170^{mev} at room temperature. Fig. 2 shows that even at best condition, which is before heat treatment process, the current density peak of GaAs tunnel diode doesn't reach 100 A/cm^2. The peak current density is obtained for a voltage of 0.1 V. This value is greater than 15000 A/cm^2 for InSb junction at 0.05 volt reverse bias (Fig. 4-a).

It is predicted that in case of an InSb junction instead of a tunnel diode, the results of V_{oc} and subsequently the performance will be better. In order to examine this issue, solar cells of section (I) were simulated. First the GaAs cell which is the lower section of the discussed structure, was analyzed. Energy bands and current- voltage characteristics of this diode were obtained by numerical solution of Poisson equation with Newton's method using Simba-2 model for electrons and holes mobility and ignoring quantum effects. Results are observed in Fig. 5-a and Fig. 5-b.

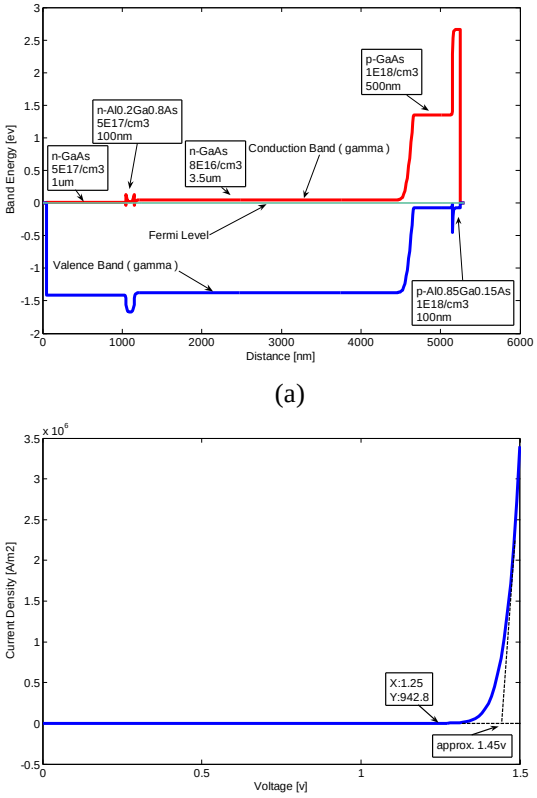
However, the diode in Fig. 5 is not a simple GaAs diode and according to necessities of production is in DH form [12]. Conduction threshold was obtained at about 1.25 V from Fig. 5-b. As can be seen, the results are well consistent with both theory and practice. Simulation for the upper cell -AlGaAs diode- was also done and it's results can be seen in Fig. 6. This time, the conduction threshold obtained from Fig. 6-b is about 1.5 volts.

Since the simulation of tunnel diodes requires consideration of quantum effects and electron's tunneling, which is very time consuming and complex, in the conventional method of calculating the efficiency of tandem solar cells, the effect of all parts are added together and then

a few tenths of volts is subtracted from the total amount of V_{oc} in order to include the tunnel junction voltage drop.
Here, we have only simulated the energy band structure in the tandem solar cell shown in Fig. 1. The result of simulation and the magnified portion of the tunnel junction can be seen in Fig. 7.

Fig. 8 shows the maximum displacement in a crystal lattice of the cell of Fig. 1. We already know that AlGaAs and GaAs crystalline lattices, even for the greatest amount of Al, present a good lattice match. So not much displacement and strain in the lattice would be observed.
The maximum displacement is about 0.012 Å which agrees with the theory [18].

Certainly in practice, a lot of parameters make the final result different from what was ideally anticipated by the theory. For example, V_{oc} of the GaAs cell in Fig. 1, which is made alone, is equal to 1.047 volts in practice [12]. This value is measured to be 2.420 volts for Tandem cell. Both of these values are rather smaller than what was calculated theoretically from the simulation results.



(a)

(b)

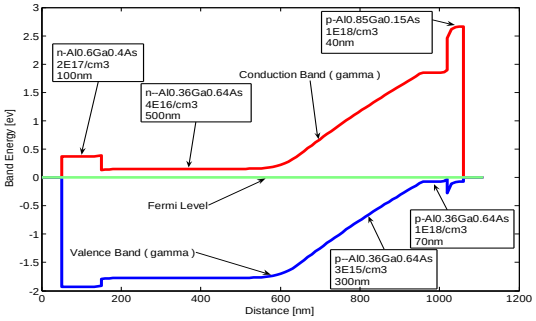
Fig. 5. (a) Band structure and (b) I-V characteristic for GaAs junction

Finally, the new AlGaAs/InSb/GaAs structure was completely simulated. Since there is no tunnel connection, we can use classical calculations for current- voltage behavior. Simulation results for the energy band structure are shown in Fig. 9. One of the noteworthy points in this regard is the modified form of the energy band in the crystal lattice of InSb caused by the exerted strain. As it is clearly shown in Fig. 9-b, the energy gap in this case has increased to about 370^{mev}.

On the other hand, energy band related to GaAs and AlGaAs diodes are modified because of the stress exerted on that region and rather above the InSb layer which is shown in Fig. 9-b. Maximum displacement in the crystal lattice is shown in Fig. 10.

As we expected, this value in the new structure was far higher than the previous structure. Finally current-voltage characteristic of the new structure was calculated by simulation with the results shown in Fig. 11.

The theoretical results show that V_{oc} of this structure must be about 3.4 volts. However, due to manufacturing limitations, of course in practice the open circuit voltage would be somewhat less. Anyway, this structure is expected to have a high efficiency.



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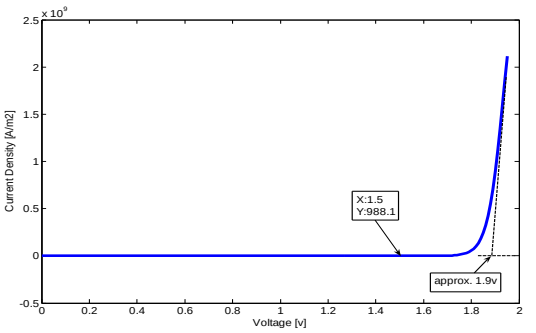


(b)

Fig. 6. (a) Band structure and (b) I-V characteristic for AlGaAs junction

III. CONCLUSION

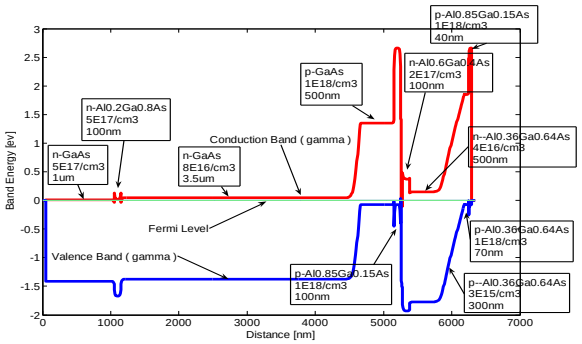
The new structure proposed for the Tandem-type solar cells can greatly benefit the market of solar energy. Cells made from III-V semiconductors are advancing rapidly but in comparison with silicon and polymer solar cells, they are more expensive. So today they are used in more demanding applications such as satellites.

However, the proposed idea was initiated by studying the characteristics of InSb layers grown by MBE in previous works and observing their ability to produce high ranges of current. By using InSb layers instead of tunnel diode in Tandem cells a new structure was invented and the simulation results confirmed its appropriate performance.

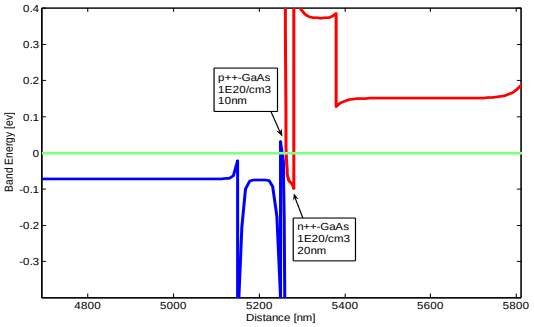
This structure has some deficiencies such as: light absorption in InSb region, formation of crystal flaws due to unmatched lattice constant of InSb with GaAs and AlGaAs, and also the possibility of damaging the InSb lattice in the case of growing AlGaAs at high temperatures. Of course, first and second cases can be effectively moderated by choosing a thin layer of InSb.

On the other hand, if the layers are grown at low temperature or smaller rate, the third problem will also be solved. Low growth rate in MBE will result in improvement

of the crystalline structure. Other growing methods such as MOVPE can also be effective in this case.



(a)



(b)

Fig. 7. (a) Band structure of tandem solar cell shown in Fig. 1 and (b) magnified portion of the tunnel junction

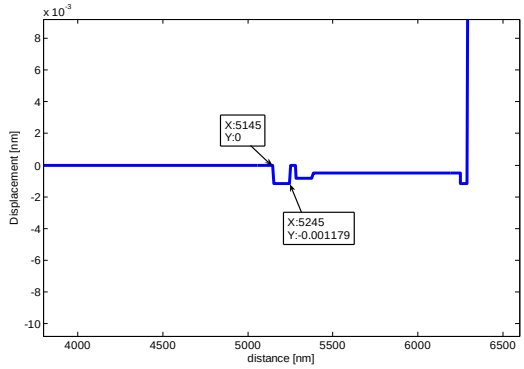
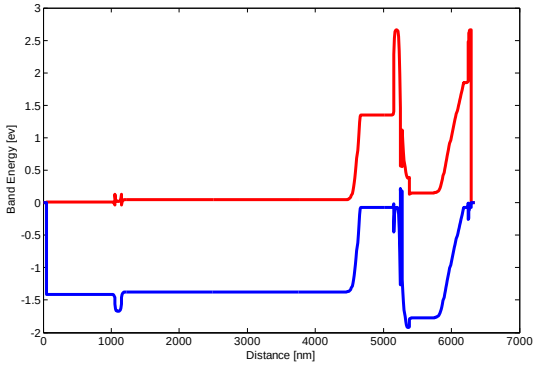
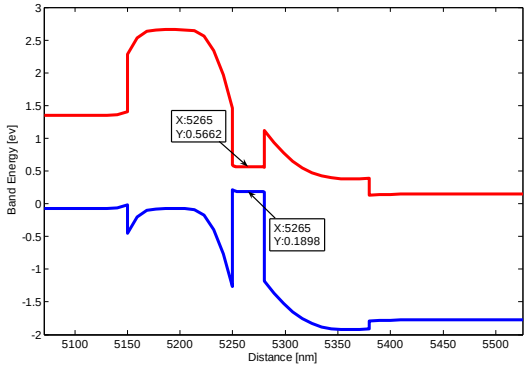


Fig. 8. Maximum displacement in crystalline lattice of tandem solar cell of Fig. 1



(a)



(b)

Fig. 9. (a) Band structure of new tandem cell and (b) magnified portion of the InSb junction

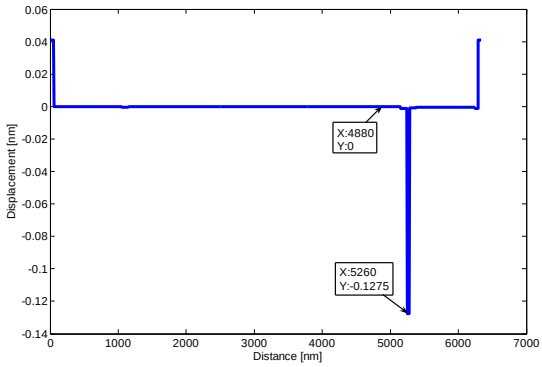


Fig. 10. Maximum displacement in crystalline lattice of new structure

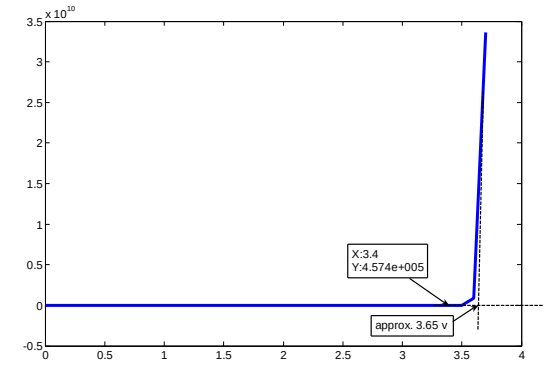


Fig. 11. I-V characteristic of new structured tandem solar cell

REFERENCES

[1] C.H. Henry, Limiting efficiencies of ideal single and multiple energy gap terrestrial solar cells, *J. Appl. Phys. 51(8)* (1980) p.4494

[2] Mae-Wan Ho, Peter Bunyard, Peter Saunders, Elizabeth Bravo, Rhea Gala, Which Energy?, *2006 Institute of Science in Society Energy Report* (ISIS 2006)

[3] NAGASAKI SHIPYARD & MACHINERY WORKS, Microcrystalline High-Efficiency Tandem Solar Cell to Begin Production, *Mitsubishi Heavy Industries, Ltd. Technical Review Vol. 44 No. 4* (Dec. 2007)

[4] Green, et al., Nanostructured Silicon-Based Tandem Solar Cells, *GCEP Technical Report 2006*
[5] Arvind Shah, J. Meier, E. Vallat-Sauvain, C. Droz, U. Kroll, N. Wyrsch, J. Guillet, U. Graf, Microcrystalline silicon and micromorph tandem solar cells, *Thin Solid Films* 403-404, 179-187, 2002
[6] J. Meier a, S. Dubail, R. Platz, P. Torres, U. Kroll, J.A. Anna Selvan, N. Pellaton Vaucher, Ch. Hof, D. Fischer, H. Keppner, R. Fliickiger, A. Shah, V. Shklover, K.-D. Ufert, Towards high-efficiency thin-film silicon solar cells with the micromorph concept, *Elsevier Science, Solar Energy Materials and Solar Cells 49* (1997) 35-44
[7] Serap GÜNEŞ, Niyazi Serdar SARIÇİFTÇİ, An Overview of Organic Solar Cells, *Journal of Engineering and Natural Sciences, Sigma Vol./Cilt 25* Issue/Sayı 1, 2007
[8] Armin G. Aberle, Nils-Peter Harder, and Stefan Oelting, Recent Advances in Crystalline Silicon Film and Thin-Film Solar Cell Growth by Ion-Assisted Deposition, *17th European PV Conference*, Munich, Oct. 2001
[9] F. Dimroth, High-efficiency solar cells from III-V compound Semiconductors, *phys. stat. sol. (c) 3, No. 3*, 373–379 (2006), DOI 10.1002/pssc.200564172
[10] Masafumi Yamaguchi, Physics and technologies of super-high-efficiency tandem solar cells, *Toyota Technological Institute*, (1999)
[11] National Center for Photovoltaics, High-Efficiency Concepts and Concentrators, p.1-3 (2005)
[12] Ken Takahashi, Shigeki Yamada, Tsunehiro Unno, High-efficiency AlGaAs/GaAs Tandem Solar Cells, *Advanced Research Center, Hitachi Cable, Ltd.*, U.D.C. 621.383.51 : 523.9-7: [546.681'62'19 : 546.681'19]
[13] M. W. Wanlass, S. P. Ahrenkiel, D. S. Albin, J. J. Carapella, A. Duda, K. Emery, J. F. Geisz, K. Jones, Sarah Kurtz, T. Moriarty, and M. J. Romero, Ultra-Thin Triple-Bandgap GaInP/GaAs/GaInAs Monolithic Tandem Solar Cells, *National Renewable Energy Laboratory (NREL)*, NASA/CP—2007-214494
[14] M. W. Wanlass, J. S. Ward, K. A. Emery, and T. J. Coutts, Monolithic, Two-Terminal $InP/Ga_{0.47}In_{0.53}As$ Tandem Solar cells, *National Renewable Energy Laboratory*, 1993
[15] John C. Zolper, Jhon F. Klem, Thomas A. Plut, and Chris P. Tigges, GaAsSb-Based Heterojunction Tunnel Diodes For Tandem Solar Cell Interconnects, *Sandia National Laboratories*, Albuquerque, NM 87185-0603
[16] Tim Ashley, Ian. M. Baker, Theresa M. Burker, David T. Dutton, John A. Haigh, Leslie G. Hipwood, Richard Jefferies, Andrew D. Johnson, Peter Knowles, J. Chris Little, InSb focal plane arrays grown by molecular beam epitaxy, DOI: 10.1117/12.391753, Proceedings Vol. 4028 *Infrared Detectors and Focal Plane Arrays VI*, Eustace L. Dereniak; Robert E. Sampson, Editors, pp.398-403, Date: 17 July 2000
[17] M. Mohammadkhani, J. Fariborz, and A. Mohades Kassai, Growth and Characterization of p-type InSb on n-type (111) and (110) Insb Substrates Using Molecular Beam Epitaxy, *Journal of Applied Sciences*, 2010, ISSN 1812-5654
[18] H.C. Casey Jr., M.B. Panish, Heterostructure Lasers, *Academic Press* New York (1978)

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