Journées Nationales sur l'Énergie Solaire
28 au 30 juin 2016 Campus université Perpignan

INVESTIGATIONS OF NEW APPROACHES FOR HIGH EFFICIENCY INGAN SOLAR CELLS

Muhammad **ARIF**[a,b], Jérémy **STREQUE**[b], Matthew B. **JORDAN**[b,c], Suresh **SUNDARAM**[b], Youssef **EL GMILI**[b], Xin **LI**[b], Paul L. **VOSS**[b,c], Jean-Paul **SALVESTRINI**[a,b], Abdallah **OUGAZZADEN**[b,c]

[a] *Université de Lorraine et CentraleSupélec, LMOPS, EA4423, 57070 Metz, France*

[b] *Georgia Tech Lorraine, Georgia Tech-CNRS. UMI2958, 57070, Metz, France*

[c] *School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, Georgia 30332-0250 USA*
Contact e-mail : jean-paul.salvestrini@univ-lorraine.fr

RÉSUMÉ

The InGaN material system, with high absorption coefficient (10^5 cm^{-1}) and a bandgap from 0.7 eV to 3.4 eV spanning the entire visual spectrum, make the development of all-InGaN multi-junction solar cells with overall efficiency larger than 50% theoretically possible. However, to reach this goal high-quality and thick InGaN layers with high indium (In) concentration are required, which is not a trivial task. Reports of InGaN-based junctions with an In mole fraction exceeding 0.3 are rare due to issues such as strong phase separation and relaxation of the layer due to lattice mismatch with the substrate which lead to InGaN layers with large dislocation density and In-clustering. These material problems, significantly limit the performance of InGaN-based photovoltaic cells, and whatever the In content, performance still remains far from the theoretical ones. We propose to use two new approaches (see Figure 1) that may overcome the issues of phase separation and high dislocation density in the absorber and thus grow InGaN-based PIN solar cells with improved properties. The first approach consists in the replacement of a bulk $In_xGa_{1-x}N$ absorber with a thick multi-layered InGaN/GaN semibulk absorber (see Figure 1(a)). The periodic insertion of thin GaN interlayers should absorb the In excess and relieve compressive strain. These GaN interlayers need to be thick enough to be effective and thin enough to allow carrier transport through tunneling. The InGaN layers need to be thick and numerous enough to efficiently absorb the incoming light beam, and thin enough to remain fully strained without phase separation. The second approach consists in the growth of InGaN nano-structures for the achievement of high In content thick InGaN layers (see Figure 1(b)). This approach allows the elimination of the preexisting dislocations in the underlying template. It also allows strain relaxation of InGaN layers without any dislocations, leading to higher In incorporation and reduced piezo-electric effect. The electro-optical characterization of semibulk $In_{0.08}Ga_{0.92}N$ PV devices show a maximum EQE of 85%, which is the maximum EQE peak reported so far for an $In_{0.08}Ga_{0.92}N$ PIN heteroj-unction solar cell (see Figure 1(c)). The voltage dependence of the current density, under AM 1.5 G solar spectrum for the semibulk $In_{0.08}Ga_{0.92}N$ solar cells results in values of J_{sc}, V_{oc}, fill factor (FF) and power conversion efficiency (PCE) as 0.57 mA/cm^2, 1.04 V, 65% and 0.39% respectively (see inset Figure 1(c)). A comparison of the results to the literature show that the Jsc is four to five times of what has been reported for a bulk $In_{0.08}Ga_{0.92}N$ PV structure. This value of J_{sc} lead to a PCE for the semibulk $In_{0.08}Ga_{0.92}N$-based PV cell which is at least three times higher than the PCE for the bulk $In_{0.08}Ga_{0.92}N$ structure under AM 0. High crystalline structural quality for InGaN nano-structures with 35% of indium concentration has been obtained. The electro-optical characterization for $In_{0.10}Ga_{0.90}N$ nano-structured PV cells shows a significant enhancement in the performance of the devices. The devices result in a J_{sc} and V_{oc} of 12 mA/cm^2 and 1.89 V under concentrated light.

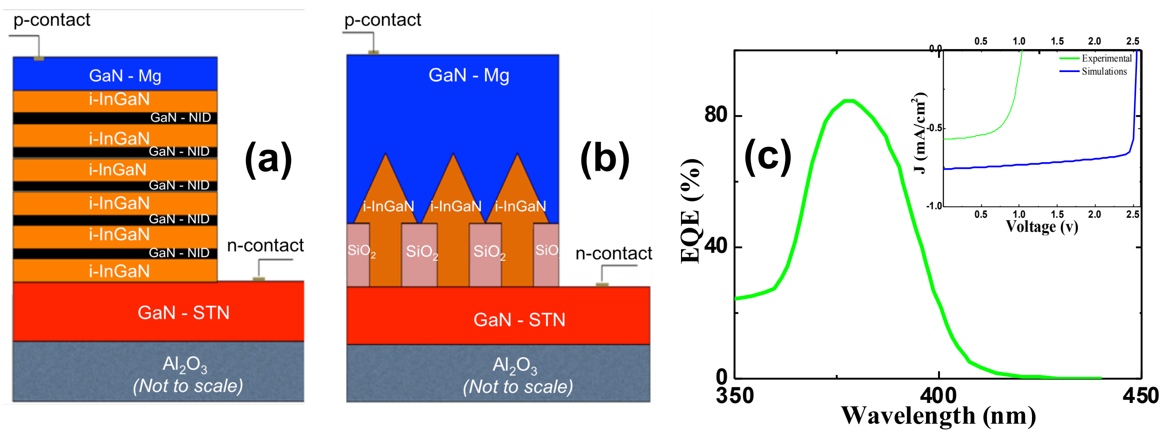

Figure 1: (a) Semibulk InGaN, (b) Nano-structured InGaN, (c) EQE and *J-V* results for semibulk $In_{0.08}Ga_{0.92}N$ PV cell.