Modeling of polarization effects in InGaN PIN solar cells

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Abstract—In this paper, we study the effect of polarization on the performance of InGaN solar cells. By using the APSYS software, we show that device performance is adversely affected due to the interface charges near GaN contact layers and that alternate means of creating ohmic contacts should be considered.

I. INTRODUCTION

The InGaN material system has attracted a lot of interest for solar cells due to the wide bandgap range available (0.65-3.4 eV) [1] [2]. Several approaches have been suggested to generate the required depletion layer including homojunctions [3], heterojunctions [4] [5] and graded layers [6].

In all these designs it is commonly believed that defects are the main cause of poor device performance, especially at higher In concentrations. However, since this material system is subject to strained-induced polarization effects [7], lattice mismatch also produces interface charges that affect device performance and this effect is often neglected.

In this paper, we continue the work started in Ref. [8]. We use the APSYS finite element software [9] to model various InGaN solar cells. The material parameters used in the simulation are the same as in Ref. [6].

II. DEVICE DESIGN

For the purposes of this study, we have chosen to use three device designs based on the one from Ref. [4]. The first device (A) consists of a PIN heterojunction $In_{0.12}Ga_{0.88}N$ cell with top contacts as shown in Fig. 1. Device B is similar but replaces the GaN contact layers with InGaN to form a homojunction. Device C is based on B but adds a 20 nm GaN layer on top of the p-doped InGaN as is commonly done to facilitate the ohmic contact.
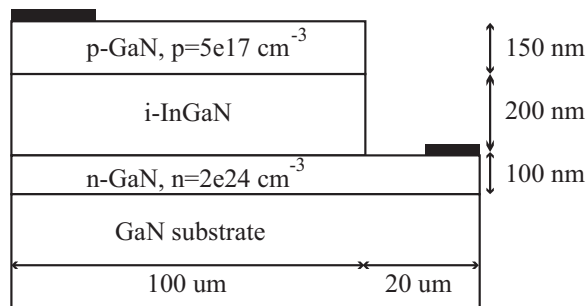

Fig. 1. Solar cell design used in this study

III. RESULTS

We show in Fig. 2 plots of the current density vs. voltage for devices A,B and C under AM15 illumination. The various curves correspond to fractions of the interface charge predicted by theory [7] (screening).

As we can see from the results, devices A and C suffer from a reduced fill factor with screening values as low as 10 % and 20 %, respectively; experimental screening values are expected to be much higher. However, device B seems almost immune to the effects of the interface polarization charge. We believe this can be explained by the lack of sign change in the current path of the device.

This point of view is supported by the equilibrium band diagrams of Fig. 3. Both device A and C show band bending obstructing the flow of current at the GaN/InGaN interface. In device B, no such effect is present: the barrier on the left-hand side is simply the substrate and does not obstruct the current in this design.

We note that this band bending effect has been reported before [6] and a graded InGaN region was recommended to smooth out the discontinuity in the band diagram. However, the authors did not include polarization effects in their study to to the difficulty of determining the strain in the graded region. Given the importance of of the polarization charge shown in our results, this issue warrants further study and alternate means of creating ohmic contacts should be considered.

REFERENCES

[1] J. Wu *et al.*, "Unusual properties of the fundamental band gap of InN," *Appl. Phys. Lett.*, vol. 80, p. 3967, 2002.

[2] T. Matsuoka *et al.*, "Optical bandgap energy of wurtzite InN," *Appl. Phys. Lett.*, vol. 81, p. 1246, 2002.

[3] X. M. Cai *et al.*, "Fabrication and characterization of InGaN pin homo-junction solar cell," *Appl. Phys. Lett.*, vol. 95, p. 173504, 2009.

[4] C. J. Neufeld *et al.*, "High quantum efficiency InGaN/GaN solar cells with 2.95 eV band gap," *Appl. Phys. Lett.*, vol. 93, p. 143502, 2008.

[5] B. Jampana *et al.*, "InGaN solar cell design by surface inversion caused by piezoelectric polarization," in *Proc. 34th PVSC*, 2009, p. 002175.

[6] G. Brown *et al.*, "Finite element simulations of compositionally graded InGaN solar cells," *Solar Energy Materials & Solar Cells*, vol. 94, pp. 478–483, 2010.

[7] V. Fiorentini *et al.*, "Evidence for nonlinear macroscopic polarization in III-V nitride alloy heterostructures," *Appl. Phys. Lett.*, vol. 80, p. 1204, 2002.

[8] Y. Xiao *et al.*, "Modeling of InGaN PIN solar cells with defect traps and polarization interface charges," in *Proc. 35th PVSC*, in press.

[9] *Crosslight Device Simulation Software - General Manual*, Crosslight Software, 2009.
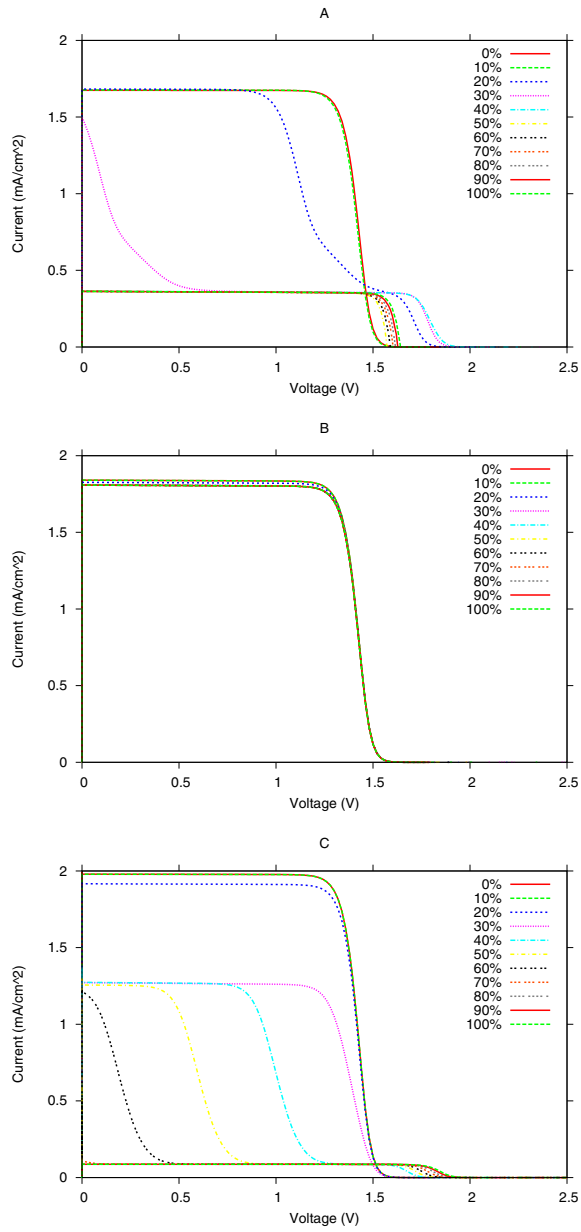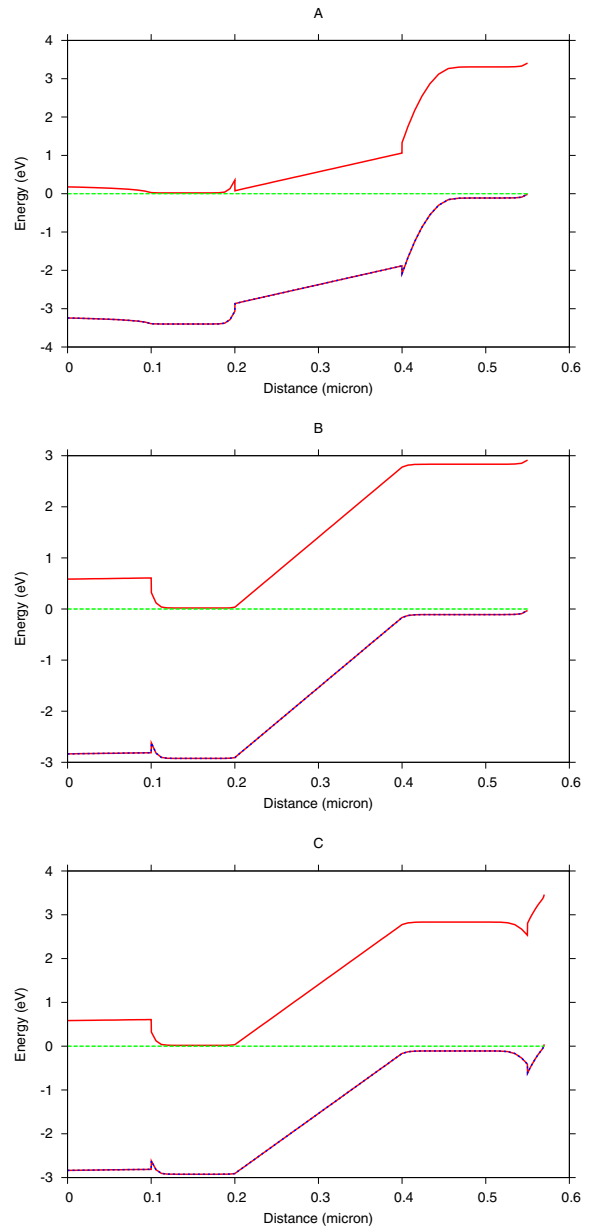
Fig. 2.   Effect of polarization charge on InGaN solar cell

Fig. 3.   Band diagram at equilibrium