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# Effect of Interface Properties on the Electrical Characteristics of InGaN-based Multijunction Solar Cell

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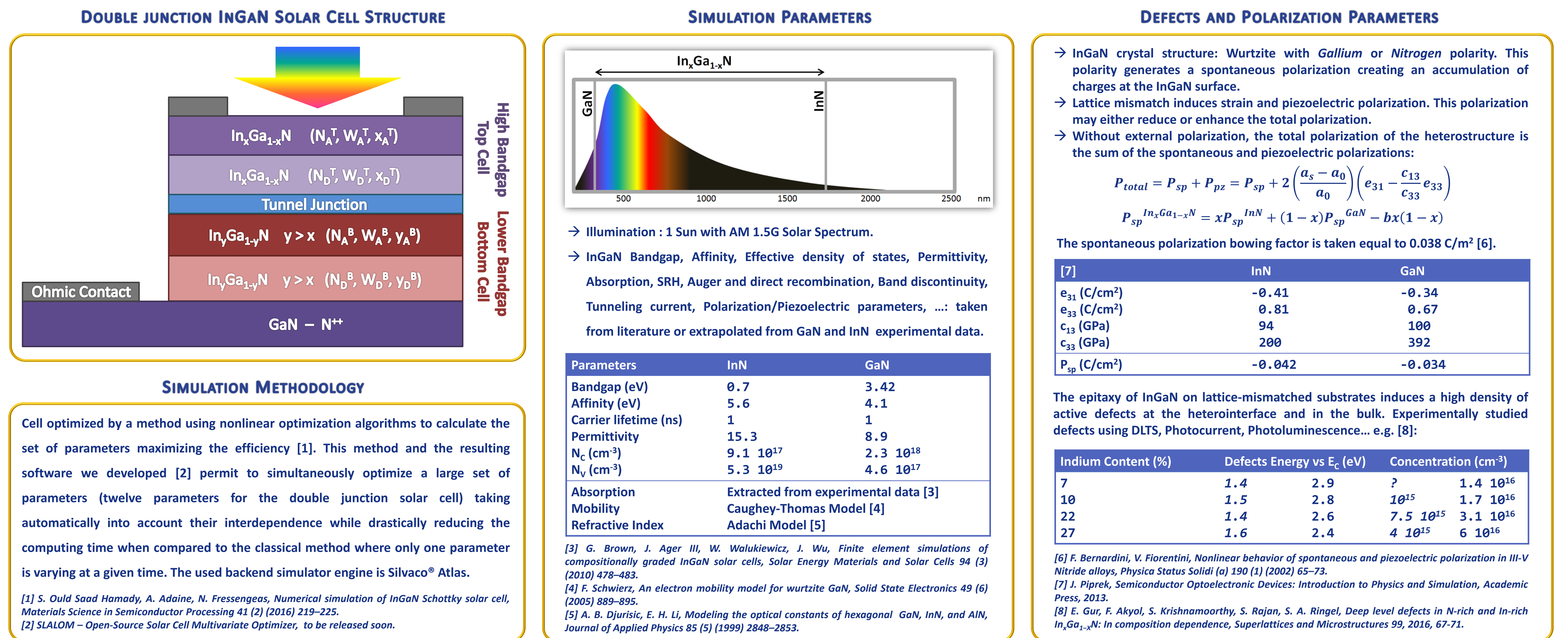
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## Summary

The InGaN ternary alloy has the potentiality to achieve high efficiency solar cells: tunable bandgap in the whole solar spectrum, high absorption coefficient, high stability and radiation tolerance. These very promising characteristics make InGaN potentially ideal for designing and developing next-generation high-efficiency thin films solar cells. However, challenging issues remain to address: (i) the difficulty to elaborate sufficiently thick monocrystalline InGaN layers with a high Indium content; (a) the high defects density and the spontaneous and piezoelectric polarizations; (iii) the p-doping which remains difficult to master. In this report, we use rigorous optimization approach based on state-of-the-art optimization algorithms to investigate the effect of defects and polarization (spontaneous and piezoelectric) on a double junction InGaN solar cell. A better understanding of the mechanisms involved in the heterostructure has a crucial impact on the design and elaboration of high efficiency InGaN thin films solar cells which require, in particular, a precise control of the Tunnel Junction elaboration which is still very challenging.

## Double Junction InGaN Solar Cell: Effect of Spontaneous/Piezoelectric Polarization and Defects

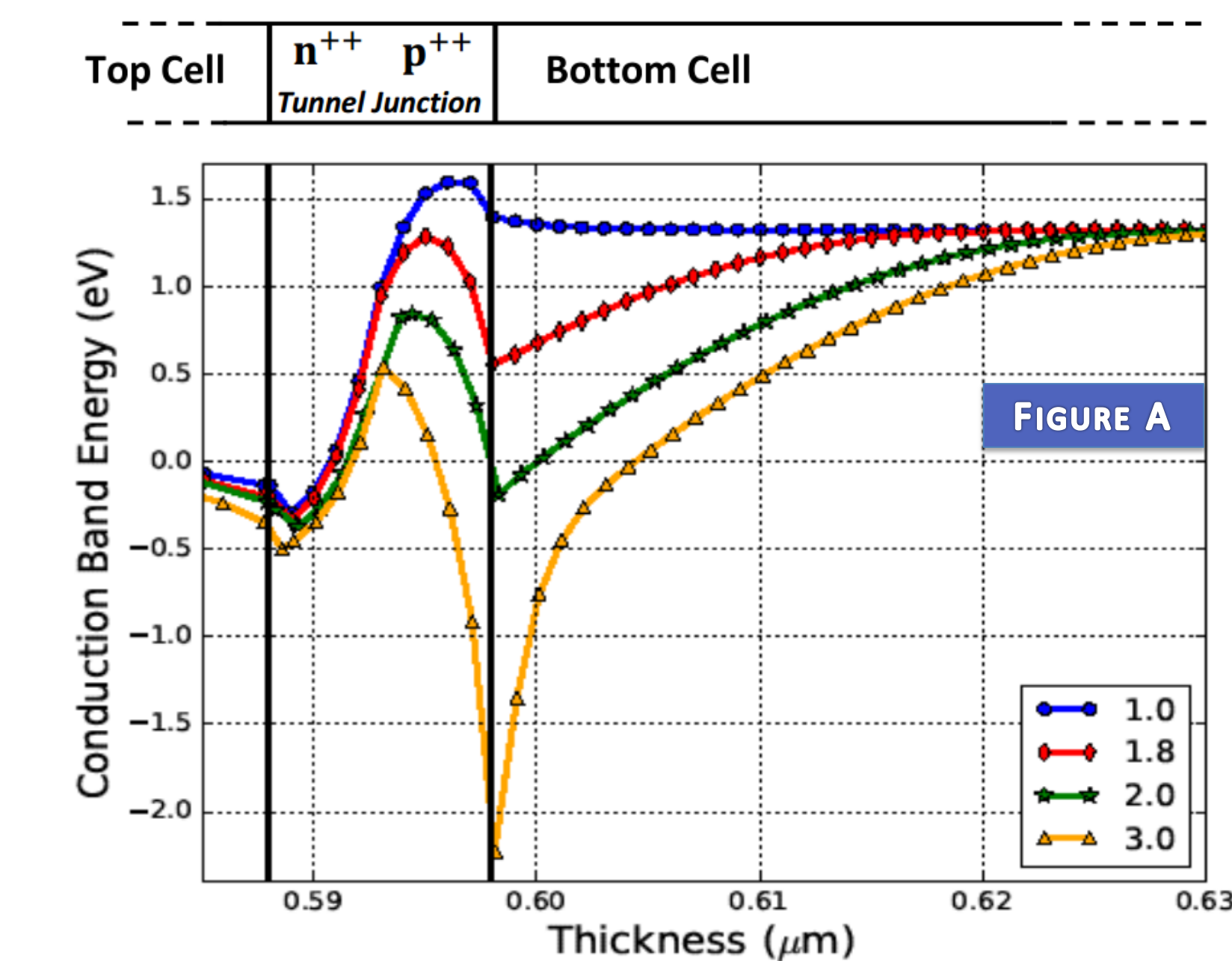


## SPONTANEOUS/PIEZOELECTRIC POLARIZATION AND DEFECTS EFFECTS

Optimal InGaN double junction solar cell parameters giving efficiency of about 25%

| InGaN Top Cell     |                              |                              |                  |                  | InGaN Tunnel Junction |                              |                              |                  |                  | InGaN Bottom Cell  |                              |                              |                  |                  | GaN                          |                  |
|--------------------|------------------------------|------------------------------|------------------|------------------|-----------------------|------------------------------|------------------------------|------------------|------------------|--------------------|------------------------------|------------------------------|------------------|------------------|------------------------------|------------------|
| Indium Content (%) | P-Doping (cm <sup>-3</sup> ) | N-Doping (cm <sup>-3</sup> ) | P-Thickness (μm) | N-Thickness (μm) | Indium Content (%)    | P-Doping (cm <sup>-3</sup> ) | N-Doping (cm <sup>-3</sup> ) | P-Thickness (μm) | N-Thickness (μm) | Indium Content (%) | P-Doping (cm <sup>-3</sup> ) | N-Doping (cm <sup>-3</sup> ) | P-Thickness (μm) | N-Thickness (μm) | N-Doping (cm <sup>-3</sup> ) | N-Thickness (μm) |
| 40                 | 8.04 · 10 <sup>18</sup>      | 2.38 · 10 <sup>16</sup>      | 0.010            | 0.580            | 50                    | 5.00 · 10 <sup>19</sup>      | 5.00 · 10 <sup>19</sup>      | 0.005            | 0.005            | 59                 | 2.51 · 10 <sup>18</sup>      | 1.00 · 10 <sup>17</sup>      | 0.570            | 0.010            | 1.00 · 10 <sup>19</sup>      | 0.160            |

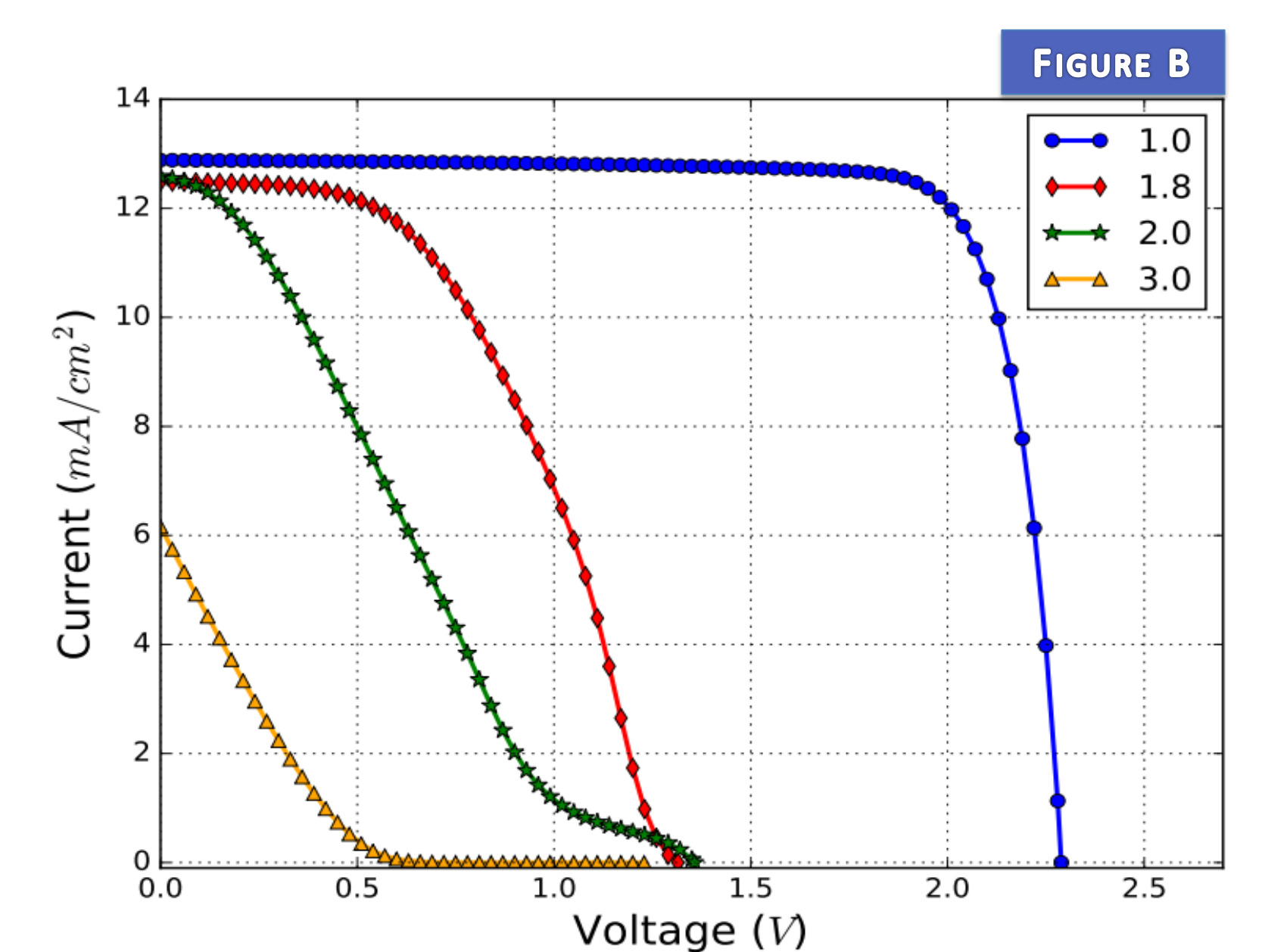
Efficiency = 25% less than what previous theoretical works predicted (35%) → comprehensive and empirical models (Absorption, Mobility, Recombination, Tunneling, Bandgap narrowing, etc.) → Effective result tightly linked to the actual device realization.



### SPONTANEOUS/PIEZOELECTRIC POLARIZATION

Conduction band in the Tunnel Junction region (FIGURE A) and current-voltage characteristic (FIGURE B) variation with respect to the total (spontaneous + piezoelectric) polarization. The normalized polarization value of 1.0 corresponds to the nominal value in C/m<sup>2</sup> extrapolated from experimental data for GaN and InN. The polarization is increased up to 3 times its nominal value.

Polarization in the Tunnel Junction region → bands bend → charges accumulate at the interface and induce electric field in the direction opposite to that of the PN junction → “parasitic diode” in the double junction solar cell. This “parasitic diode” induces a decrease of the solar cell open-circuit voltage and, if the induced field is greater than that of the cell, a decrease of the short-circuit current.



### DEFECTS AT TOP / TUNNEL JUNCTION / BOTTOM HETEROINTERFACES

Photogeneration and recombination rate distribution (FIGURE C) and effect of deep defects located in Top and Bottom Cells bulk (FIGURE D) and located at the Tunnel Junction heterointerfaces (FIGURE E) on the efficiency. The role of the Tunnel Junction is crucial in the multijunction InGaN solar cell by enhancing the current matching between the top and bottom cells and drastically reducing the voltage loss. It is very sensitive to the interface deep defects: the decrease of the efficiency begins at a defect concentration as low as 10<sup>12</sup> cm<sup>-3</sup>, while the effect of bulk deep defects becomes noticeable only at 10<sup>16</sup> cm<sup>-3</sup>. The recombination rate around the Junction Tunnel (FIGURE C) illustrates this effect.

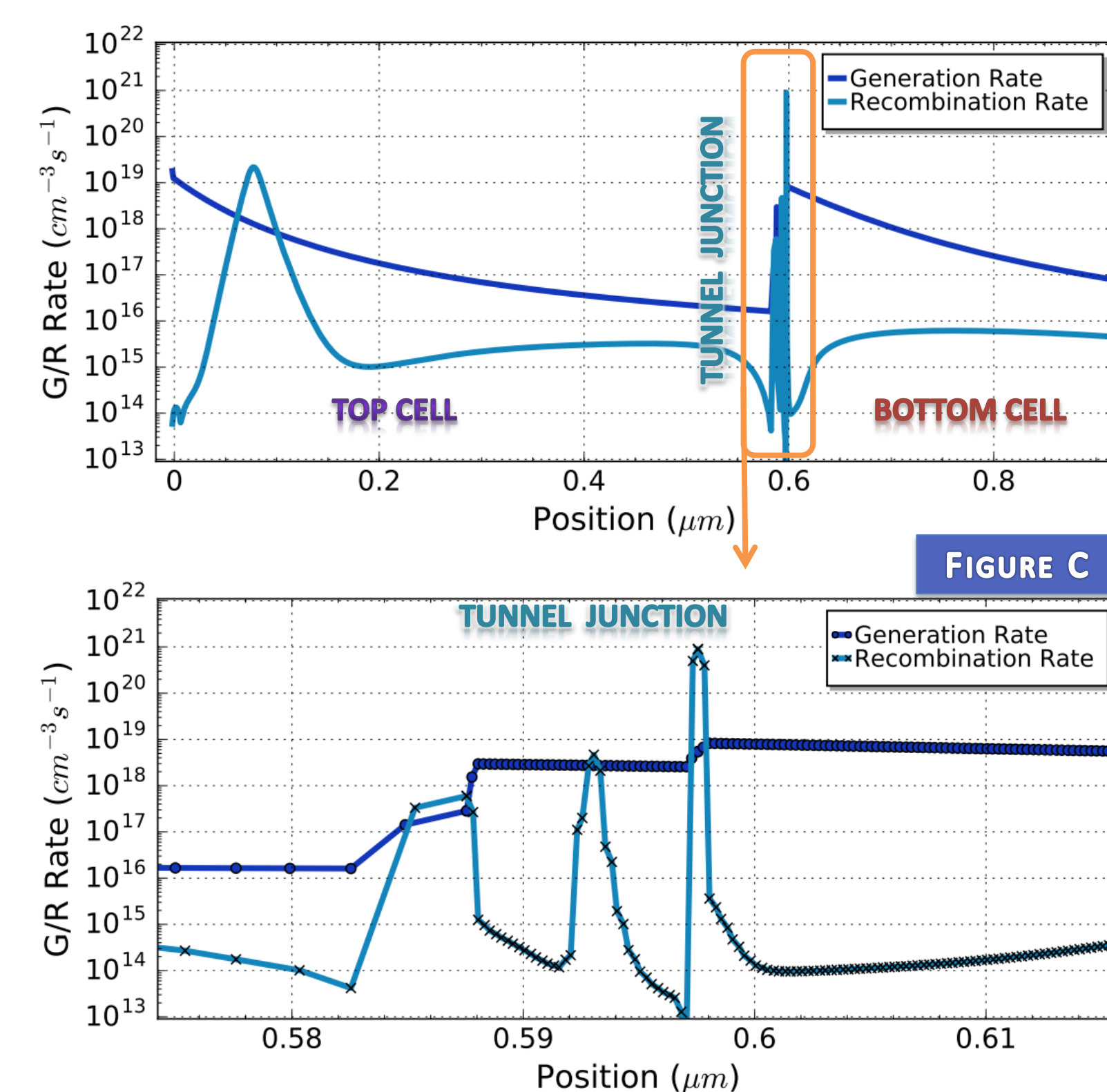
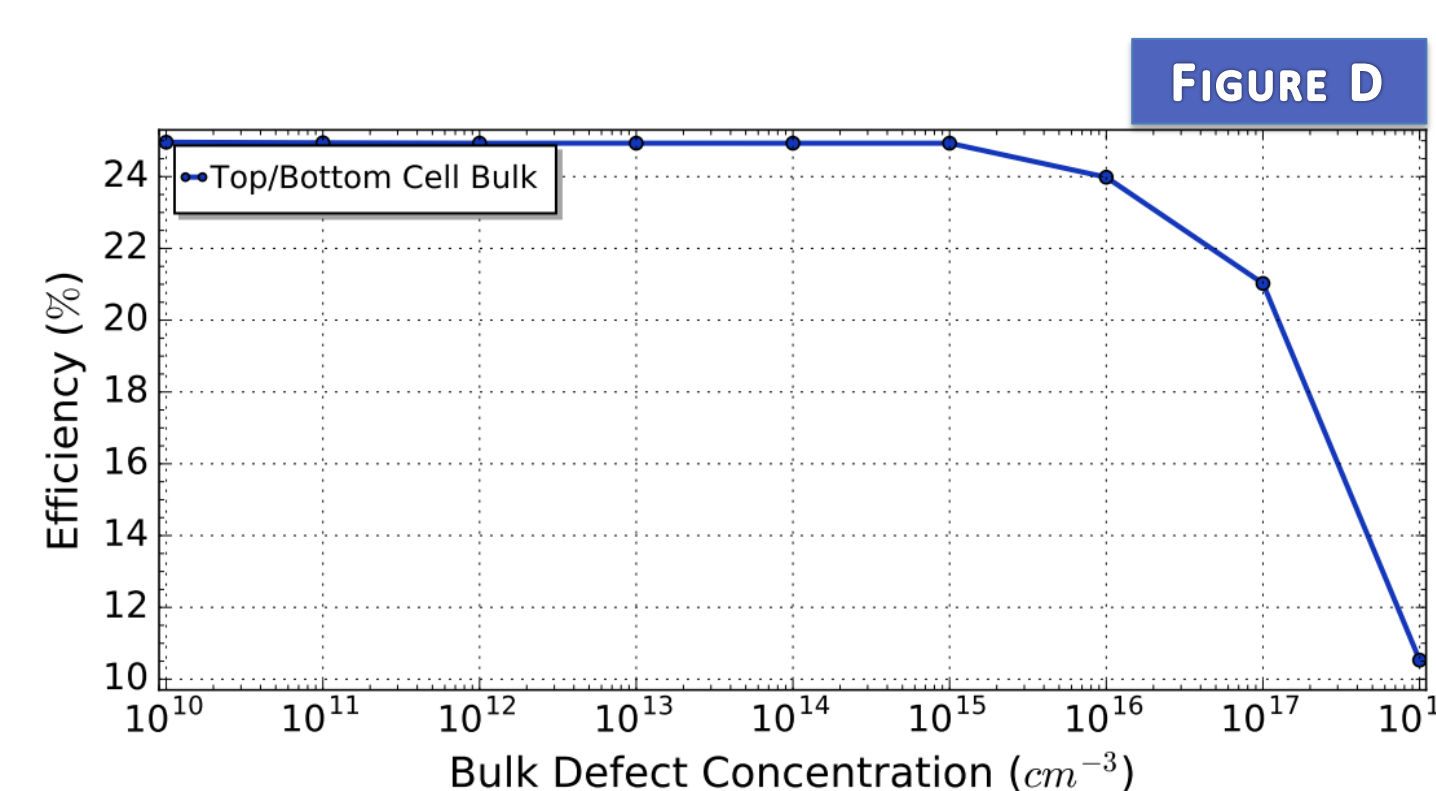


Figure C: Photogeneration and Recombination distribution in the InGaN double junction solar cell in full scale (top figure) and zoomed in the Tunnel Junction region (bottom figure).



The studied defects are located at the Tunnel Junction interfaces where their impact is most sensitive. Deep defects as experimentally studied with N up to 10<sup>18</sup> cm<sup>-3</sup>.

