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High temperature simulation of InGaN/GaN pin solar cells

B. Chouchen¹, F. Ducroquet², M.H. Gazzah¹

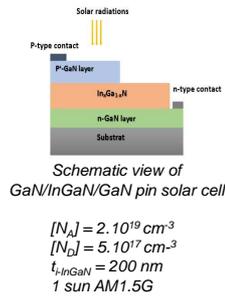
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Context

- Space missions, concentrated PV, hybrid solar PV/thermal systems...
- Solar cells working at high temperature
- Decrease of PV efficiency with temperature (V_{oc})
- Wide band gap absorber needed (η)
- Trade-off between band gap energy and conversion efficiency depending on the targeted operation temperature

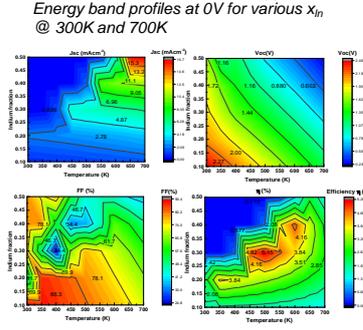
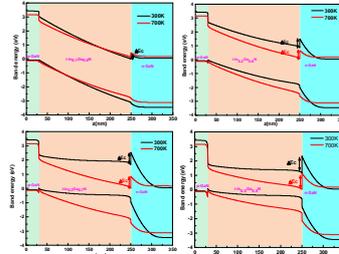
Simulation parameters

- Structure: double heterojunction GaN/In_xGa_{1-x}N/GaN pin solar cell
- Parameters varying with temperature:
 - Band gap: $E_g(x, T)$
 - Mobility: $\mu_{e,h}(T, N)$
 - Radiative recombination: $\tau_{rad} \propto T^{1.5}$
 - SRH recombination: $\tau_{n,p}^{SRH} \propto T^{-0.5}$
 - Doping level: $N_A^-(T), N_D^+(T)$

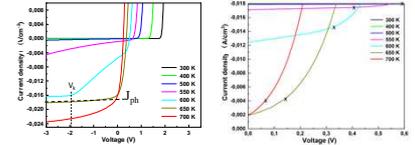
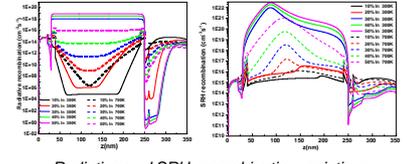


- Charge transport:
 - Silvaco® software: self-consistency Poisson and current continuity equations solving
 - At the heterointerfaces: thermionic emission
$$J_n = q(v_{n2}n_2(0^+) - v_{n1}n_1(0^-)) \exp\left(\frac{-\Delta E_c}{kT}\right)$$
 - Competition between recombination and escape mechanisms
- $$\frac{1}{\tau} = \frac{1}{\tau_{rad}} + \frac{1}{\tau_{non rad}} + \frac{1}{\tau_{therm}}$$

Variations with In content and temperature

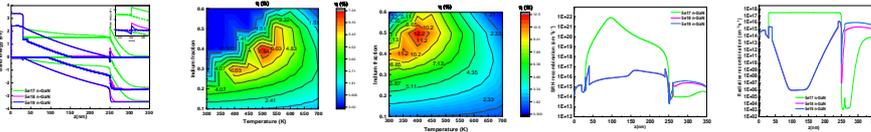


→ The optimization of the conversion efficiency is obtained for an Indium composition at a given working temperature



- At 300K, for $x_{In} > 0.2$, the band offset is sufficiently high to prevent the transport of the photogenerated carriers towards the electrodes: J_{sc}
- When T increases, the photogenerated carriers can more easily surmount the potential barrier at the interface by thermionic emission: J_{sc}
- FF rollover: FF reaches a minimum when only a part of the carriers can be collected

n+ GaN layer doping level

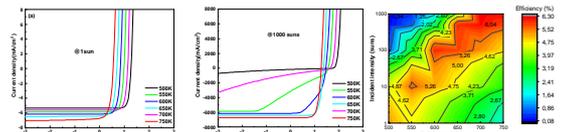


SRH center density

- n+ GaN layer doping level changes the potential profile at the more limiting interface
- For higher doped n+ GaN layer, all the photogenerated carriers are collected at a lower temperature → The maximum efficiency is shifted towards higher Indium composition
- The efficiency value is strongly dependent on the density of non-radiative centers

SRH recombination rate vs the density of SRH centers

Light concentration



- When the solar concentration increases, maximum J_{sc} increases in proportion
- At fixed x_{In} , the temperature for which all the photogenerated are collected is shifted towards lower temperatures
- The conversion efficiency optimization is modified by the light intensity

Conclusions

- For a targeted working temperature, optimized efficiency lies in a compromise between the absorber bandgap energy and the band offset at the heterointerface due to the capability for the photogenerated carriers to cross through the barrier by thermionic emission
- However, when working temperature increases, the band offset is no more a limiting parameter as it is reduced with the x_{In} decrease and as higher temperature increases the thermionic transport probability.

Prospects

- The impact of the defects (non radiative centers, mismatch related defects...) has to be quantified as the material quality is still very challenging for GaN based devices.
- Under high irradiance regime, the impact of the excess heat generated during operation has to be taken into account self-consistency.
- Potential performance degradation of the InGaN/GaN solar cell aging under electron and proton irradiation has to be simulated.

[1] B. Chouchen et al, Sol. Energy Mat. Sol. Cells, 234 (2022) 111446, [2] J.R. Lang et al., Appl. Phys. Lett. 101, 181105 (2012)