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High temperature simulation of InGaN/GaN pin solar cells

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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 (Voc, Jsc)
- Wide band gap absorber needed (n+) 
- Trade-off between band gap energy and conversion efficiency depending on the targeted operation temperature

Simulation parameters
- Structure: double heterojunction GaN/In,Ga,xN/GaN pin solar cell
- Parameters varying with temperature:
  - Band gap: E_g(T, N)
  - Mobility: μ(T, N)
  - Radiative recombination: \( r_{rad} \propto T^{-1.5} \)
  - SRH recombination: \( r_{SRH} \propto T^{-0.5} \)
  - Doping level: \( N_T^e(T), N_T^h(T) \)
- Charge transport:
  - Silvaco® software: self-consistency Poisson and current continuity equations solving
- At the heterointerfaces: thermonionic emission
  \( J_n = q \left( v_{na} T^3 - v_{nh} T^3 \right) \exp(-\frac{E_c}{kT}) \)
- Competition between recombination and escape mechanisms
  \( \gamma = \frac{1}{\frac{1}{r_{rad}} + \frac{1}{r_{SRH}} + \frac{1}{f_{D,\text{therm}}} + \frac{1}{f_{D,\text{therm}}}} \)

Variations with In content and temperature
- At 300K, for \( x_p>0.2 \), 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 thermonionic emission: \( J_{sc} \)
- FF rollover; FF reaches a minimum when only a part of the carriers can be collected

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 thermonionic emission
- However, when working temperature increases, the band offset is no more a limiting parameter as it is reduced with the \( x_n \) decrease and as higher temperature increases the thermonomic 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.