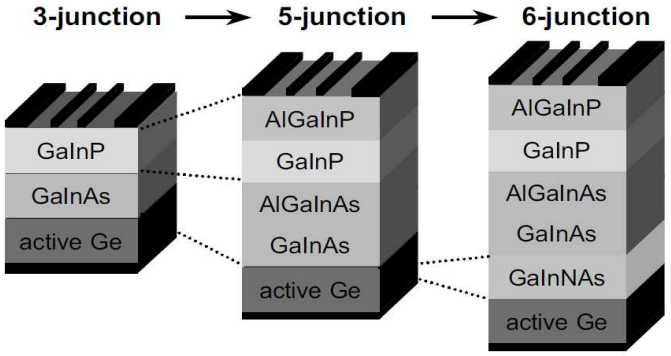
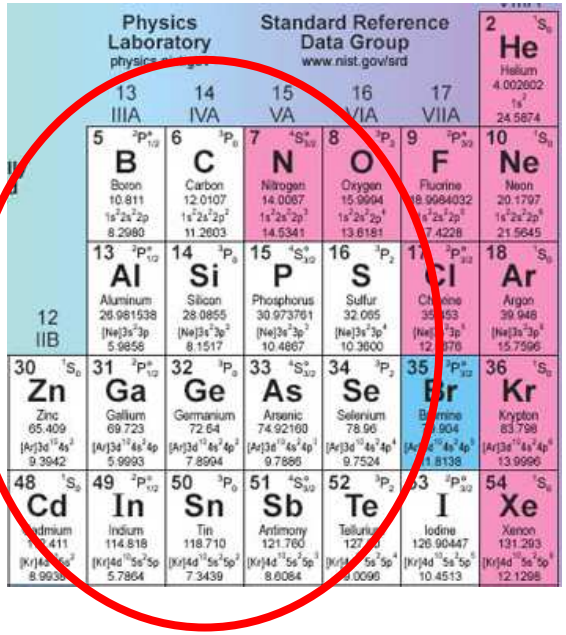
PVcell – software for modeling semiconductor solar cells

General description of the simulator

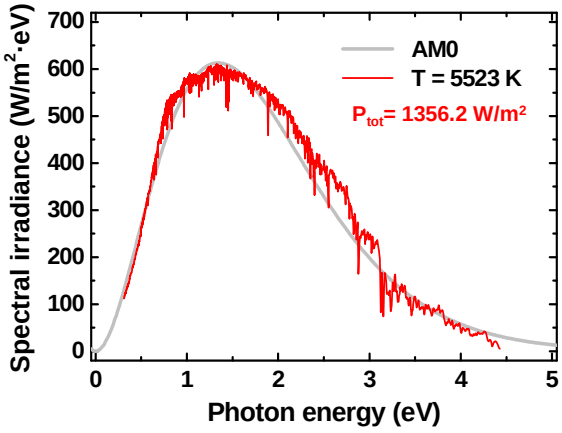


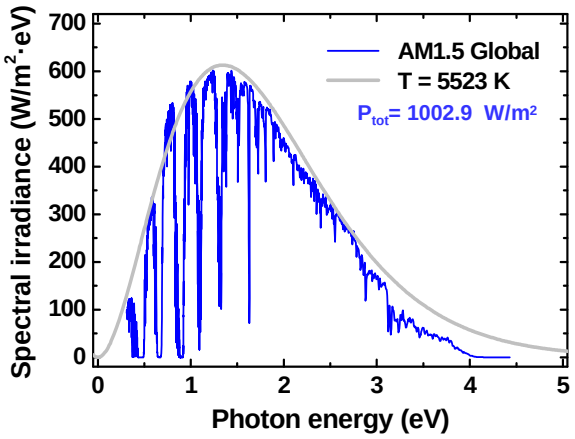
- ✓ **Simple p-n junction and tandem solar cells made of various inorganic semiconductor materials**
- ✓ **Materials systems: Si, Ge, conventional III-V binary compounds and alloys, III-nitride and II-oxide wurtzite semiconductors and alloys**
- ✓ **Bulk semiconductor layers, multiple-quantum wells, and superlattices with possible account of partial strain relaxation**
- ✓ **Quasi-1D approach providing fast and efficient simulations**

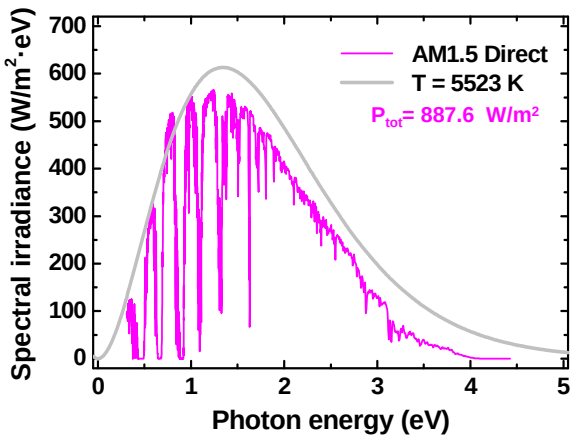


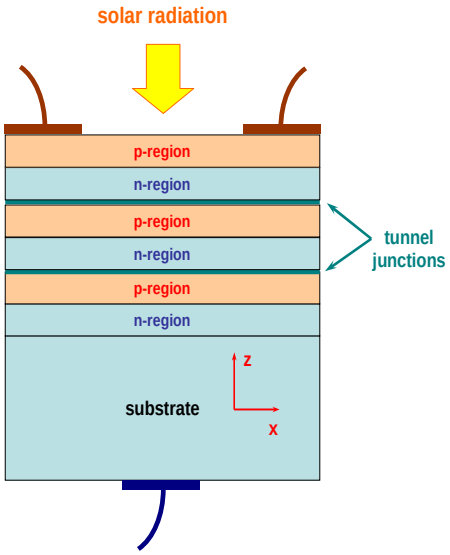
Input parameters and characteristics

- ✓ a number of tabulated solar radiation spectra are available





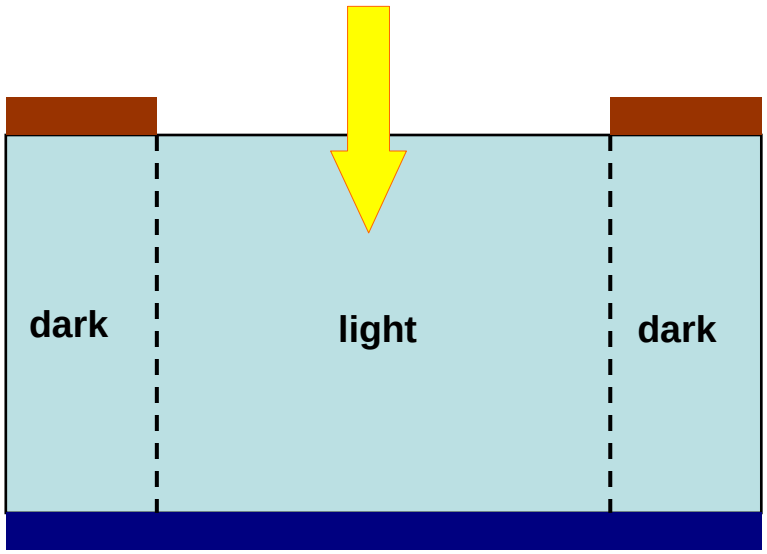




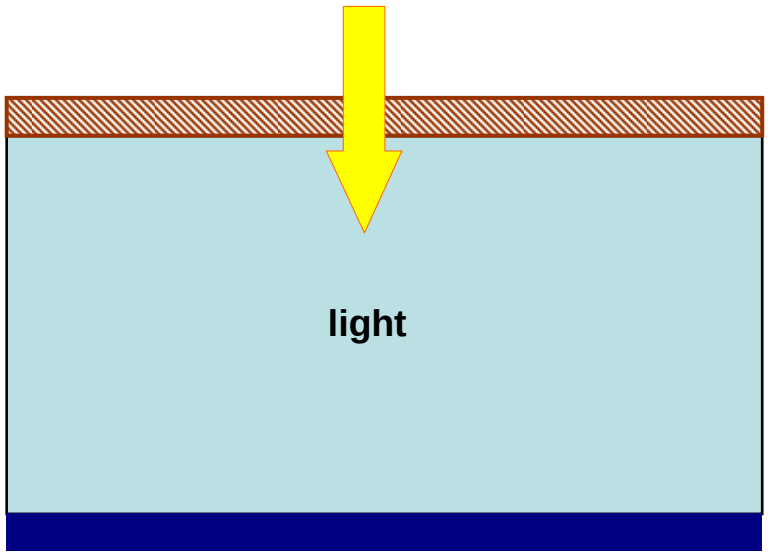
- ✓ concentration factor (in ‘suns’)
- ✓ optical properties of the top and bottom surfaces, including multi-layer coatings; a way of the SC structure illumination
- ✓ heterostructure design, including combination of different materials systems; degree of strain relaxation in every particular epilayer and some materials properties

1D Approximation

Real device (2D)



Model device (1D)

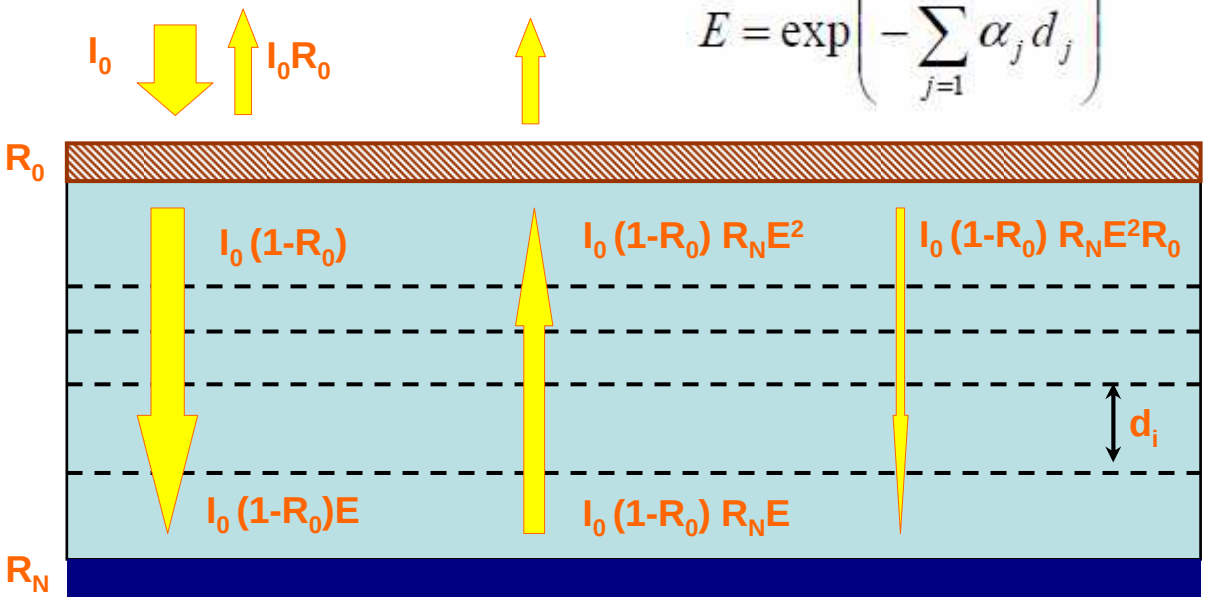


- ✓ Bottom contact is assumed to be a reflective Ohmic contact
- ✓ Top contact is assumed to be a transparent Ohmic contact

Light absorption model

$$E = \exp\left(-\sum_{j=1}^{N} \alpha_j d_j\right)$$

For each wavelength, the intensity distribution is calculated and absorption contributes to the carrier generation

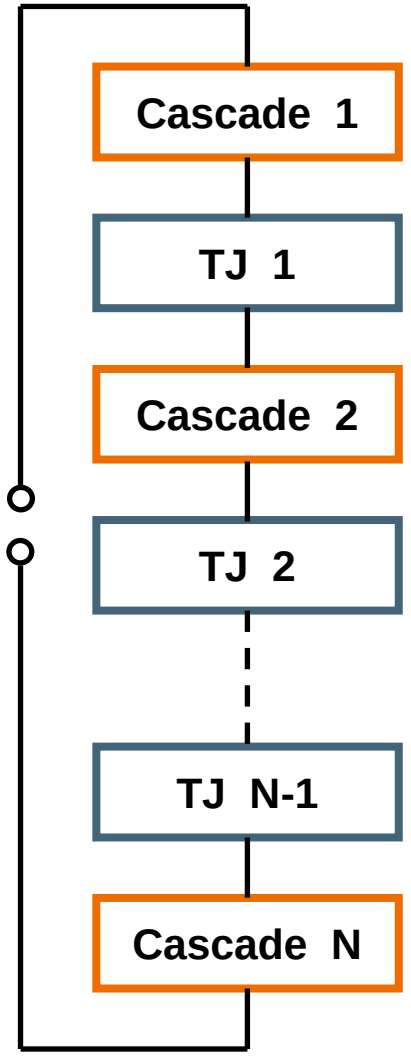


✓ Reflection coefficients of top and bottom contacts, R_0 and R_N, are directly specified by user

✓ Optical properties of each layer are calculated automatically from its composition using database of material properties

Electrical model

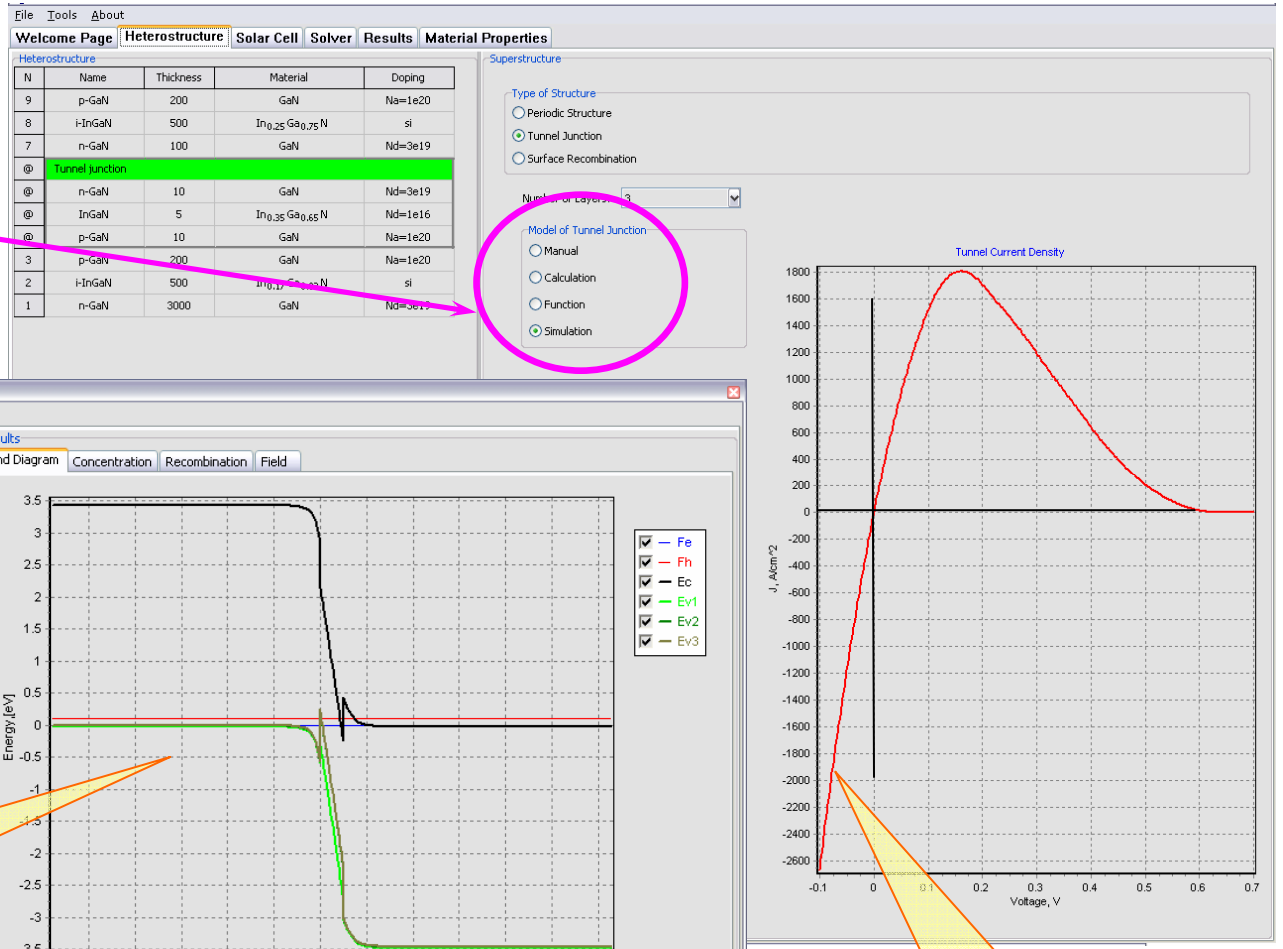
- ✓ 1D drift-diffusion model
  - ✓ Poisson equation for the electric potential
  - ✓ Drift-diffusion carrier transport equations
  - ✓ Generation and recombination rates
- ✓ Simulation of multi-cascade solar cells
  - ✓ Tunnel junction characteristics can be either specified manually or computed by simulation of the band-to-band tunneling
- ✓ Advanced numerical algorithms improve convergence and reduce computation time



Tunnel junction design and its characteristics

various options for calculating tunnel junction I-V curve:

- analytical (Kane model)
- experimental (table)
- WKB with account of interband transition

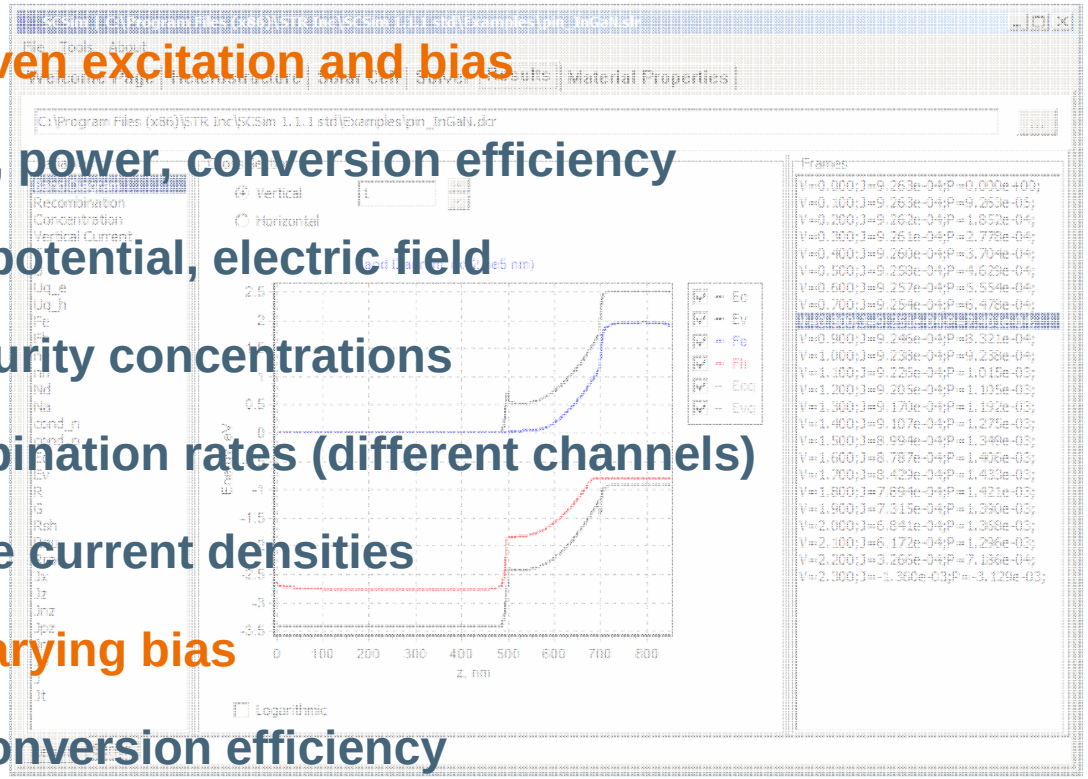


band diagrams of the tunnel junction at various biases

tunnel junction I-V curve

Output parameters and characteristics

- **Single computations at a given excitation and bias**
  - ✓ Current/current density, power, conversion efficiency
  - ✓ Band diagram, electric potential, electric field
  - ✓ Carrier and ionized impurity concentrations
  - ✓ Generation rate, recombination rates (different channels)
  - ✓ Partial electron and hole current densities
- **Series computations with varying bias**
  - ✓ I-V characteristic and conversion efficiency
  - ✓ Short-circuit current, open-circuit voltage, fill factor
- **Series computations with varying excitation wavelength**
  - ✓ Spectral dependence of IQE and EQE

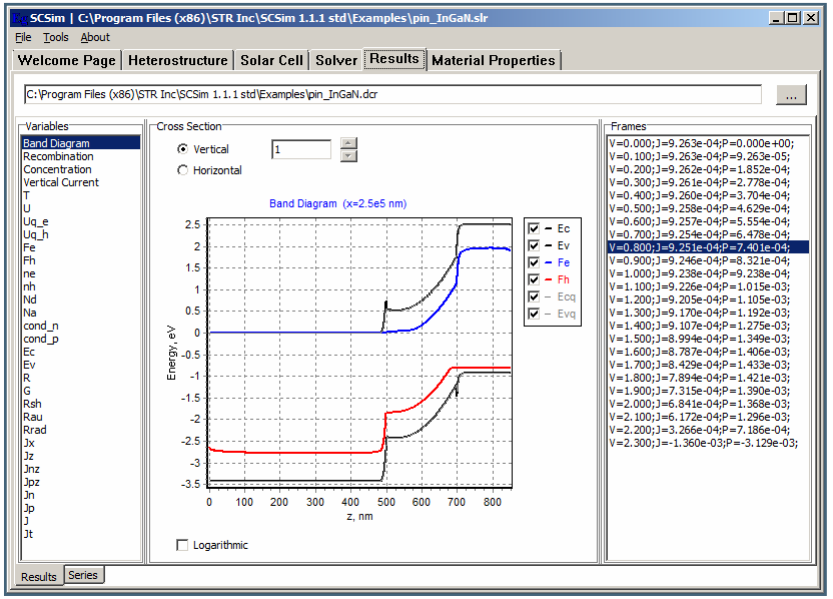


User-friendly interface

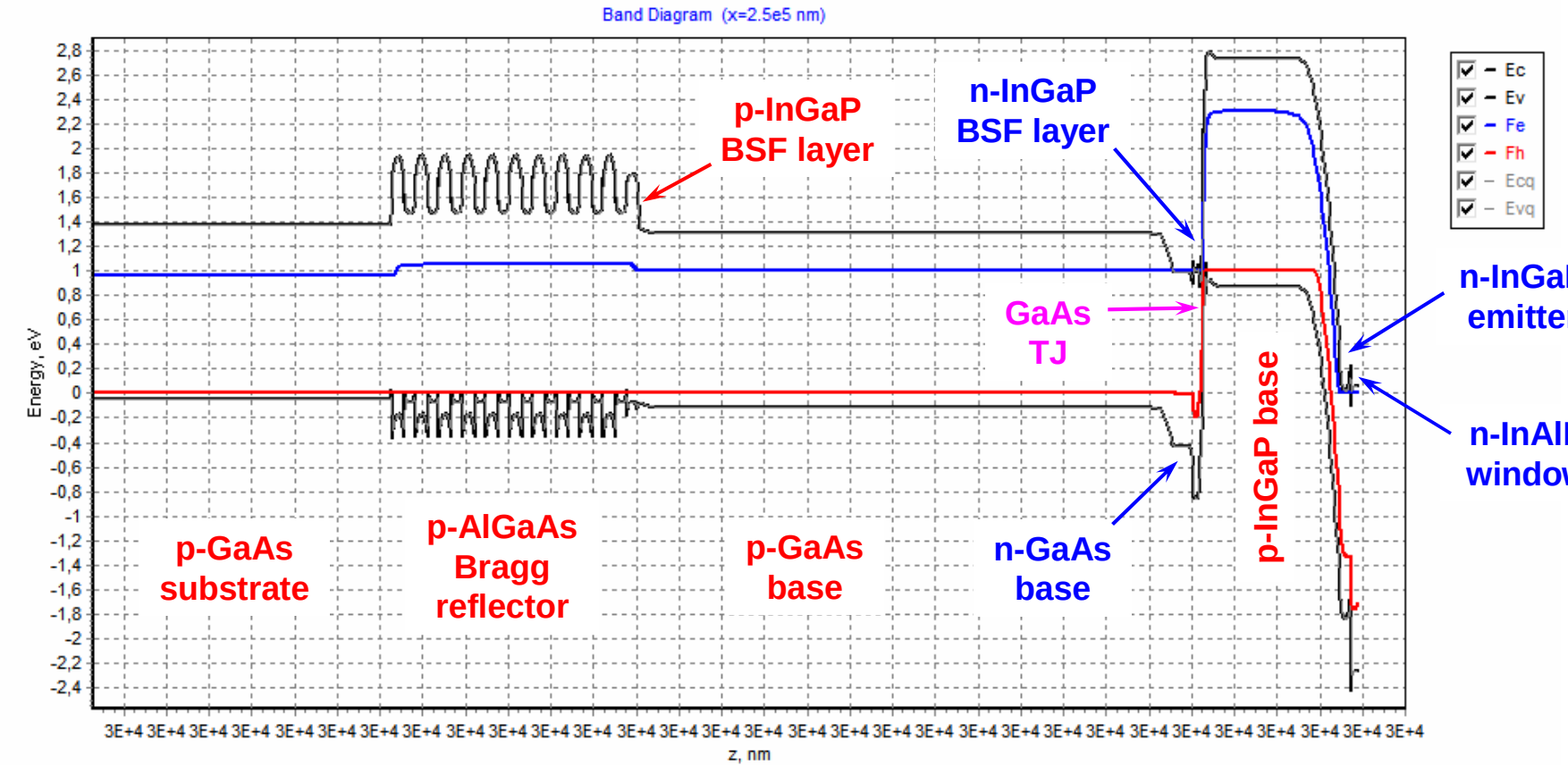
- ✓ Editable database of material properties
- ✓ Most of parameters can be specified as functional or tabulated dependencies on the temperature, wavelength, material composition, etc.
- ✓ Flexible specification of the excitation spectrum, including standard light sources, custom sources, monochromatic excitation.
- ✓ Built-in visualization of the simulation results

Learning time: ~ 3 days

Computation time: ~ 3 min

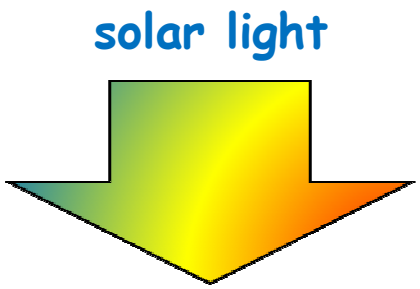


Simulation of dual-junction GaInP-GaAs solar cell

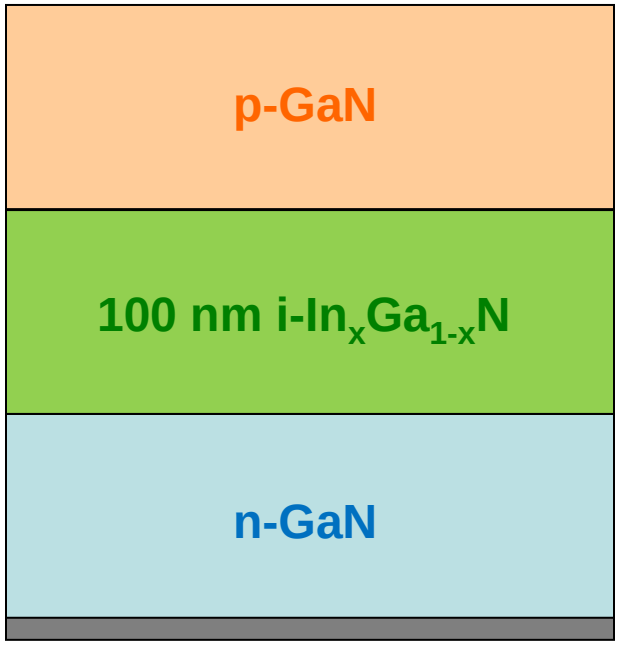


analytical model for tunnel junction j-V characteristics is used; as a result, full simulation of the dual-junction solar cell has been performed within 1.5 min (no convergence was obtained for this structure by using an another software)

Single-junction solar cell structure



Kirill A. Bulashevich and Sergey Yu. Karpov, Phys. Stat. Solidi (c) 11 (2014) 640



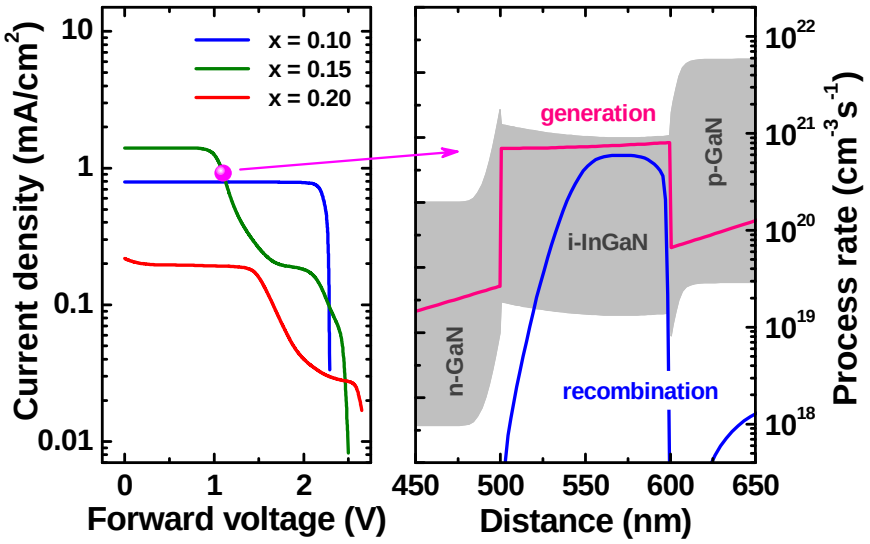
***R* = 0**

Same electron and hole non-radiative carrier life time *τ* in the InGaN active layer was chosen for the seek of simplicity. The effect of the carrier lifetime on the conversion efficiency has been also examined.

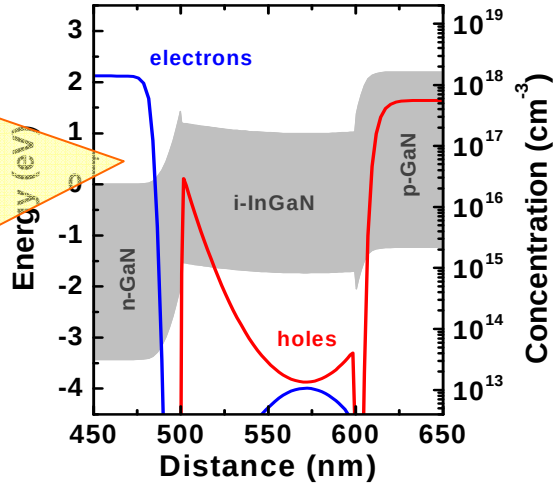
***R* = 1**

Polarity effect on operation of strained solar cell structures

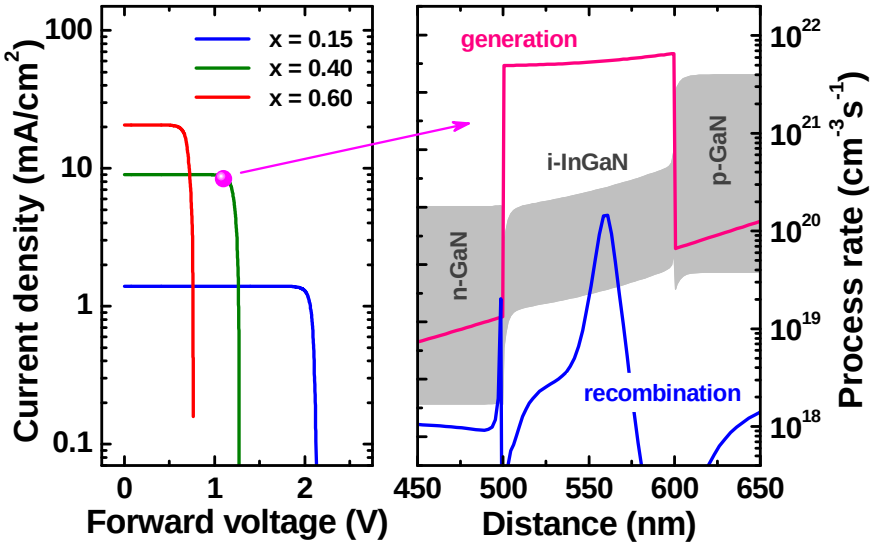
III-polar structure



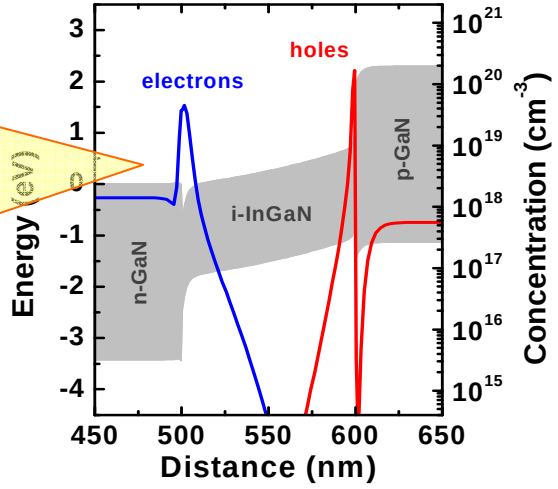
electric field in InGaN hinders separation of electrons and holes, making the structure inoperable at x > 0.20



N-polar structure

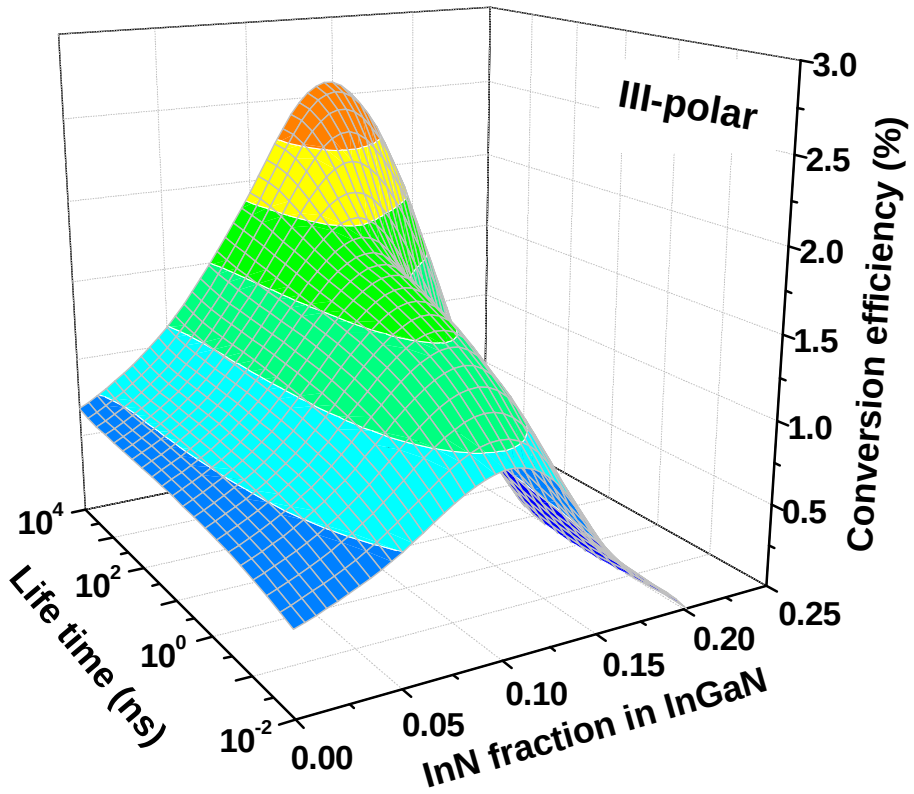


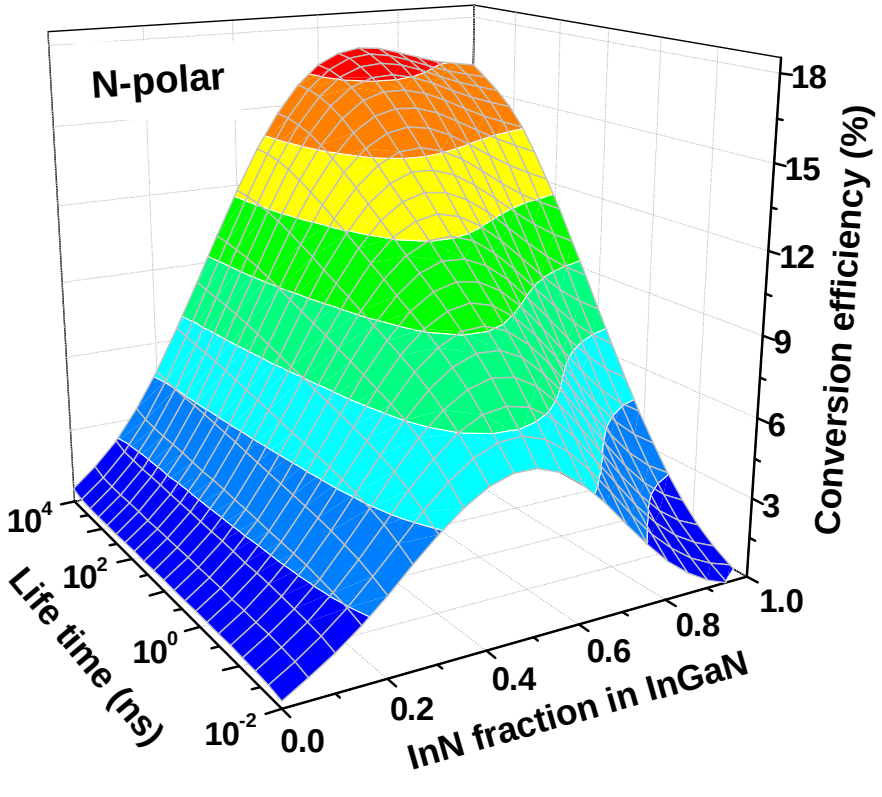
electric field in InGaN favors separation of electrons and holes at any alloy composition



Conversion efficiency of strained solar cell structures

conversion efficiency at 1 sun (AM1.5G)



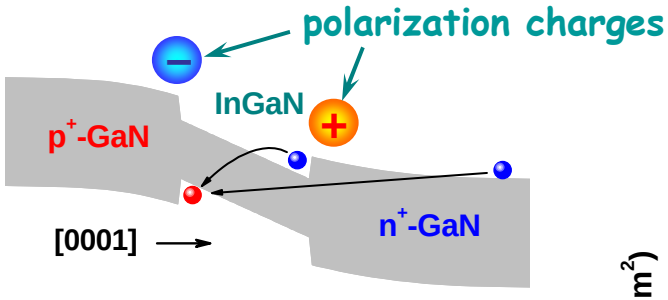


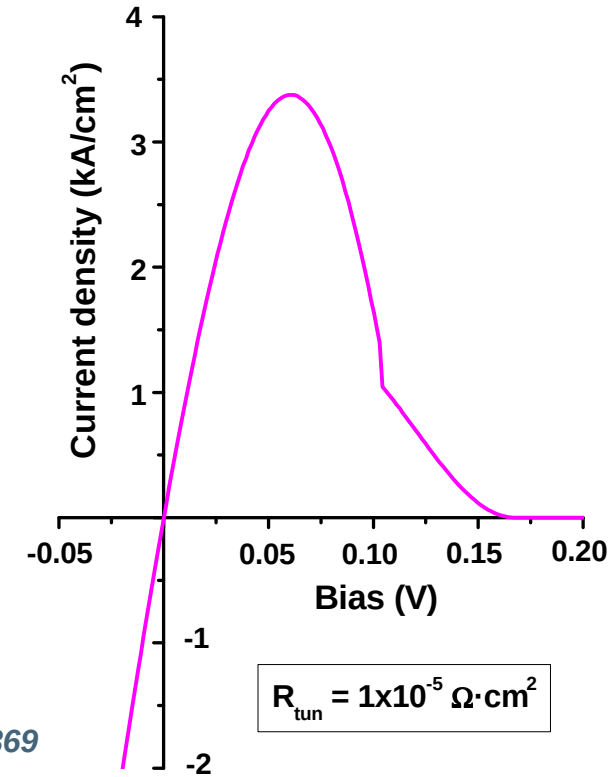
For both polarities, the conversion efficiency is limited by the absorptivity of the InGaN active layer corresponding to the optimal alloy composition, which does not exceed ~0.2 for III-polar structure.

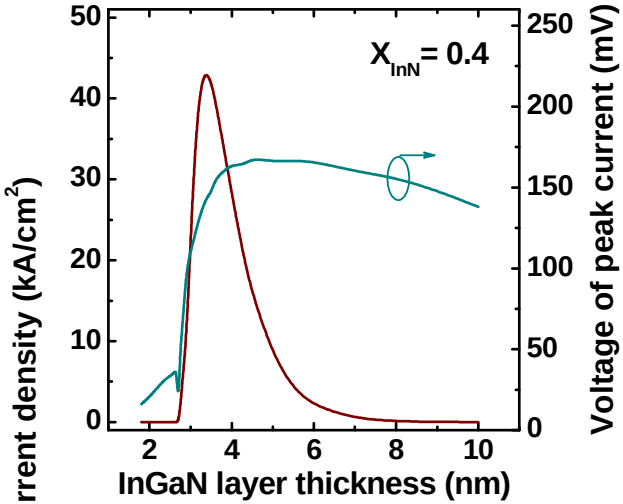
Tunnel junction for III-nitride solar cells capable of forward-bias operation

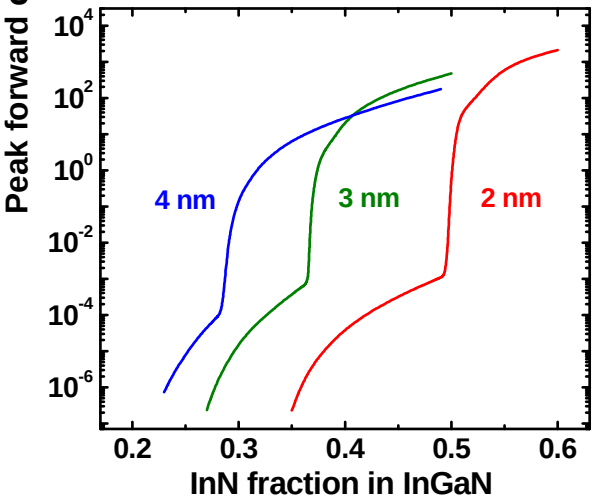
Tunnel junctions in III-nitride solar cells should maintain high forward currents to provide a low junction resistance, which is impossible for the p-GaN/n$^+$-GaN junctions because of limited hole concentrations

Using of polarization engineering may give solution of the problem









O.V. Khokhlev, K.A. Bulashevich, and S.Yu. Karpov, Phys. Stat. Solidi (a) 210 (2013) 1369

Conclusions

PVcell is the useful tool for design and optimization of semiconductor multijunction solar cells

PVcell software is supplied with

- **Physics Summary**
- **GUI Manual**
- **Materials database**
- **Set of examples**

Any questions on software operation and purchase procedure can be sent to *simuled-support@str-soft.com*