

Numerical analysis of GaInP solar cells: towards advanced photovoltaic devices modeling

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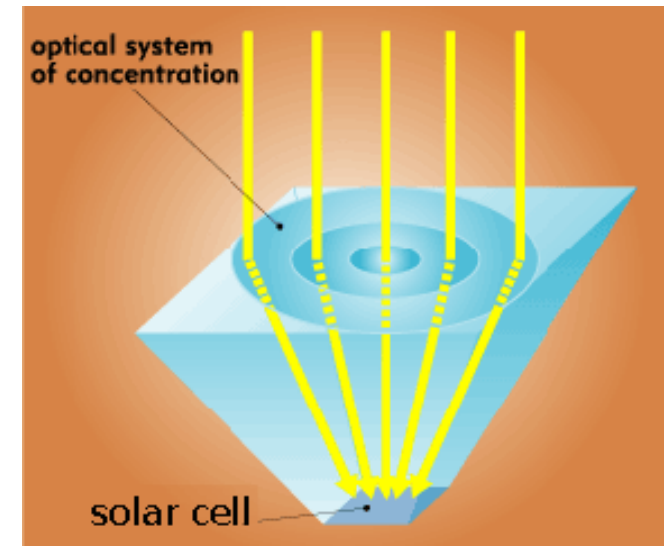
Summary

1. The concentration strategy
2. Traditional solar cells
3. Multi Junction solar Cell
4. The GaInP (top) cell
5. The simulation tool
6. Material parameters models
7. Results
8. Conclusion
9. Future works



The concentration strategy

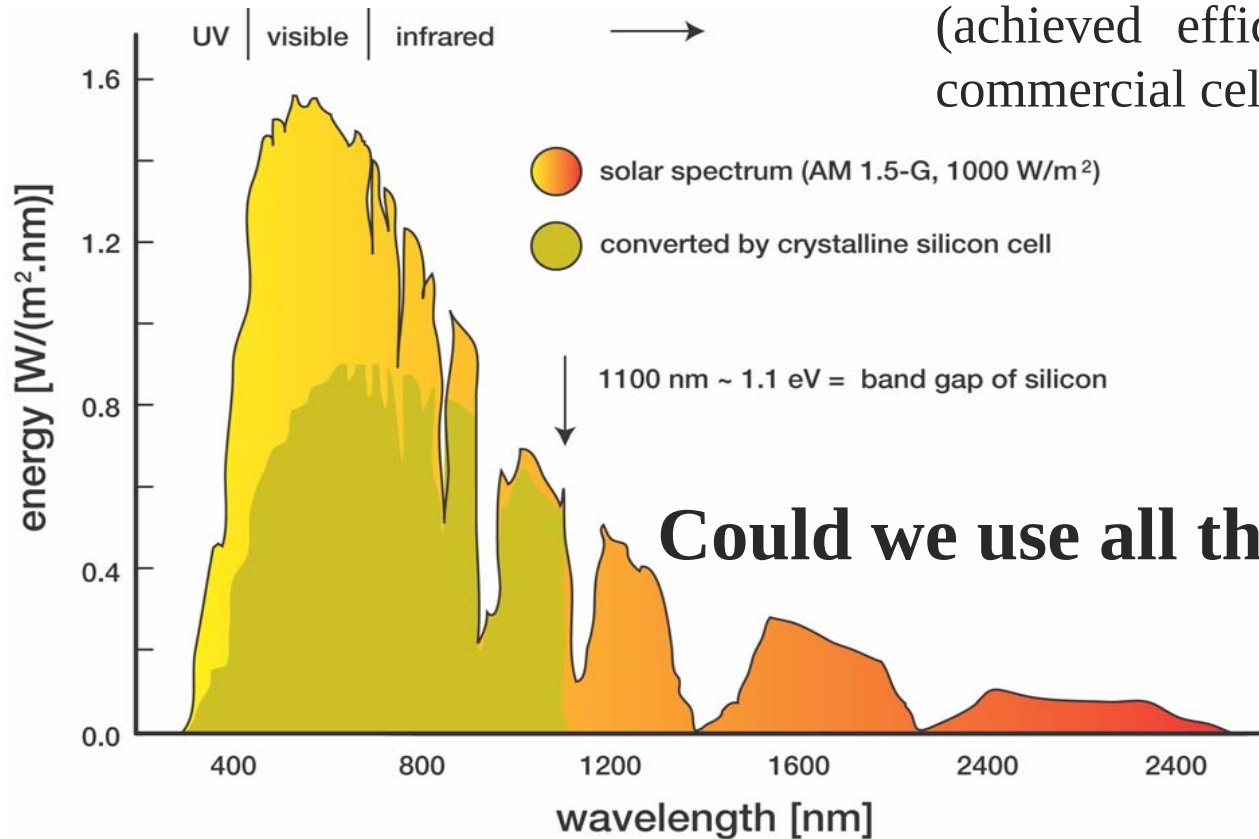
- The use of concentration allows cost reduction
 - Decreasing cell area to several mm^2
 - change price of solar cell (expensive) by price of optics
 - Increasing efficiencies
- Electricity medium term price of 3c€/kWh
- But implies several effects
 - Different illumination from the standard one
 - Inhomogeneous illumination on the cell
 - Light impinging the cell within a cone
 - Chromatic aberration
 - Temperature gradient



**→ Need for a 3D model
for the solar cell**

Traditional solar cells

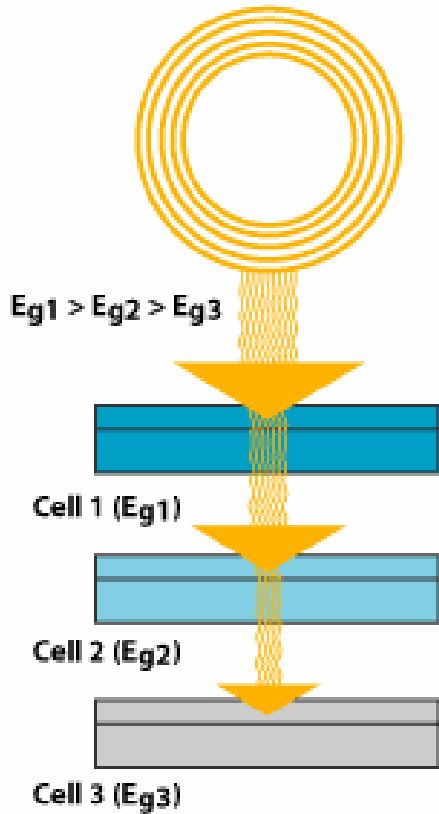
- Current solar cells are based on Si (achieved efficiencies about 15% for commercial cells)



Could we use all the solar spectrum ?



Multi Junction solar Cell



- Using different gap materials we can use all the solar spectrum
- That is the idea of **Multi Junction solar Cells**
- Efficiencies about 39% already achieved (with triple junction at 236 suns)

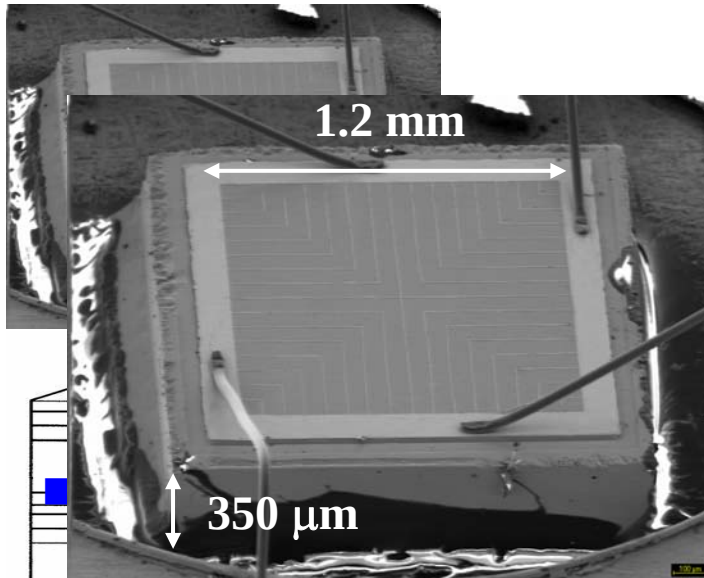


The Multi Junction solar Cell



MOVPE at IES-UPM

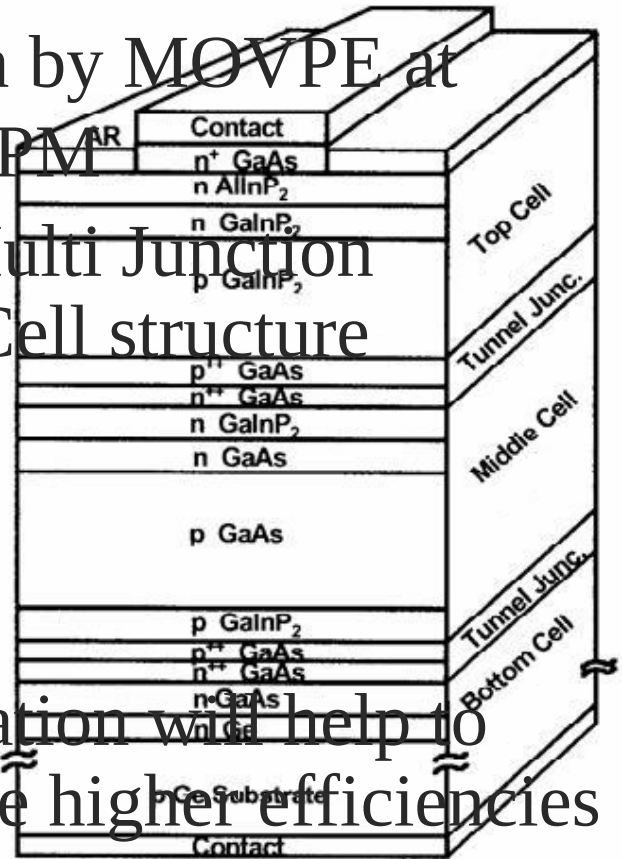
- Grown by MOVPE at



- The Multi Junction solar Cell structure

- Efficient junction

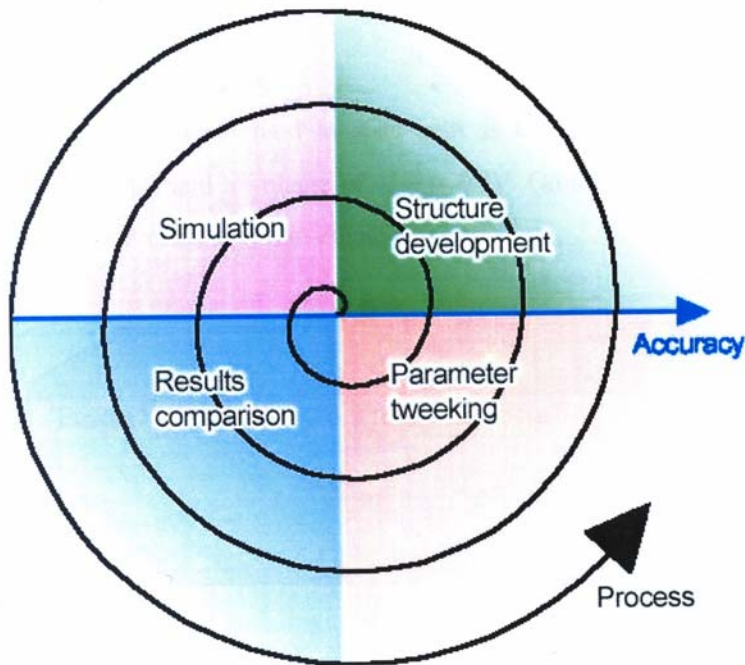
- Simulation will help to achieve higher efficiencies



%
le



Simulation Aided Optimization



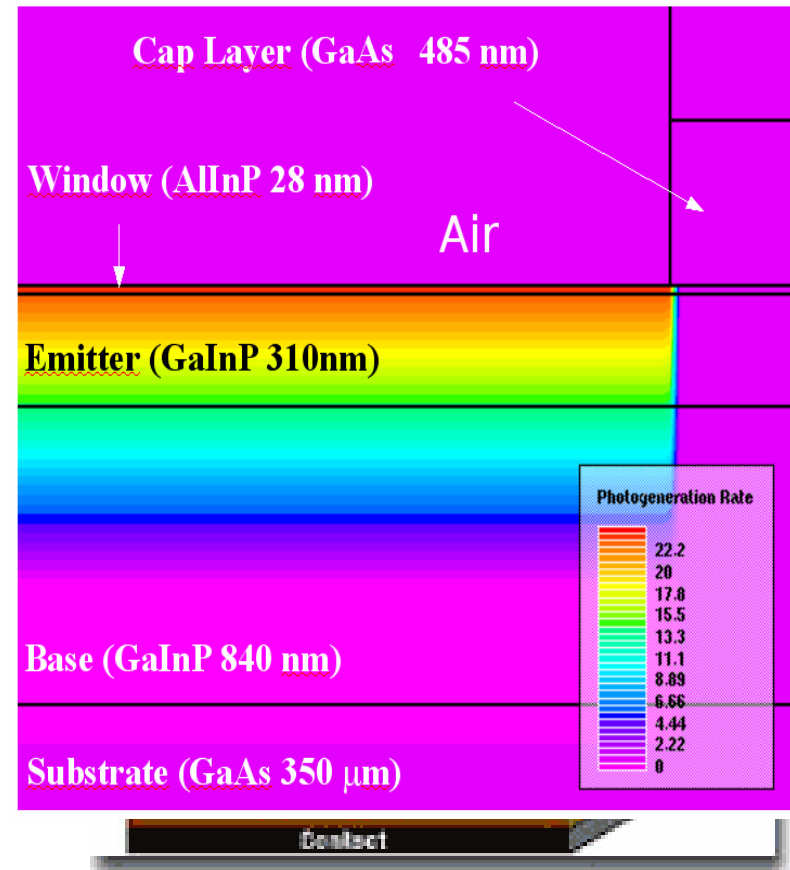
- The experimental results give material parameters (technology feedback)
- A reliable simulation tool can guide the structure optimization saving time and effort

The GaInP (top) solar cell

- The substrate is often considered as a simple mechanical support

OBJECTIVE:

Determine how the GaAs layer affects the GaInP cell behavior



The simulation tools

- Silvaco ATLAS was used for these simulations
- Physically based simulator
 - Solves Poisson's equation, carrier continuity equation, the drift-diffusion transport model and the energy balance transport model for each node of the structure
 - Versatile and highly customizable



Material parameters models

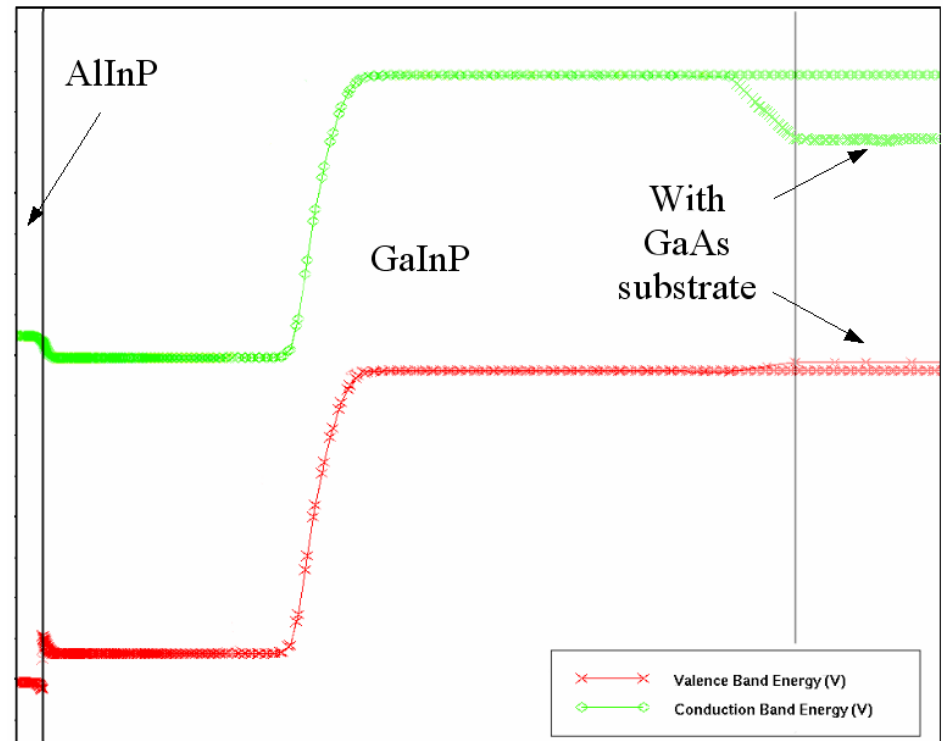
- Doping dependent mobility
- Doping dependent bandgap narrowing
- Doping and temperature dependent recombination rates
- Wavelength, doping and temperature dependent optical coefficients



Results: the substrate effect

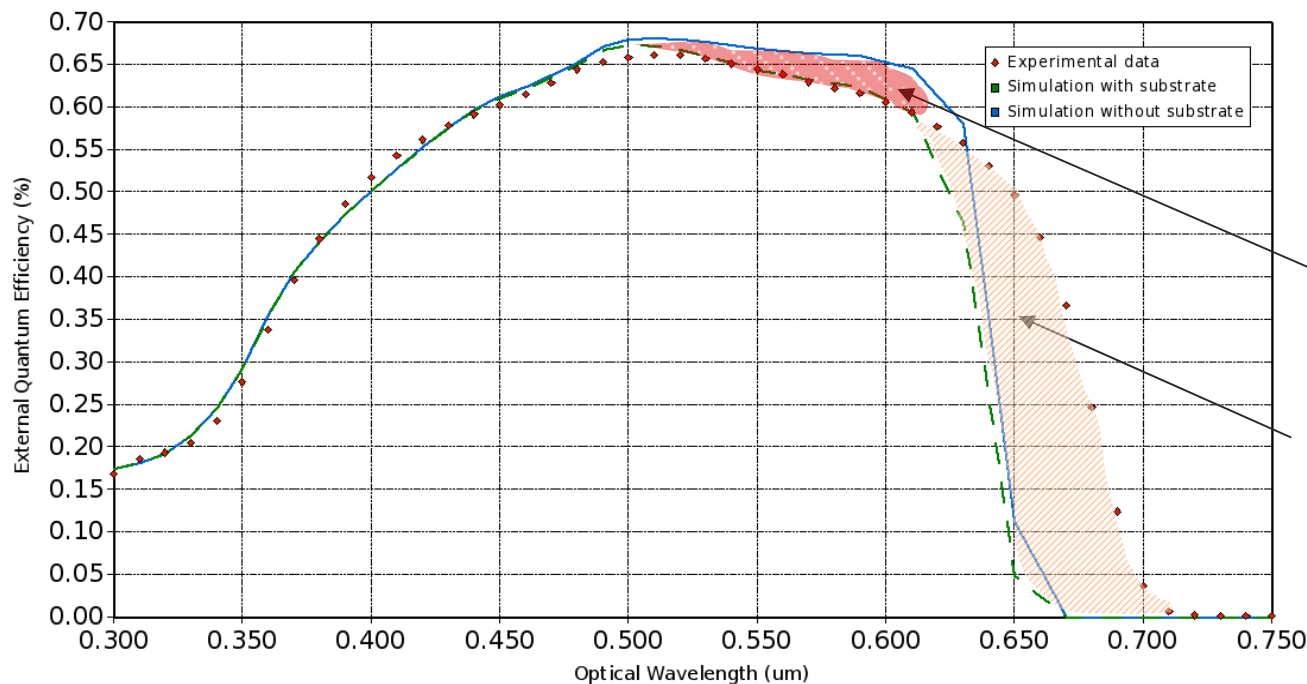
After 2h. solving the 14852 nodes 2D structure with all the external conditions, we have all the results we need to analyze: Band diagram, External Quantum Efficiency, IV curve , ...

- We see the band diagram is clearly modified by the presence of the substrate



Results: External Quantum Efficiency

- The results are quite different including or excluding the substrate
- Good agreement between experimental and numerical results
- Material parameters validated by the results



Substrate effect

Mismatch because of the formation of an undesired quaternary alloy (GaInAsP) ?



Results: layer structure comparison

- To adjust simulation and measurements we had to change some layer parameters such as thicknesses

	Foreseen thickness
<i>Total window/emitter/base thickness in nm</i>	1178

→ The simulation calculated thicknesses are closer to the real values than the foreseen values !

→ The technology feedback confirm the good behavior of the employed models



Results interpretation

- Modeling with the substrate allowed to well determine the real layer structure
- By fitting many experimental results we confirmed the validity of the GaAs, GaInP and AlInP parameters
- We proved simulation can be used to deduce structural data once accurate material parameters are introduced



Conclusion: the GaAs layer importance

We saw the importance of the substrate on the results,
so what are our conclusions for the future ?

- For Multi Junction solar Cell, the top cell will be above a tunnel junction
 - We have to consider the effect of this layer on the band diagram in the optimization process

- If not
 - We will have the best cell outside the Multi Junction solar Cell but not inside !



Future works (parameters and 2D)

- Include more accurate material parameters such as temperature dependent mobilities, ...
- Increase our material database (AlGaAs, AlGaInP, GaInNAs, InAlAs, ... are in process)
- Develop 2D models for GaInP/GaAs Double Junction solar cells and for GaInP/GaAs/Ge Triple Junction solar cells



Future works (3D)

- Achieve accurate modeling of single junction GaAs solar cell
- Include real operation conditions
 1. Different illumination from the standard one
 2. Inhomogeneous illumination on the cell
 3. Light impinging the cell within a cone
 4. Chromatic aberration
 5. Temperature gradient
- Start 3D modeling of Double Junction solar cell

