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Towards III-V on silicon solar cells

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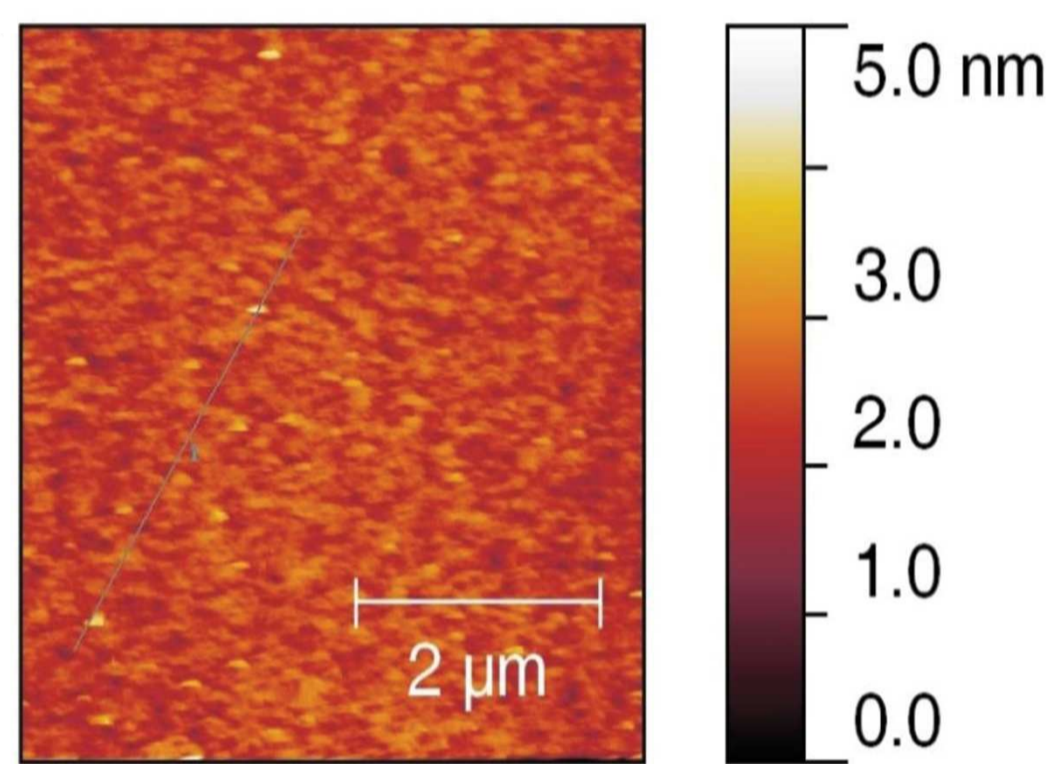
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GaP/Si heterojunctions for photovoltaics

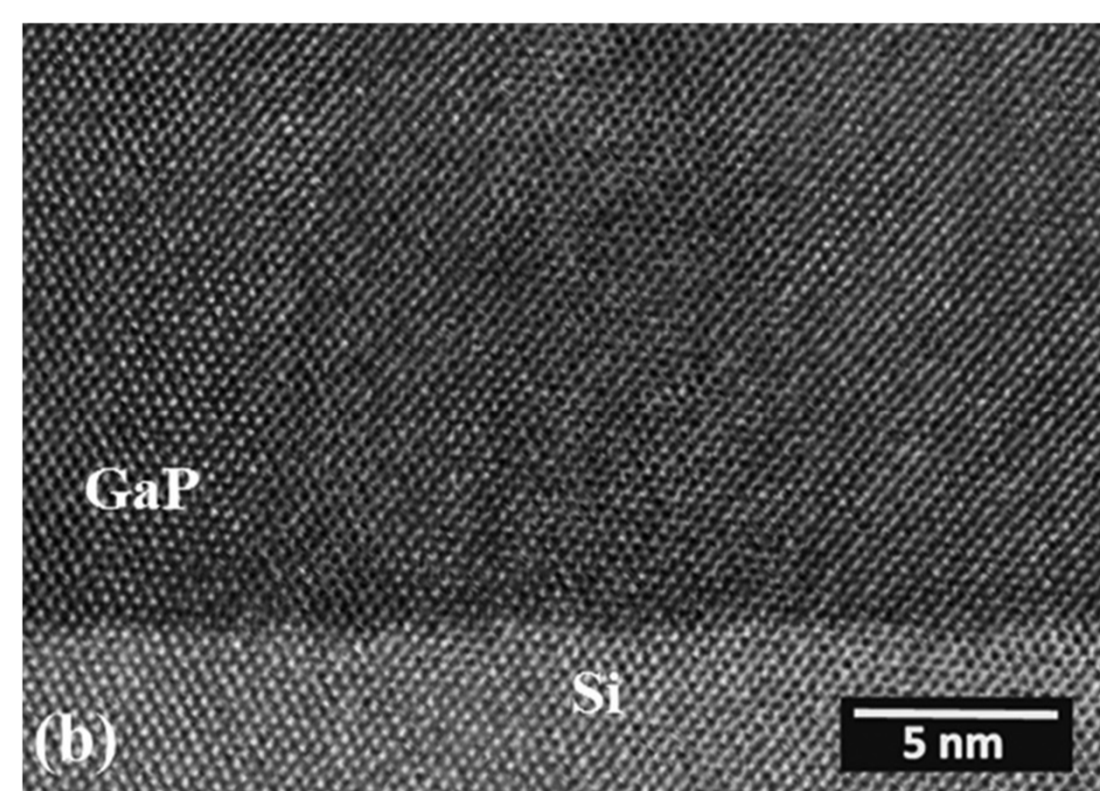
- *Tandem cells on silicon : high performance of multijunction solar cells on a classical photovoltaic substrate : silicon*
- *Epitaxial GaP layer as a transparent conductive layer on a single junction silicon solar cell to limit Si(n) absorption*
- *GaP(n)/Si(p) heterojunction to enhance V_{oc} and high energy absorption*

Optimizing GaP/Si interface

GaP MBE 35 nm (500°C)
GaP MEE 10 nm (350°C)
Si (001) substrate



AFM : Weak roughness (RMS 0.3 nm)



Cross-sectional HRSTEM image of GaP epilayer grown on Si substrate

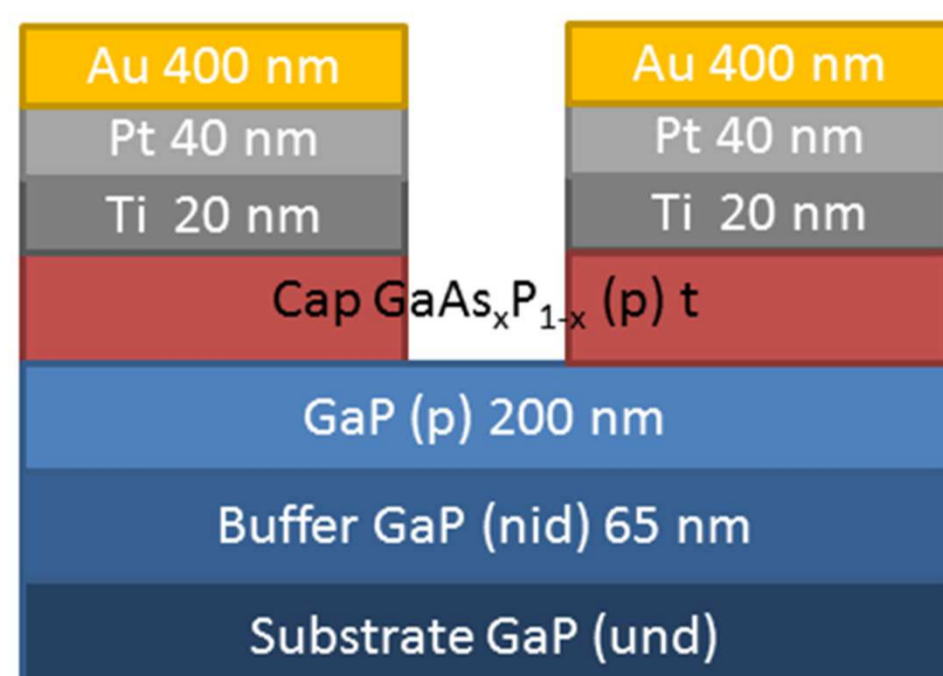
Ping Wang, Y., *Appl. Phys. Lett.* **107**, 191603 (2015)

State-of-the art GaP/Si(001) platform :

Very low density of micro-twins
annihilation of the antiphase domains after only 10 nm GaP growth

But doping GaP at the Si interface remains challenging

Ohmic contacts on GaP

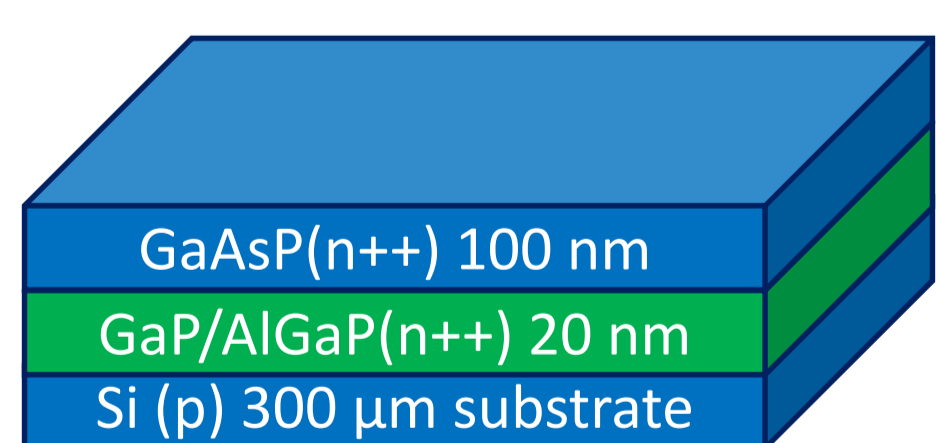


Direct p-type ohmic contact on GaP requires exotic metal : Pd/Zn/Pd

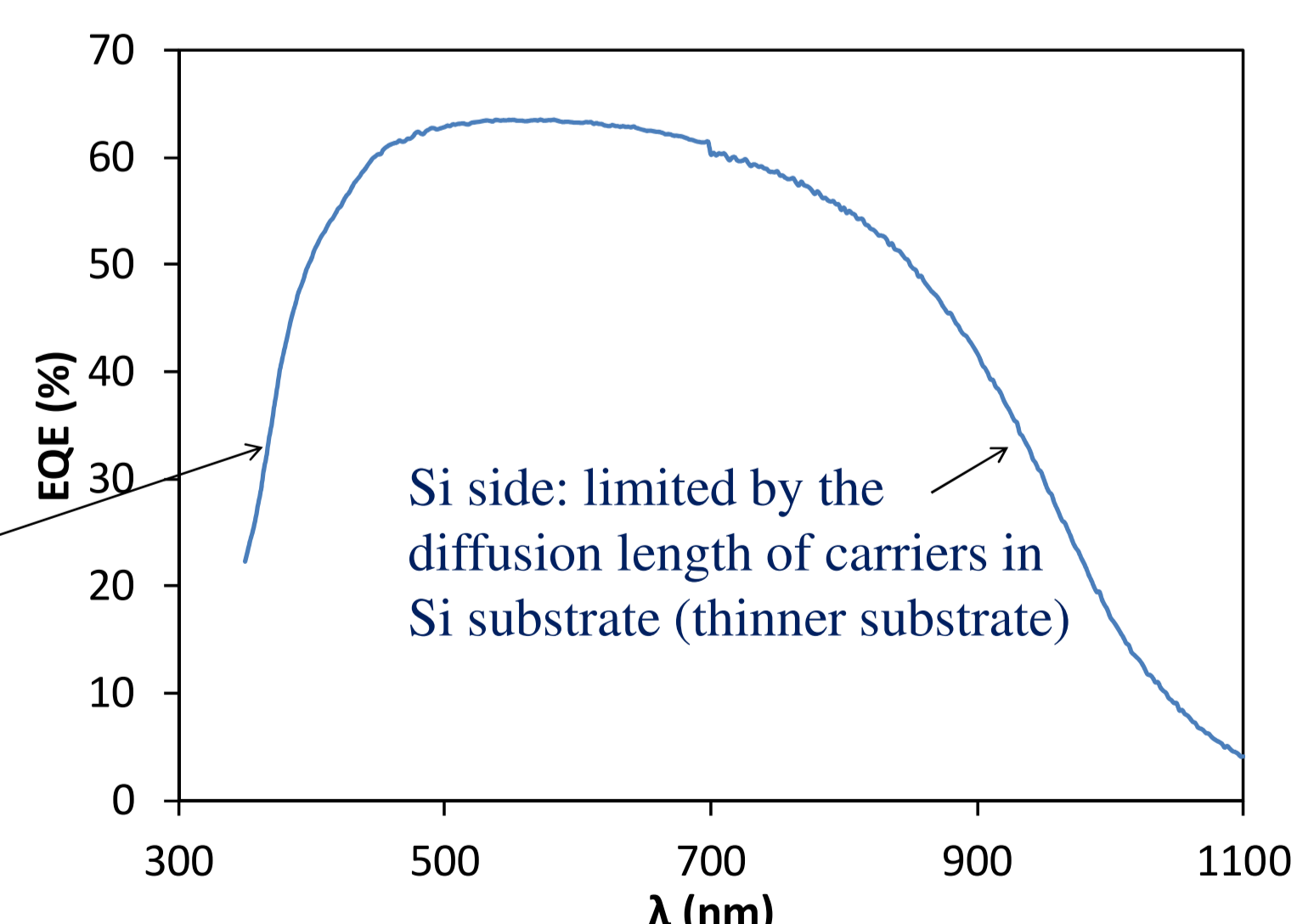
Supplementary epitaxial GaAsP allows to use Ti/Pt/Au

20 nm GaAs_{0.1}P_{0.9} heavily doped : $N_a = 3 \cdot 10^{19} \text{ cm}^{-3}$
Ohmic contact on GaP :
 $\rho_c = 4 \cdot 10^{-6} \Omega \cdot \text{cm}^2$ after 35s annealing @ 375°C

Attempt of GaP/Si heterojunction solar cell



External quantum efficiency max : 63.5%
Drop of EQE at short wavelength due to surface recombination at the n-GaP surface and diffusion length on the GaP side



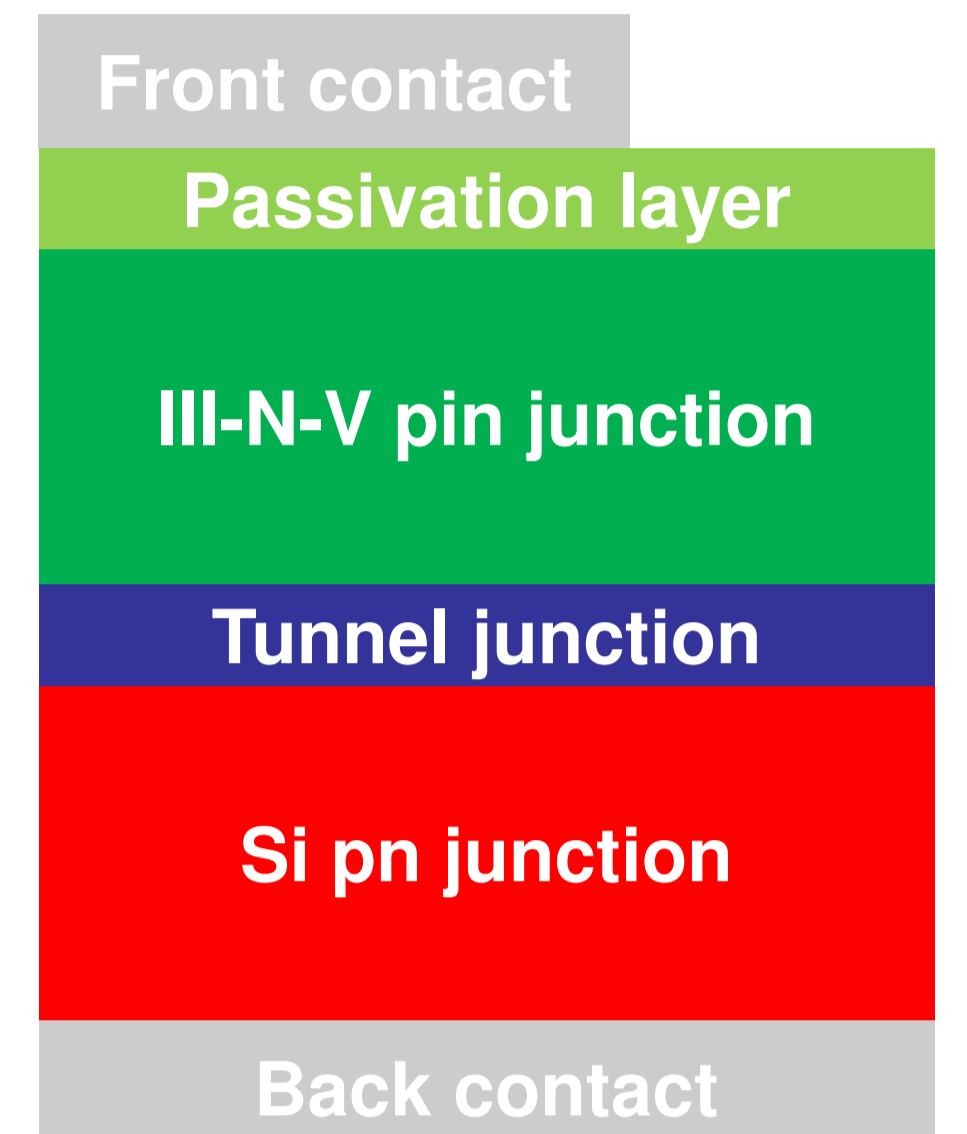
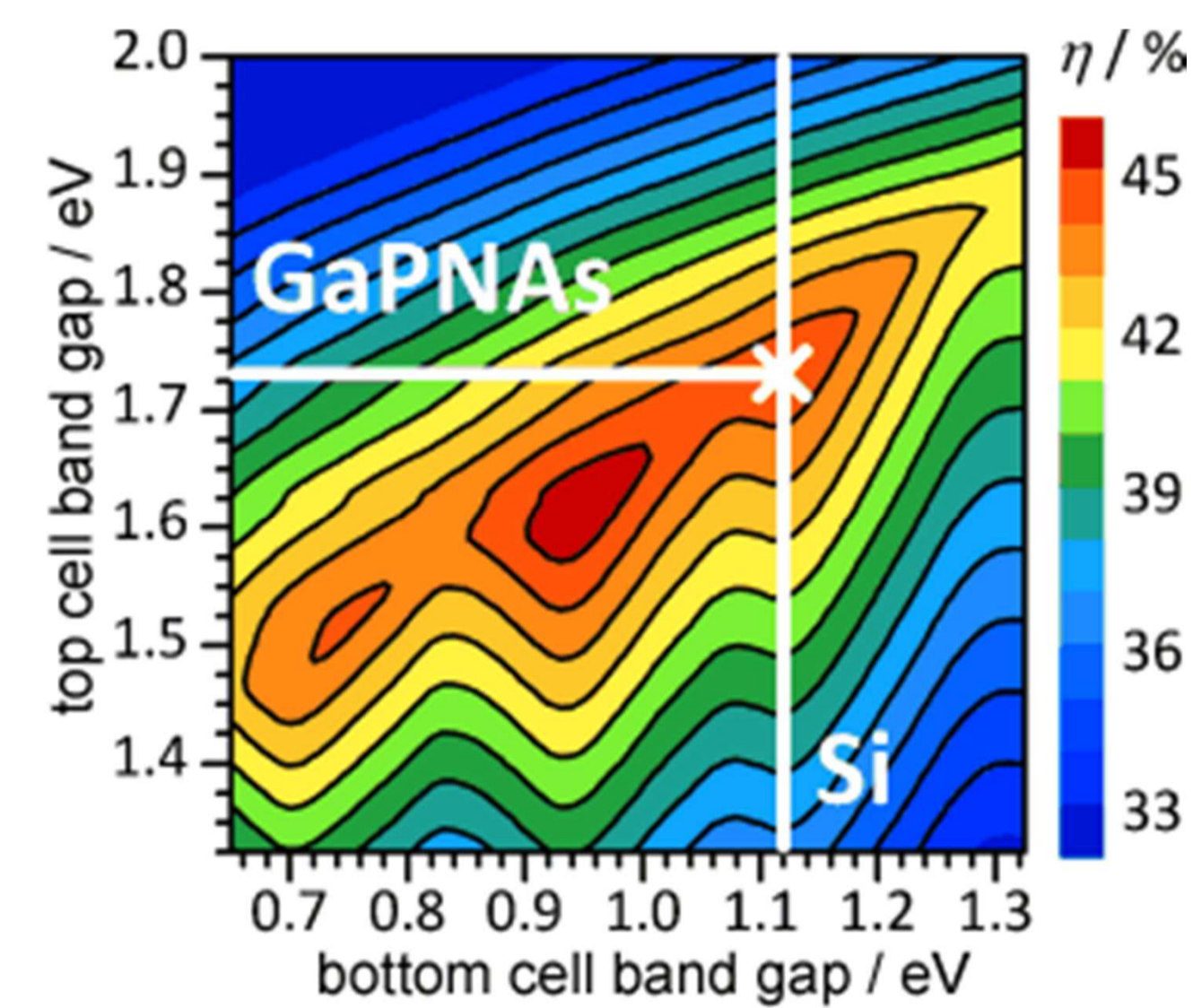
Poor electrical performances due to very bad contact on the Si side and carrier trapping at the doped GaP/Si interface : $V_{oc} = 0,244 \text{ V}$, Efficiency : 0.45 %

Doping the GaP layer at the vicinity of the GaP/Si interface is a very strong issue because dopants seem to accumulate at APBs locally overpassing the solubility limit.

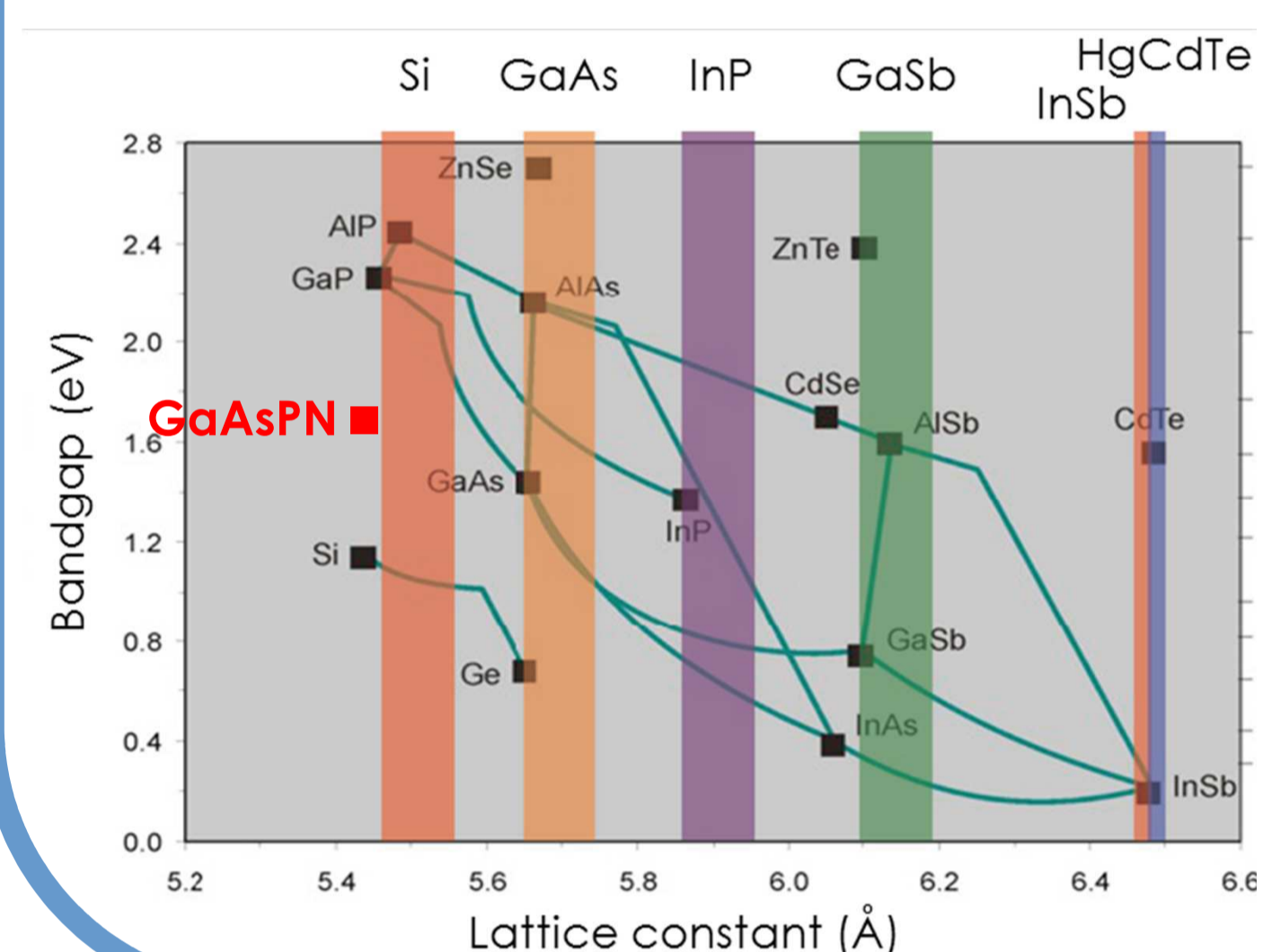
Further work :

- optimizing Si contact and GaP/Si interface with dopants
- Using the GaP layer as transparent conductive layer on a Si homojunction

GaAsPN on Si tandem cells: high efficiency and low cost



N and As decrease the GaP bandgap from 2.3 eV to 1.7 eV and ensure the lattice matching with Si



Main challenges:

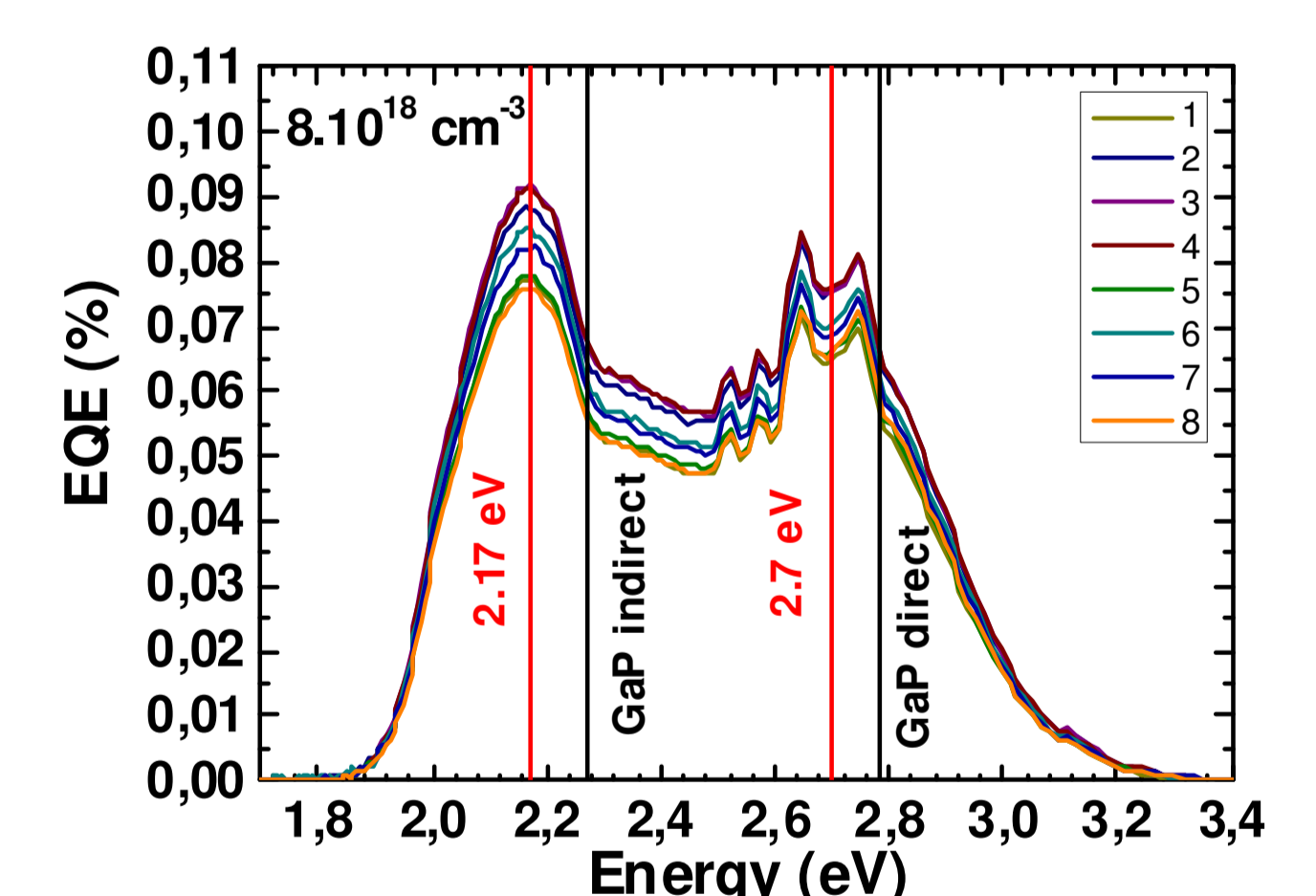
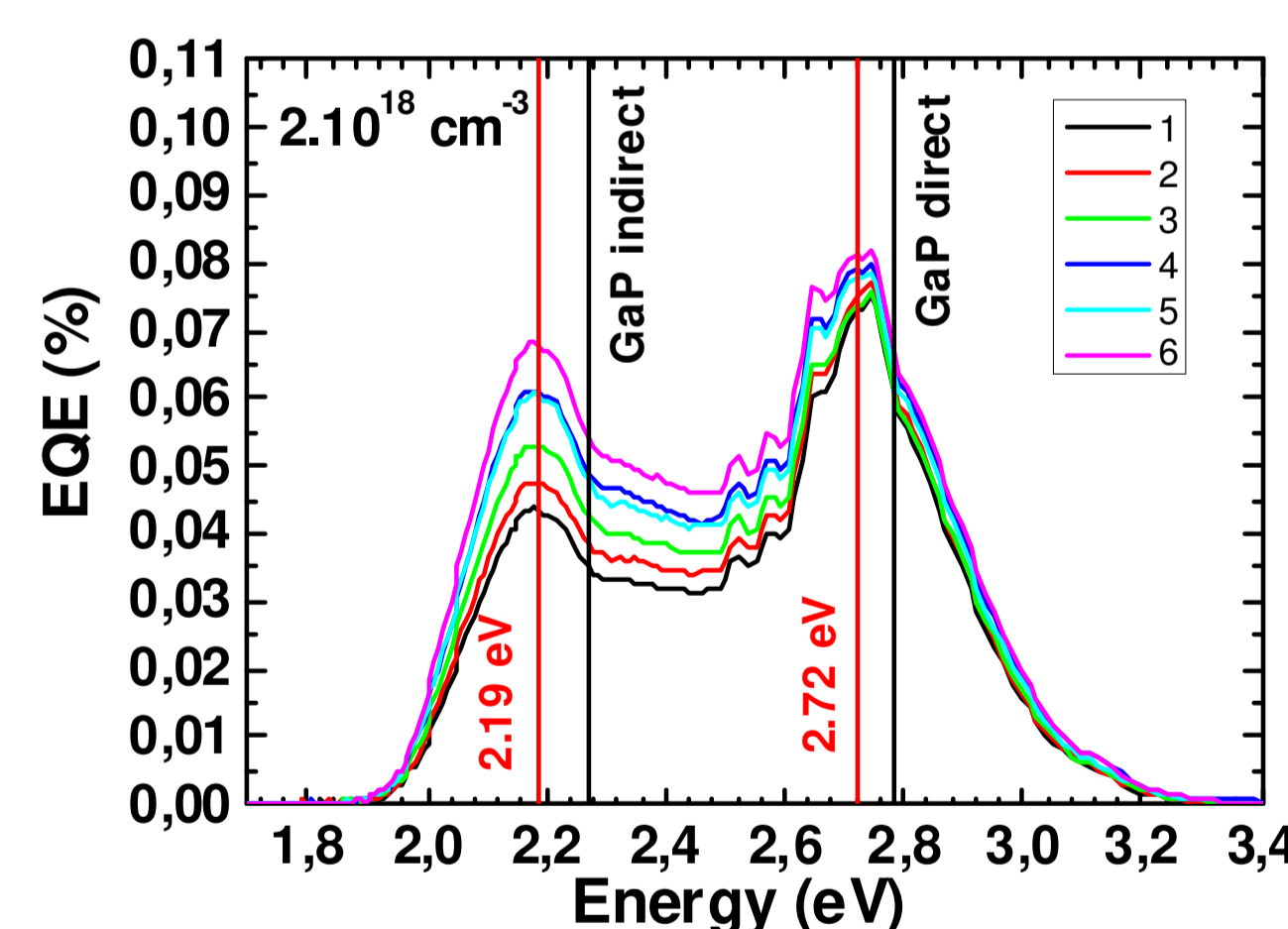
- Ohmic contacts on GaP (n: Ni/Au/Ge and p: Ti/Pt/Au on GaAsP p++)
- Reducing the surface recombination velocity
- Improving optoelectronic properties of the III-V absorber
- III-V/Si interface (Si/GaP pseudo-substrate)
- Efficient tunnel junction between III-V and Si based materials

GaP top cell optimization

Several studies already performed :

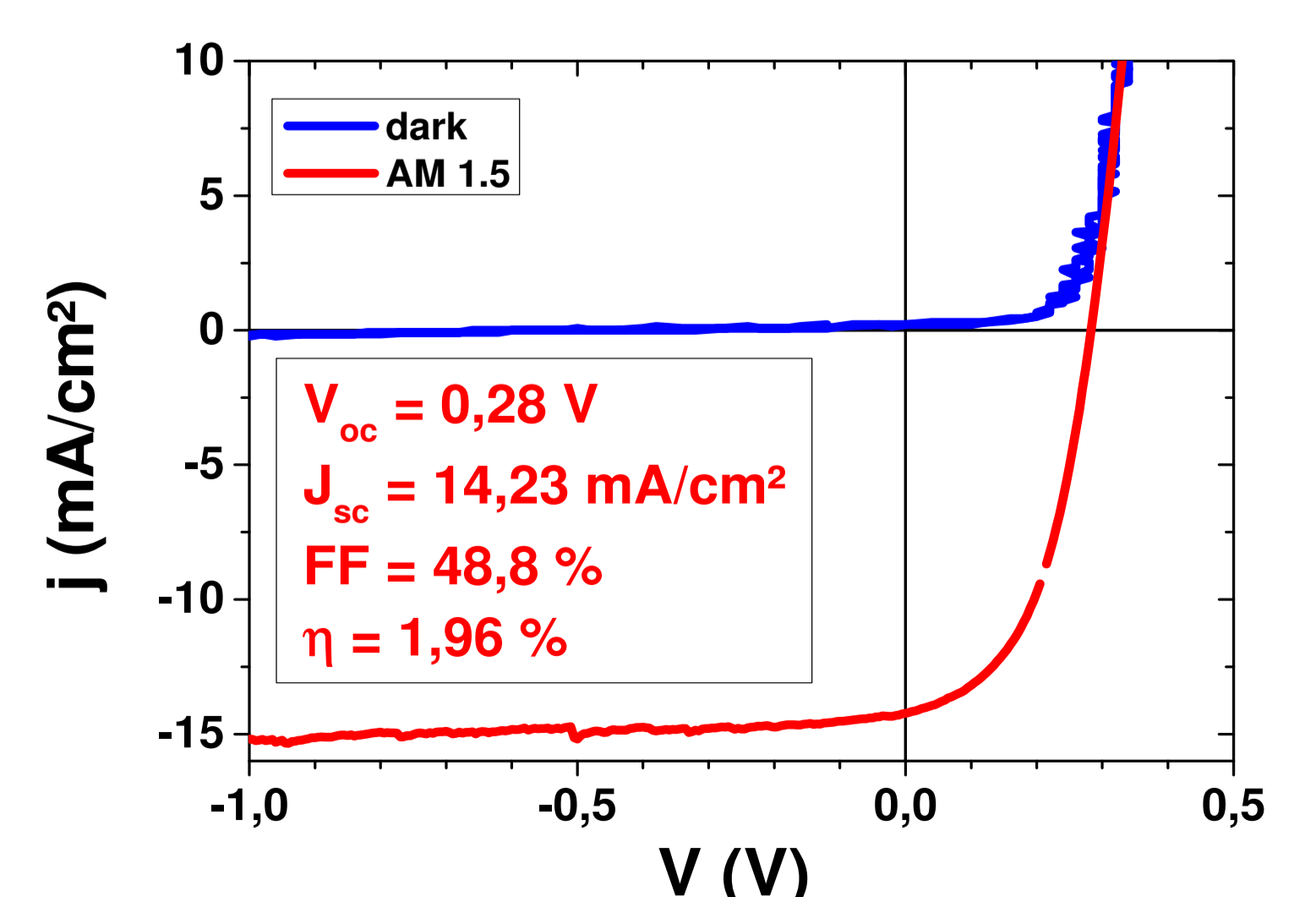
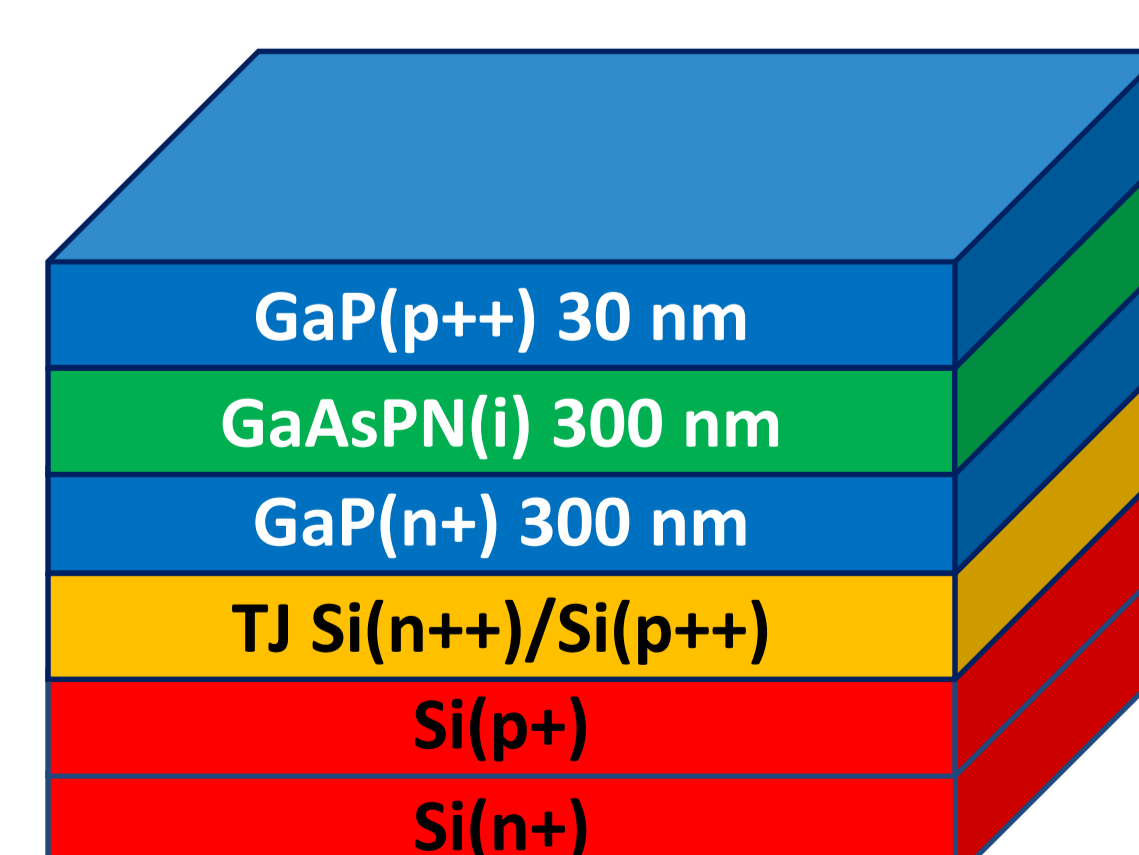
- Absorber layer optimization : $T_g = 480^\circ\text{C}$, $V/III = 10-11$, $Gr = 0,5 \text{ ML/s}$
- Low carrier mobility in GaAsPN: 300 nm-thick absorber
- Optimized composition : GaAs_{0.1}P_{0.88}N_{0.02} : pseudo-direct gap @ 1.7 eV, lattice matched to silicon

New study : optimization of the n-doped layer



Low energy peak increases with n doping level: better current collection near the GaAsPN/GaP:n interface

First tandem cell on VPE Si pn junction



Encouraging photovoltaic effect.

Non optimal regrowth due to new TJ process

→ low surface quality → interfacial recombinations = low V_{oc} ?