Resonant states in the surface depletion region of p-GaN observed by low energy photoemission

Mylène Sauty[1,2], Jean-Philippe Banon[1,3]

[1] **Laboratoire de Physique de la Matière Condensée, CNRS, Ecole polytechnique, Institut Polytechnique de Paris, Palaiseau, France**
[2] Now at Cavendish Laboratory, University of Cambridge, J. J. Thomson Avenue, Cambridge, United Kingdom
[3] Now at Laboratoire Charles Fabry, Institut d'Optique, CNRS, Université Paris-Saclay, Palaiseau, France

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Contributors

M. Sauty

J. Peretti

J. Speck

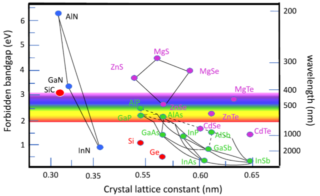
C. Weisbuch

Nicolas M. S. Lopes, Abdullah Alhassan, Yves Lassailly

Context

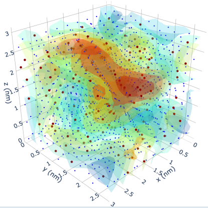
Nitrides = III-N semiconductors

Bandgap engineering

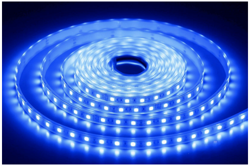


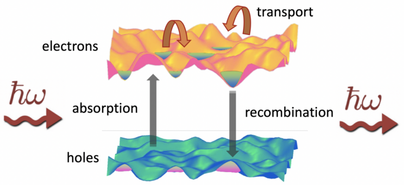
C. Weisbuch, Comptes Rendus Physique, Volume 19, Issue 3 (2018)

$In_xGa_{1-x}N$



LED, lighting applications





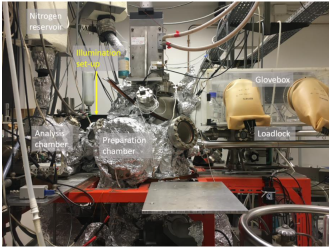
Study of the impact of alloy-disorder
→ Thursday 10:15 MC20.

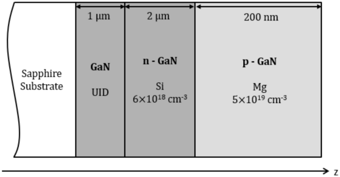
Today's talk is about GaN (no alloy disorder)

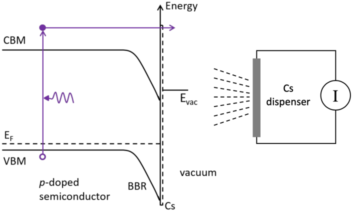
- Study of band structure of GaN by low energy photoemission.
- Sub-band gap photoemission.
- **Observation of resonant states in the surface depletion region.**

Low energy photoemission experiment

Experimental setup and basic principles







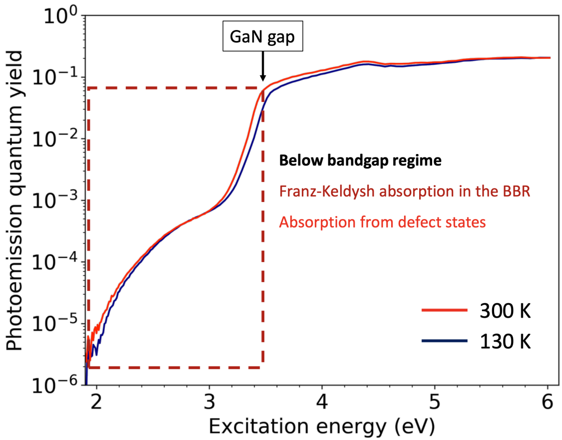
Three-step process

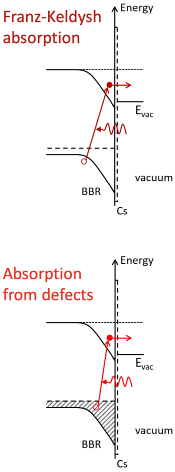
- Photon absorption, creation of e-h pair.
- Electron relaxation and transport in the conduction band.
- Electron transmission through the surface.

Sub-bandgap quantum yield

Measuring the quantum yield

$$\text{Quantum yield} = \frac{\text{number of emitted electrons}}{\text{number of incident photons}}$$



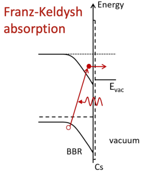


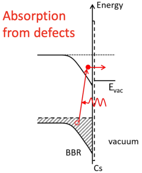
M. Sauty et al., Phys. Rev. Lett. 129(21), 216602 (2022)

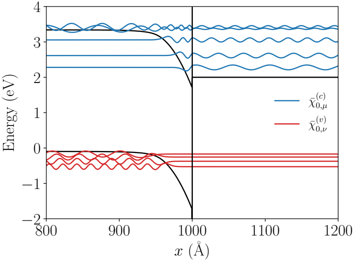
Main assumptions of the model

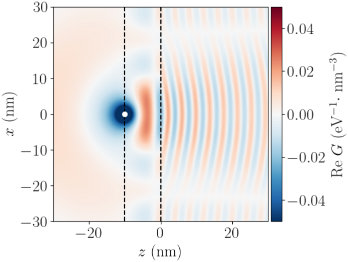
- Effective mass approximation with interface condition linking the envelope function in the semiconductor to wave function in vacuum.
- Band profile given by classical Poisson equation.
- Relaxation neglected.
- Scattering neglected.
- Recombination neglected.
- Type of initial states: "quasi" Bloch waves, point like states (defect, impurity, surface states, ionized acceptors).

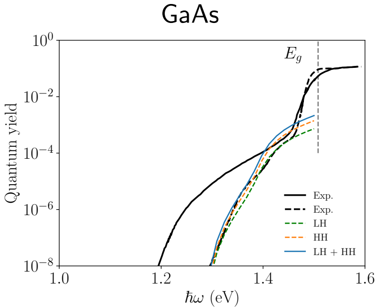
Illustration of the sub-bandgap emission processes

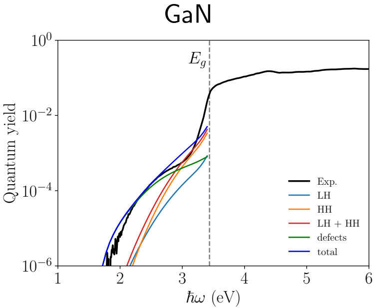












Acceptor concentration 10^{19} cm^{-3}
Bandgap ≈ 1.5 eV
Vacuum level $E_{\rm vac} - E_{\rm F} = 1.27$ eV.

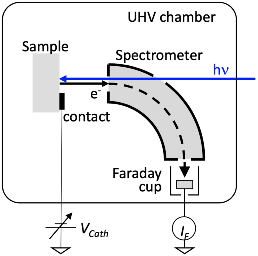
Acceptor concentration 2×10^{20} cm^{-3}
Bandgap ≈ 3.4 eV
Vacuum level $E_{\rm vac} - E_{\rm F} = 1.5$ eV.

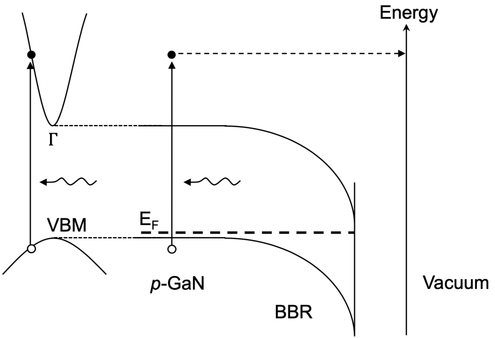
GaAs exp. data from: *A. A. Pakhnevich et al. Spin 2004 959-963* / GaN exp. data from: *M. Sauty et al., Phys. Rev. Lett. 129(21), 216602 (2022)*

Electron energy distribution

Measuring the energy distribution of the emitted electrons

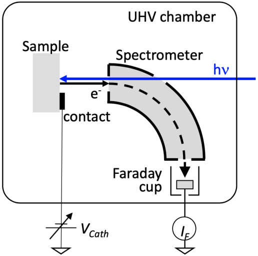
Energy resolution = 50 meV

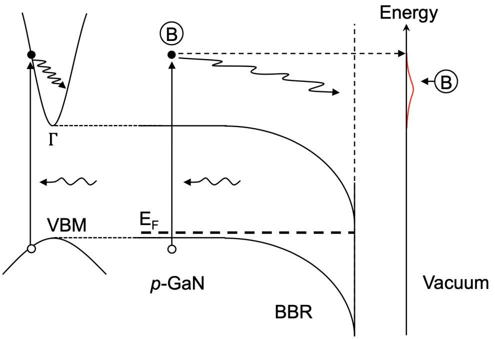




Measuring the energy distribution of the emitted electrons

Energy resolution = 50 meV





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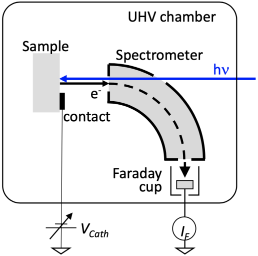

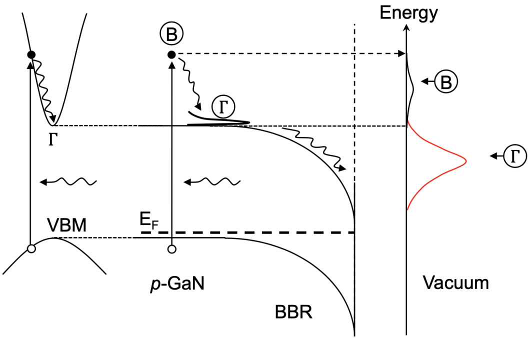

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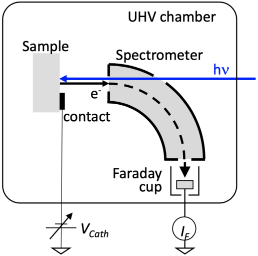

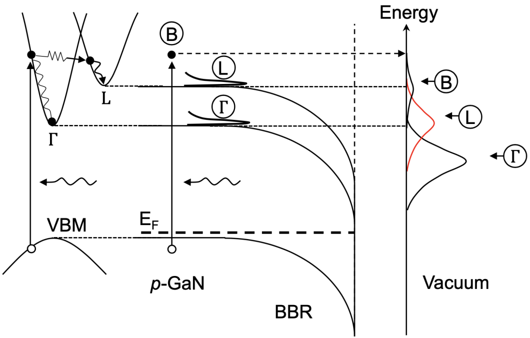

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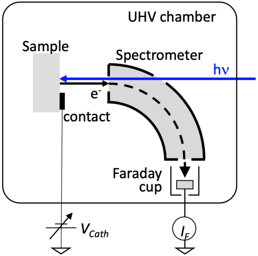

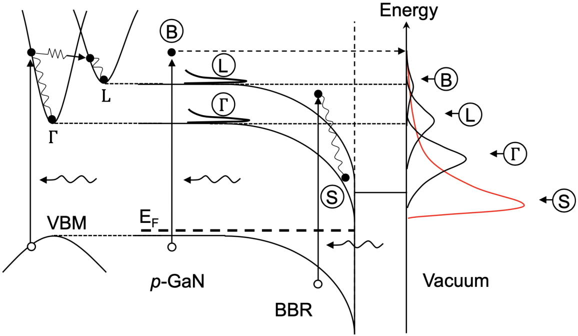

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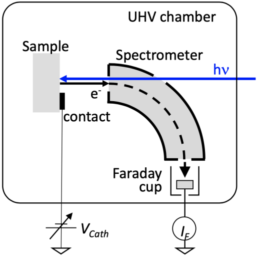

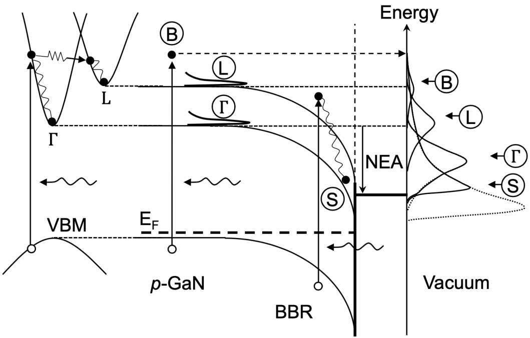

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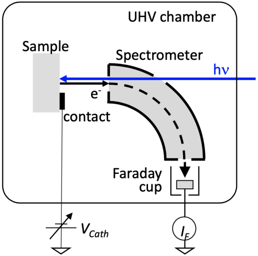
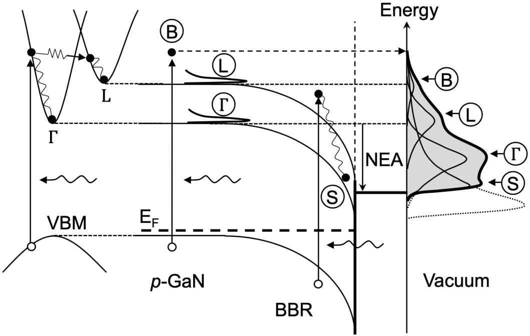
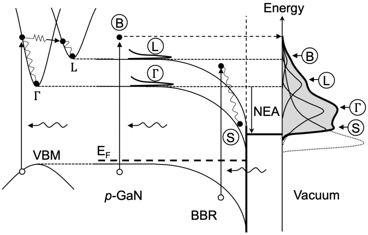
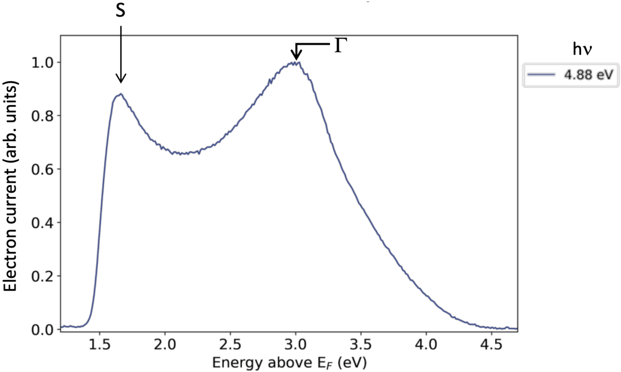


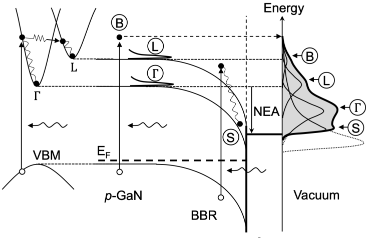


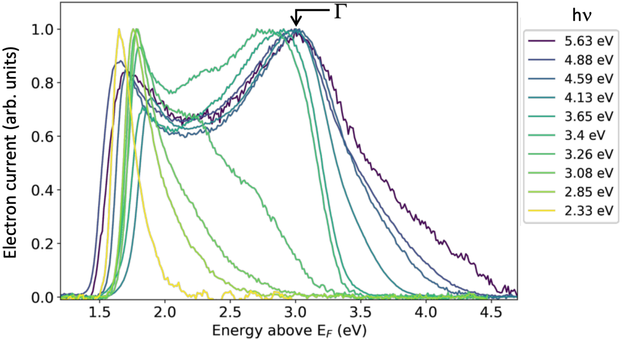
Energy distributions of emitted electrons



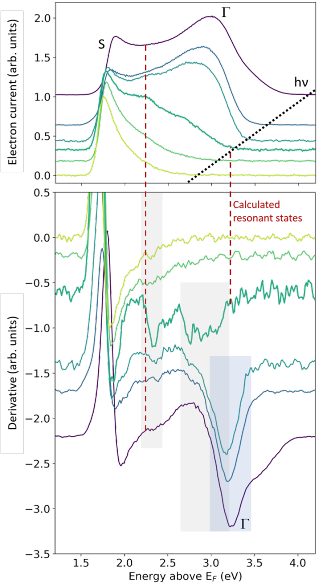


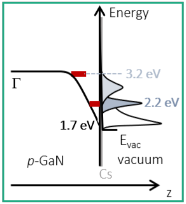
Energy distributions of emitted electrons





Signatures of resonant states?





Photon energy

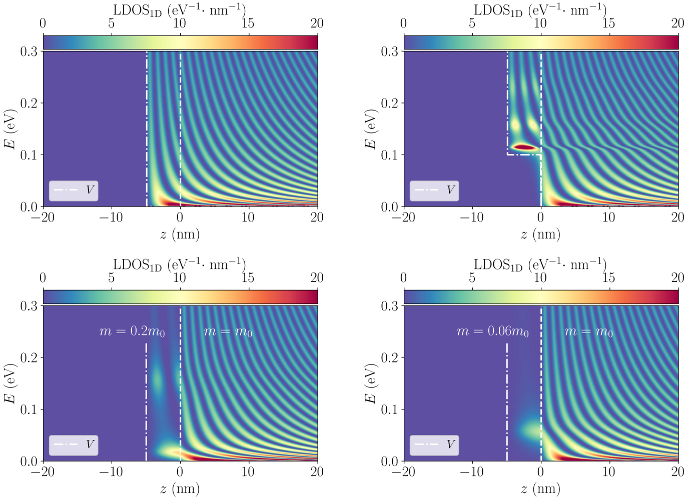
- 4.13 eV
- 3.65 eV
- 3.4 eV
- 3.26 eV
- 3.08 eV
- 2.85 eV

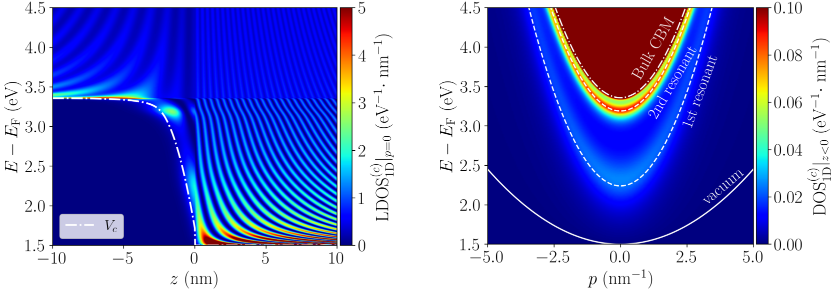
What are resonant states?

Resonant states

Consider the Schrödinger equation with varying potential *and/or* mass

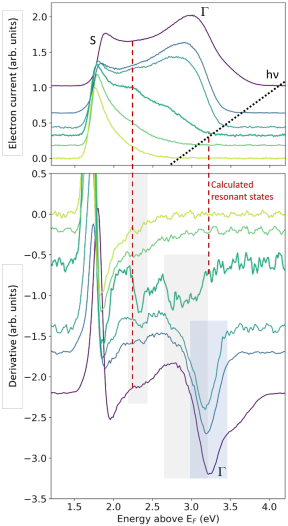
$$-\frac{\hbar^2}{2}\nabla\cdot\left[\frac{\nabla\psi}{m}\right]+V\psi=E\psi$$

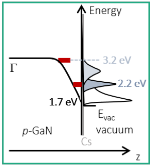


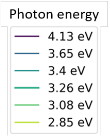


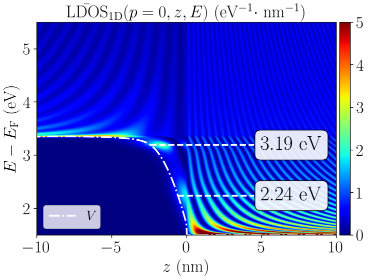
Over-doped p-GaN, $[\mathrm{Mg}] \approx 2 \times 10^{20}$ cm^{-3}.

Signatures of resonant states?









Thank you for your attention.