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

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Context
Context for the study of nitride ternary alloys

Nitrides = III-N semiconductors
Bandgap engineering

\[ \text{LED, lighting applications} \]

\[ \text{Study of the impact of alloy-disorder} \rightarrow \text{Thursday 10:15 MC20.} \]
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

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

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
Comparison experiment vs theory

**GaAs**

Acceptor concentration $10^{19}$ cm$^{-3}$
Bandgap $\approx 1.5$ eV
Vacuum level $E_{\text{vac}} - E_F = 1.27$ eV.

**GaN**

Acceptor concentration $2 \times 10^{20}$ cm$^{-3}$
Bandgap $\approx 3.4$ eV
Vacuum level $E_{\text{vac}} - E_F = 1.5$ eV.

Electron energy distribution
Measuring the energy distribution of the emitted electrons

Energy resolution = 50 meV

V_{Cath}
Measuring the energy distribution of the emitted electrons

Energy resolution = 50 meV
Measuring the energy distribution of the emitted electrons
Measuring the energy distribution of the emitted electrons

Energy resolution = 50 meV

Sample
UHV chamber
Spectrometer
Faraday cup

$V_{Cath}$
$I_F$

$e^-$ contact

$hv$

$\Gamma$

VBM

$E_F$

$p$-GaN

BBR

Energy

Vacuum

$\Gamma$

$\text{B}$

$\text{L}$

$\text{B}$

$\text{L}$

Measuring the energy distribution of the emitted electrons

Energy resolution = 50 meV

Sample

Spectrometer

Faraday cup

UHV chamber

hv

e

V_{Cath}

I

B

L

Γ

Γ'

S

VBM

E_F

p-GaN

BBR

Vacuum

Energy

J.-P. Banon

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9 / 14
Measuring the energy distribution of the emitted electrons

Energy resolution = 50 meV
Measuring the energy distribution of the emitted electrons

Energy resolution = 50 meV
Energy distributions of emitted electrons

![Diagram showing energy levels and electron distribution](image-url)
Energy distributions of emitted electrons

![Diagram showing energy levels and transitions in a material such as p-GaN, with a graph below illustrating electron current as a function of energy above the Fermi level (E_F) for different photon energies (hv).]
Signatures of resonant states?
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, $[\text{Mg}] \approx 2 \times 10^{20} \text{ cm}^{-3}$. 
Signatures of resonant states?

Electron current (arb. units)

Derivative (arb. units)

Energy above $E_F$ (eV)

Photon energy

LDOS$_{1D}(p = 0, z, E)$ (eV$^{-1}$, nm$^{-1}$)
Thank you for your attention.