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Polaritonic emission from an electrically injected semiconductor device

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LABORATOIRE DE PHOTONIQUE ET DE NANOSTRUCTURES

Motivation

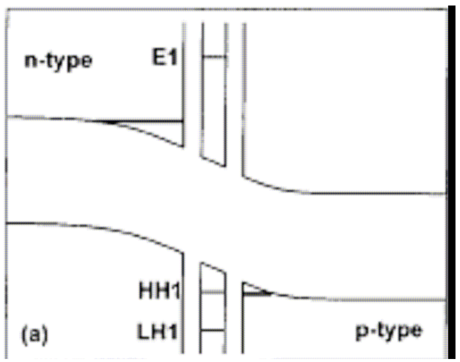
To implement the physics of the light-matter strong coupling regime in an electroluminescent semiconductor device.

Polaritons are bosons:

Exploit the strong coupling regime to realise the ***"DREAM LASER"****: a laser without population inversion*

BEC has been observed in microcavity exciton polaritons under optical excitation (Kasprzak et al., *Nature* **443**, 409 (2006)).

For exciton polaritons the electrical excitation is still a big deal …



In resonant tunnelling diodes based on GaAs/AlGaAs:

$E_{gap}(emitter/collector) < E_{exc}$

→ Absorption of the light at the exciton energy!

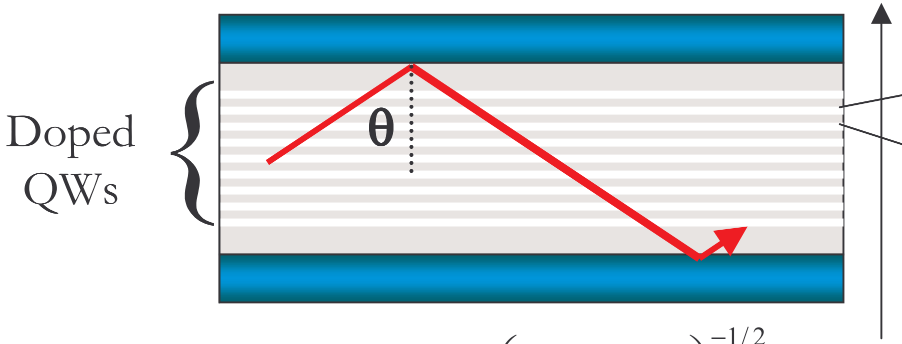
Very low current (~A/cm^2), low temperature

Outline

- Intersubband polaritons: mixed states arising from an intersubband excitation and a cavity mode
  (first observation: Dini et al. PRL 2003)
- The sample
- Reflectivity measurements: a proof of the strong coupling regime
- Electroluminescence measurements
- Selective tunnelling into polariton states : populate polariton states at a given energy

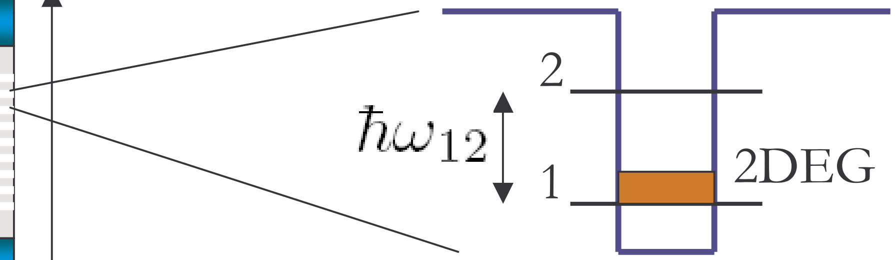
Intersubband polaritons

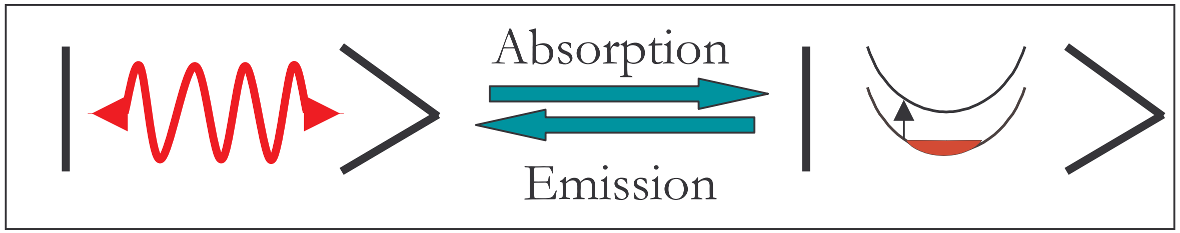
Planar optical microcavity



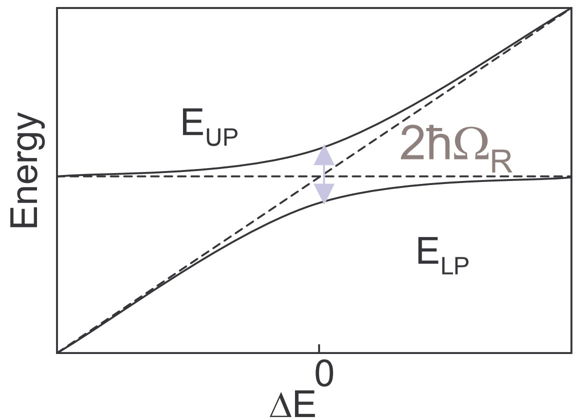
$$E_{cav}(\theta) = E_0\left(1-\frac{\sin^2\theta}{n_{eff}^2}\right)^{-1/2}$$

Intersubband transition



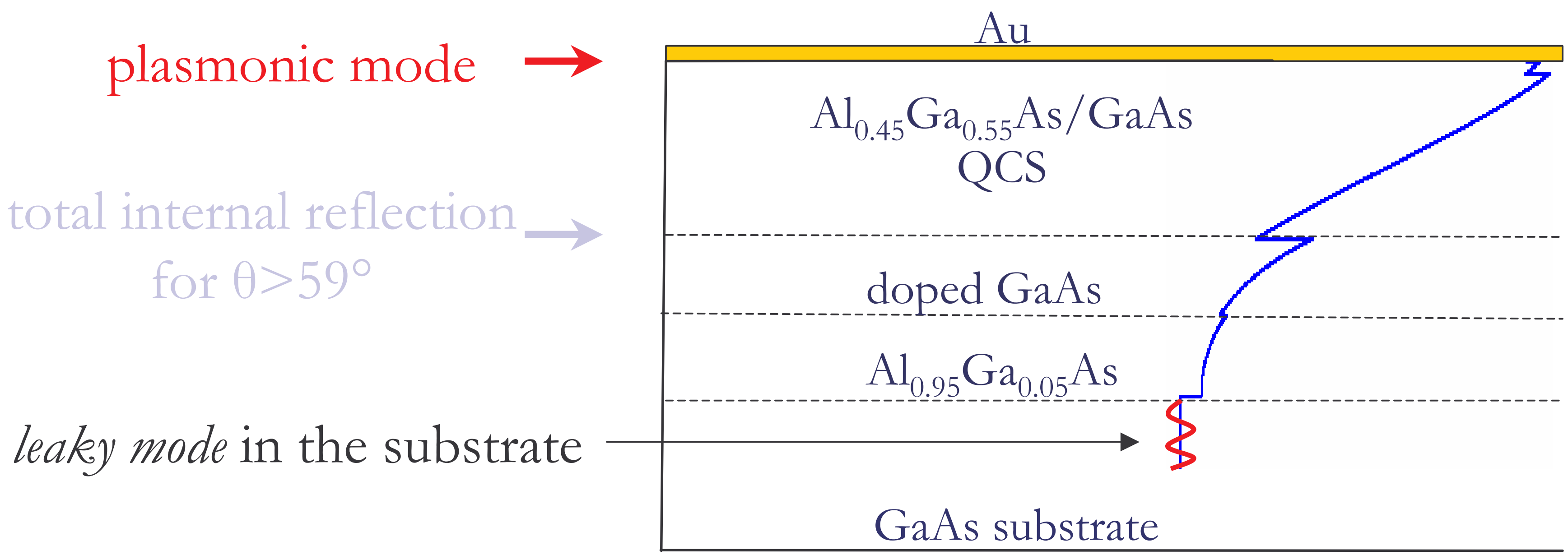


Strong coupling regime:

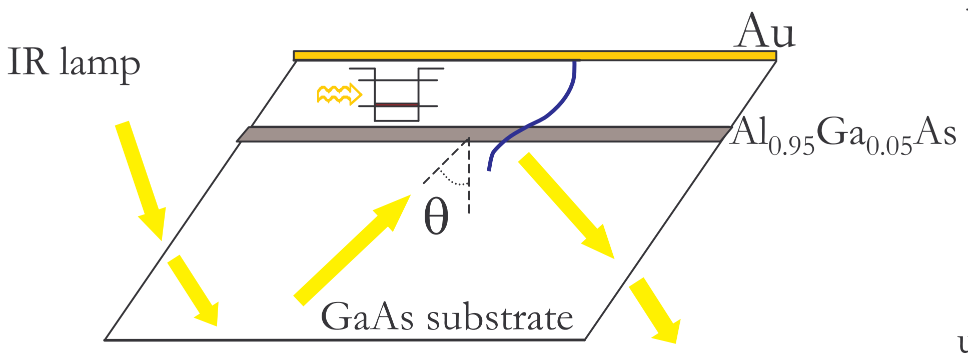


Experimental signature: anticrossing between the excitation and the photonic branches when varying the energy detuning

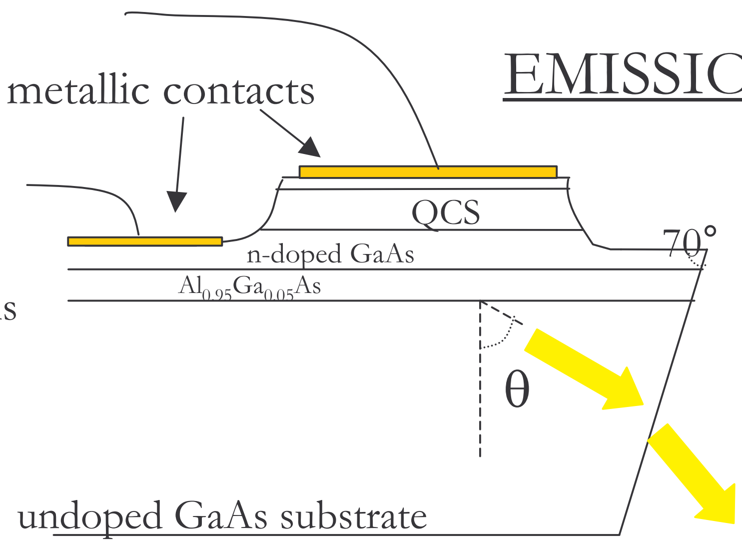
Our sample: the microcavity



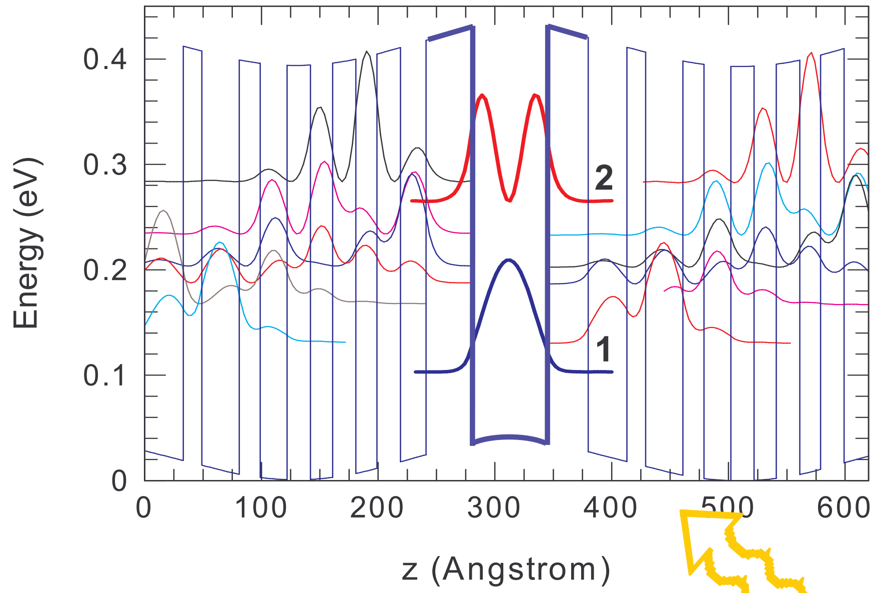
REFLECTIVITY



EMISSION



Quantum cascade structure for polariton emission

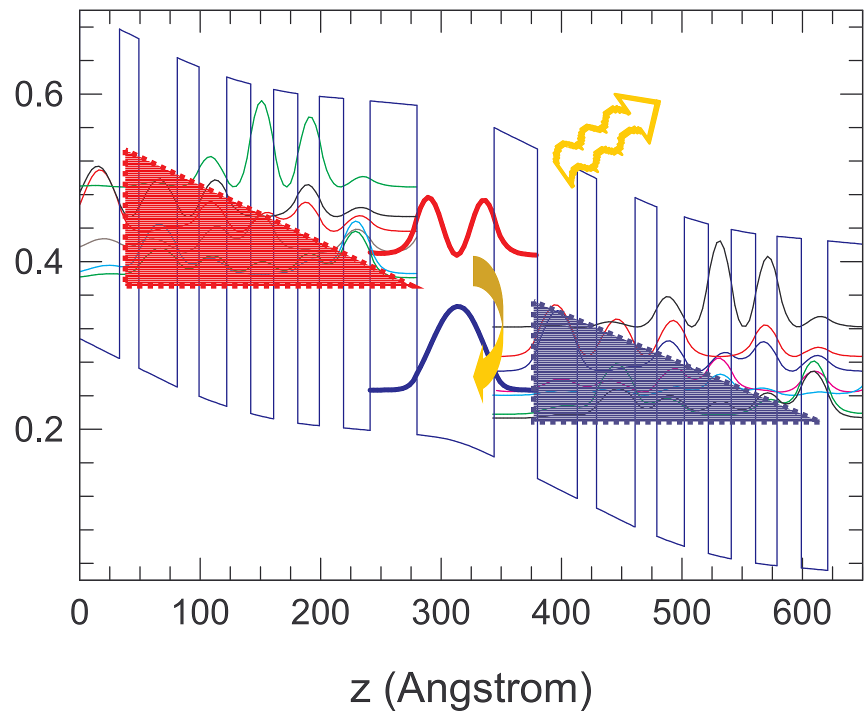


$Al_{0.45}Ga_{0.55}As/GaAs$ on GaAs

2-level highly doped
Quantum Cascade Structure (QCS)
30 periods
λ=7.7 μm
$N_{2DEG}=7.2 \cdot 10^{11}$ cm^{-2}

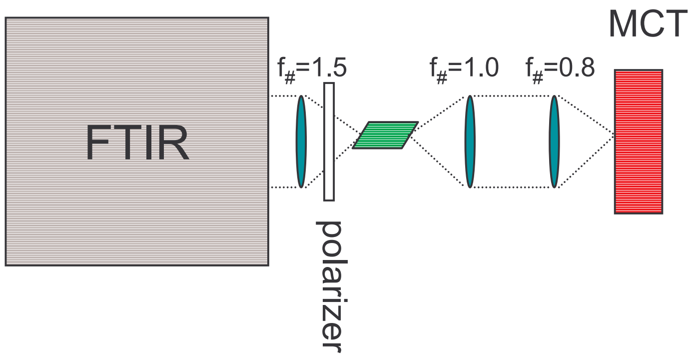
at zero bias
Reflectivity measurements

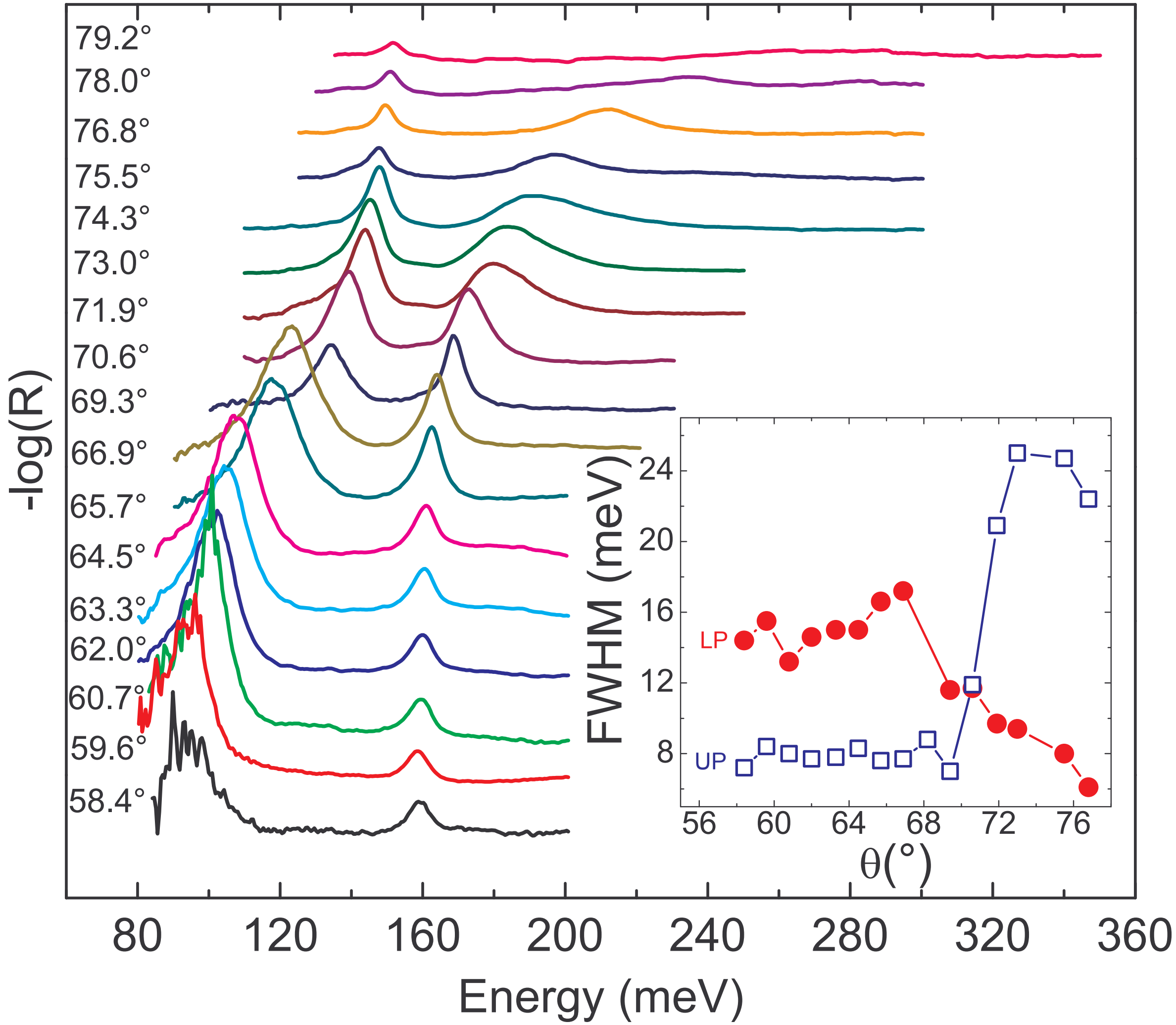
under an applied voltage
Electroluminescence



L. Sapienza et al., APL ***90****, 201101 (2007)*

Reflectivity measurements





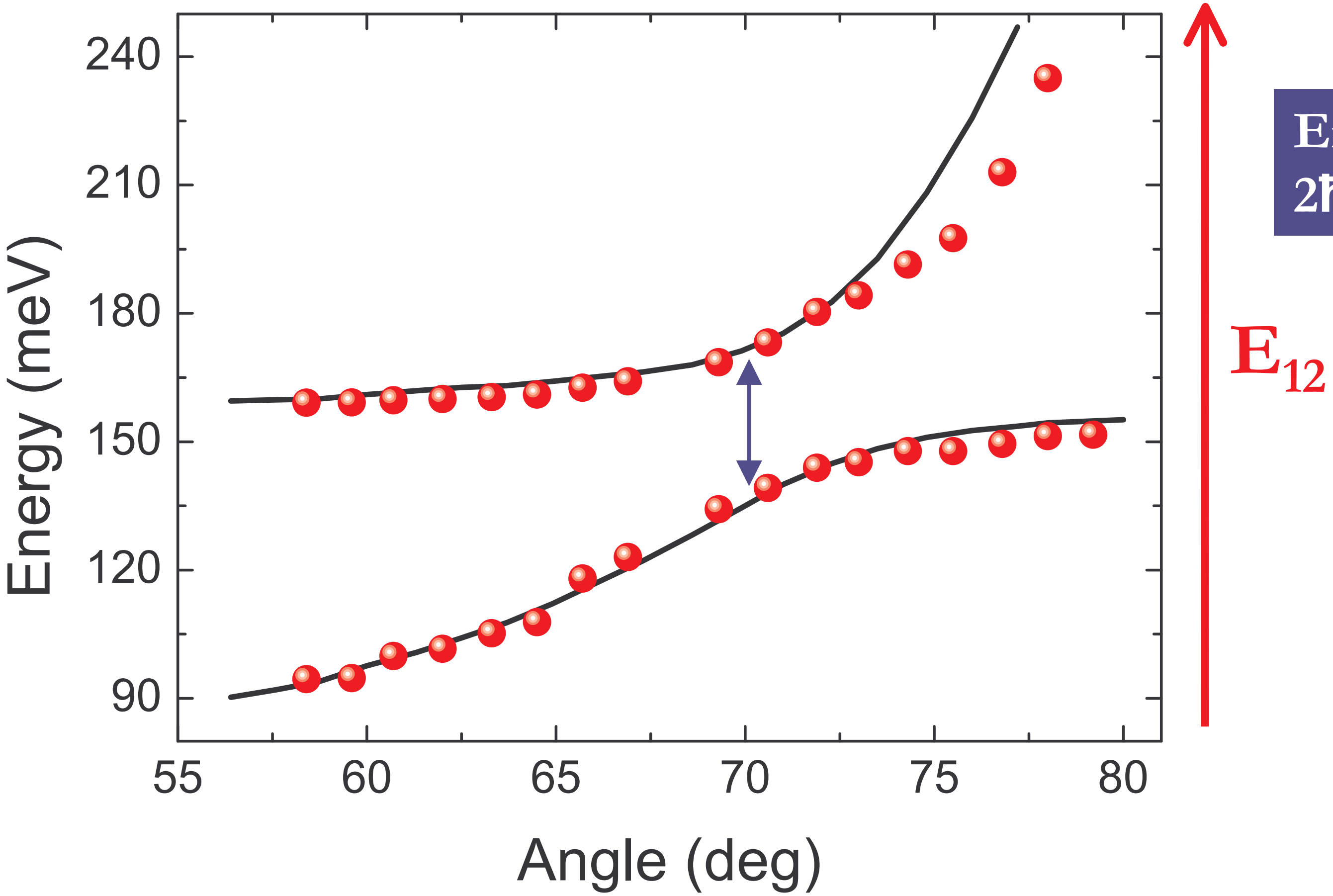
Multi-pass geometry

The sample is rotated to vary the energy of the photon cavity mode

Observation of two minima in reflectivity

Anticrossing curve

Taking into account gold and doped layers dispersion

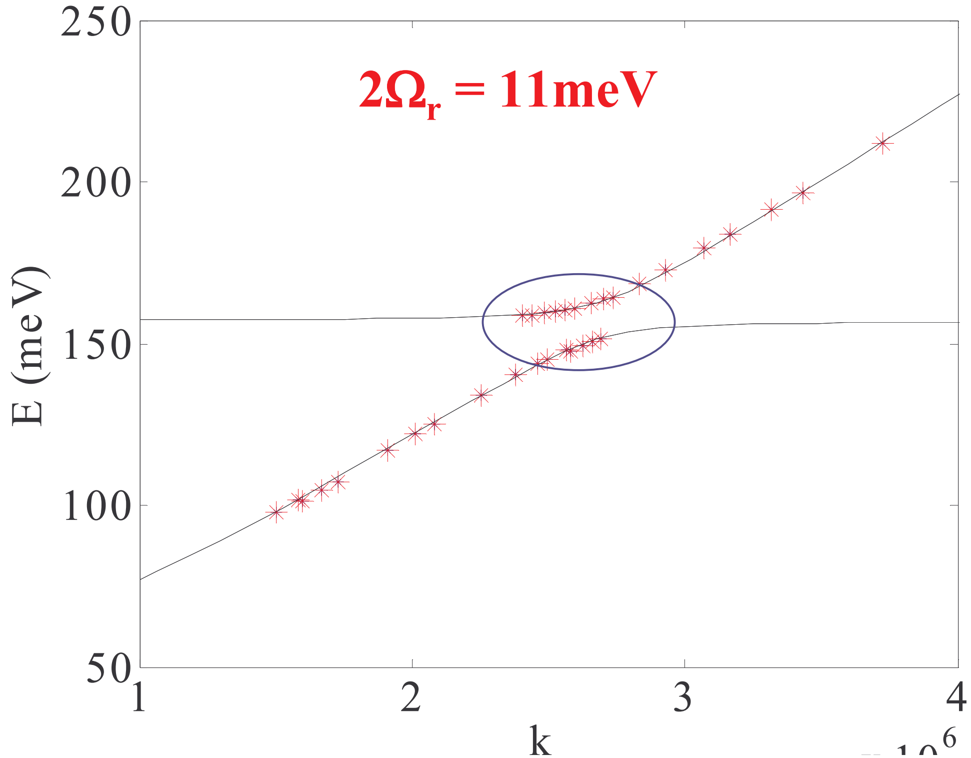


Energy splitting
$2\hbar\Omega$= 34 meV

Simulation performed with E_{12}=158 meV, N_s=6E11 cm^{-2}

The exact same behaviour is measured at room temperature ($2\hbar\Omega$= 30meV)

Splitting ≠ Rabi energy!



$$k = \frac{n}{c\hbar} E \sin \vartheta$$

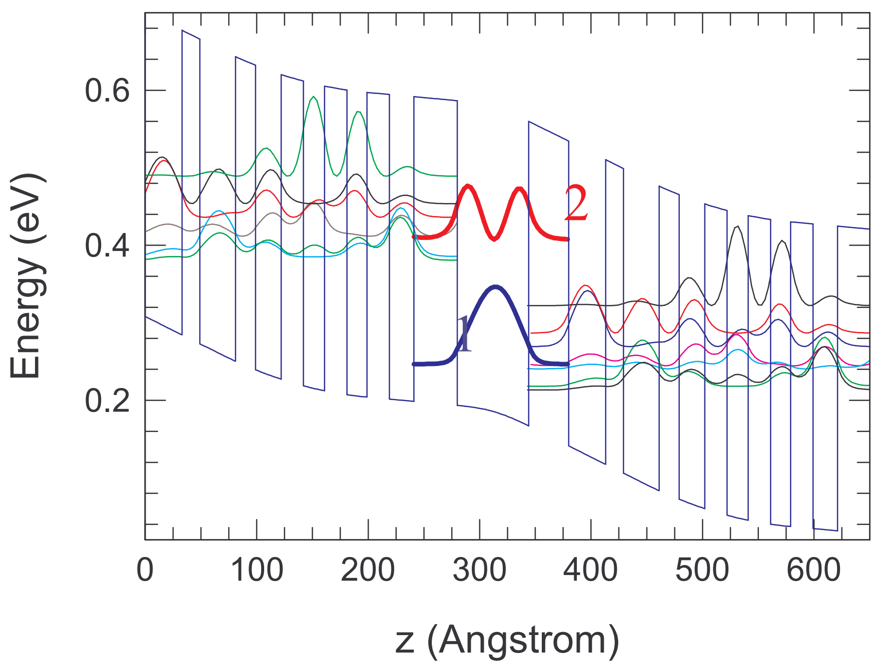
2*Rabi splitting

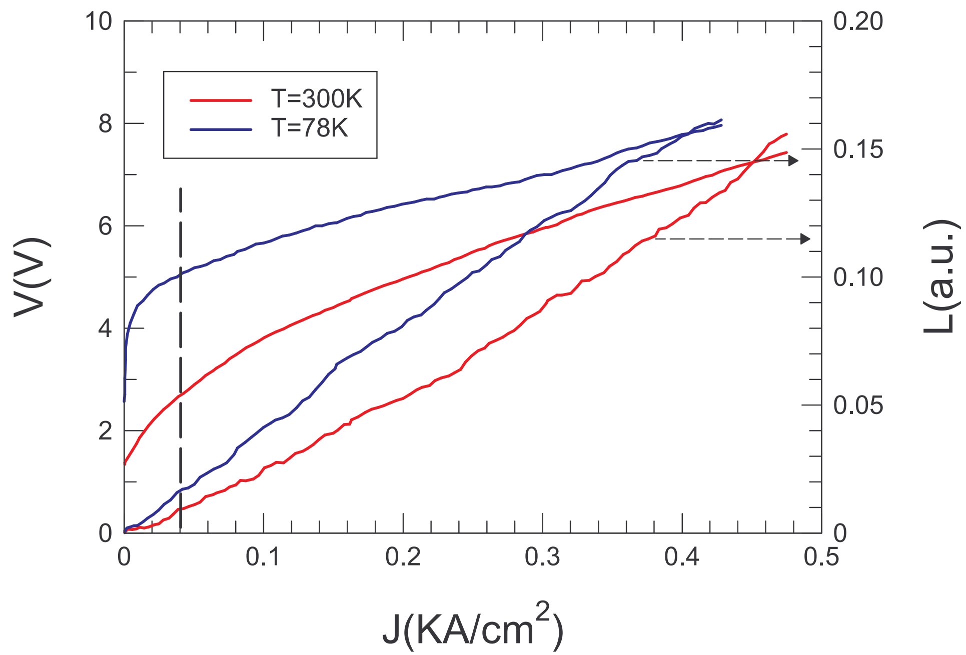
= 11 meV !!

Much smaller (~1/3!!) than the energy splitting determined from the E vs θ diagram.

S. De Liberato et C. Ciuti (private communication)

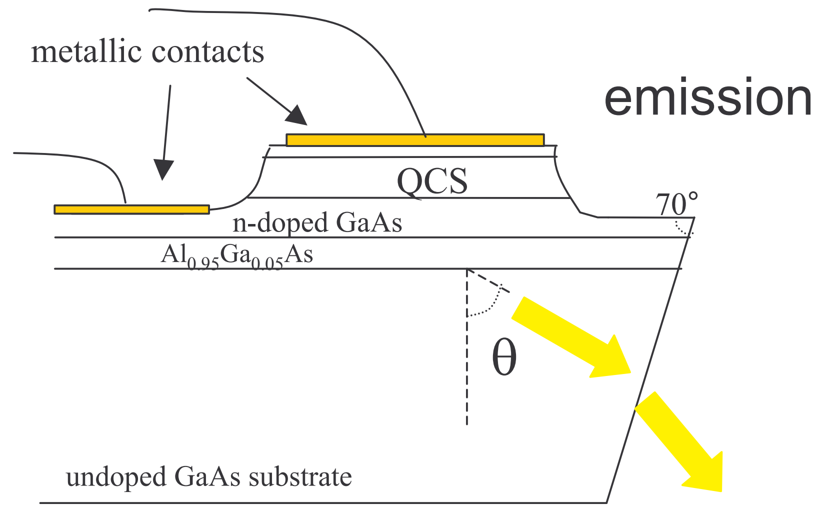
Polariton electroluminescence





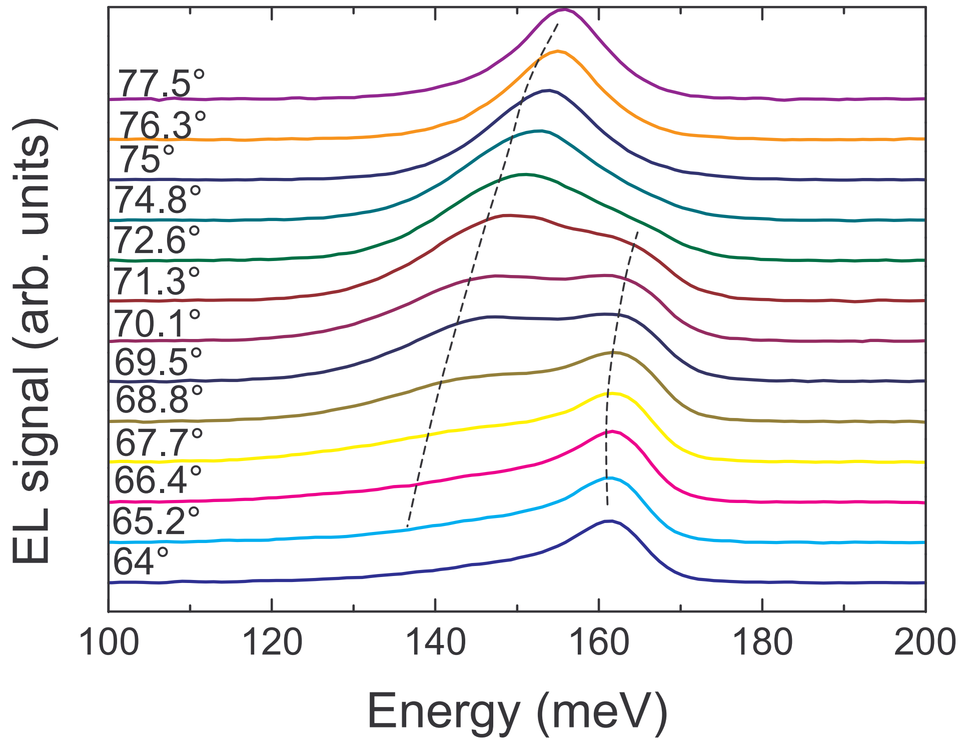
By using band structure engineering, we keep the electronic density in subband 1 as high as possible

We work at low voltage values.

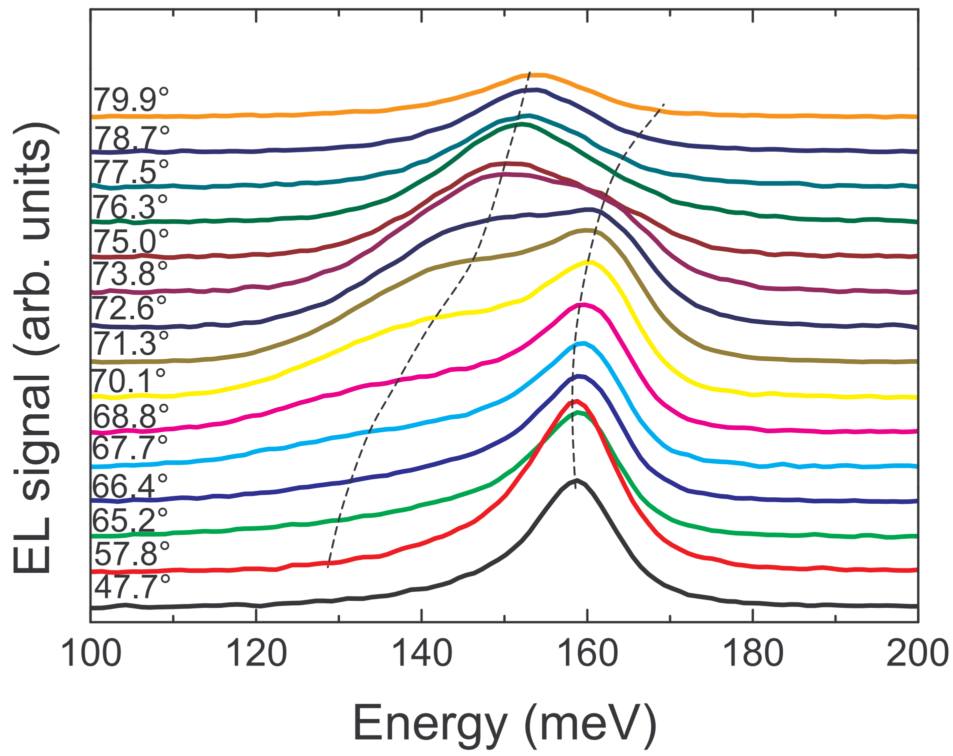


Electroluminescence spectra

T=78 K, V=5 V

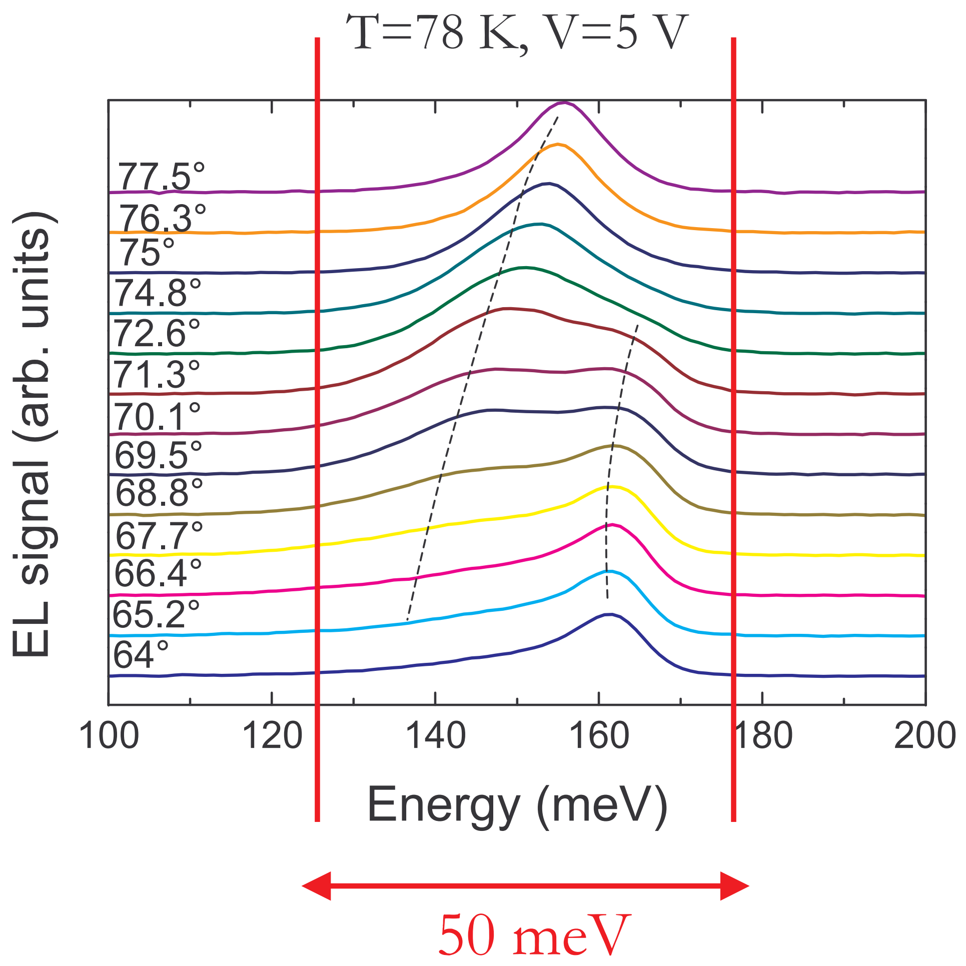


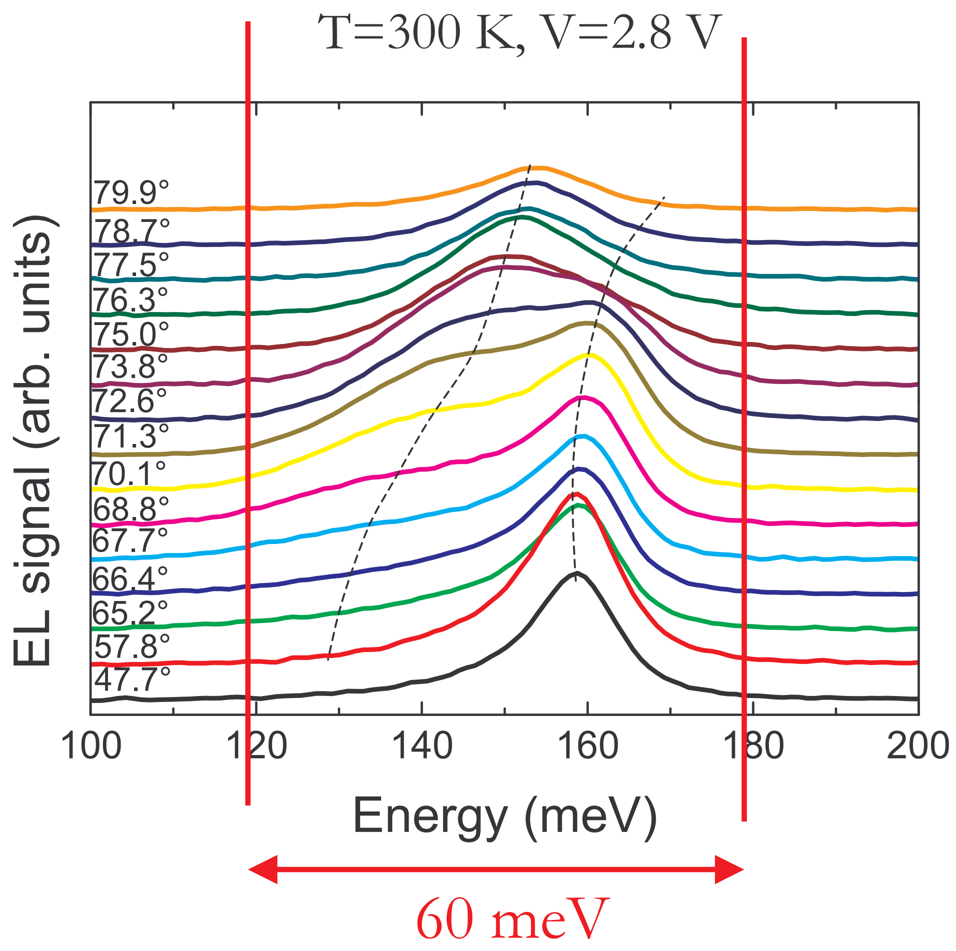
T=300 K, V=2.8 V



Very strong angular dependence of the spectra, even at room temperature

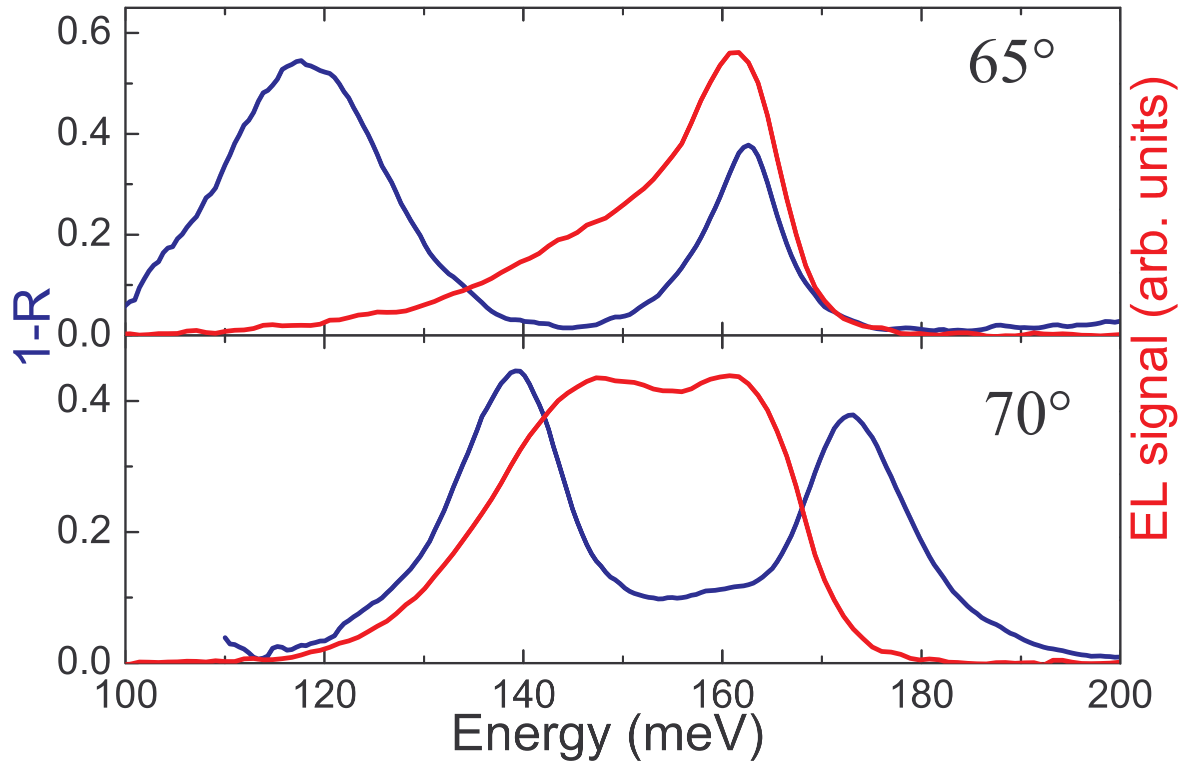
Electroluminescence spectra





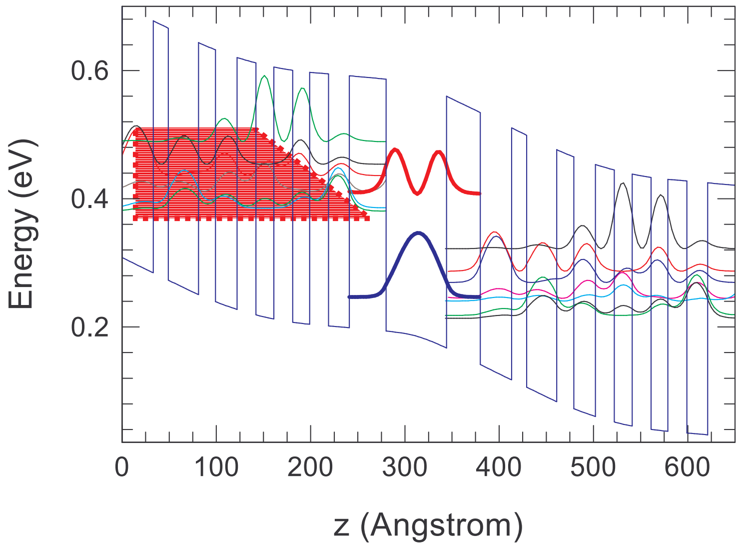
Comparison between EL and reflectivity spectra

78 K

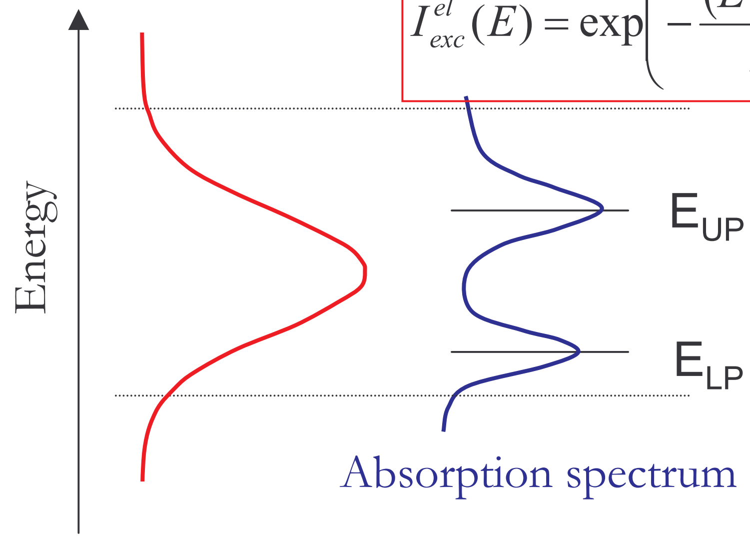


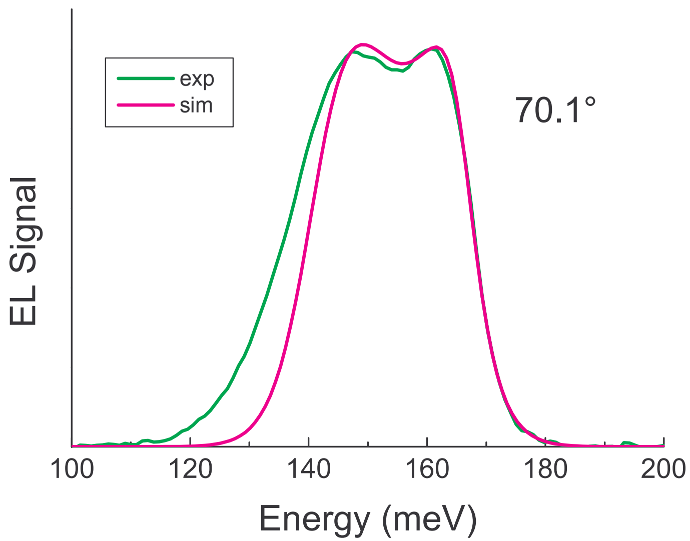
- Different energy position of the peaks
- Different shape of the spectra

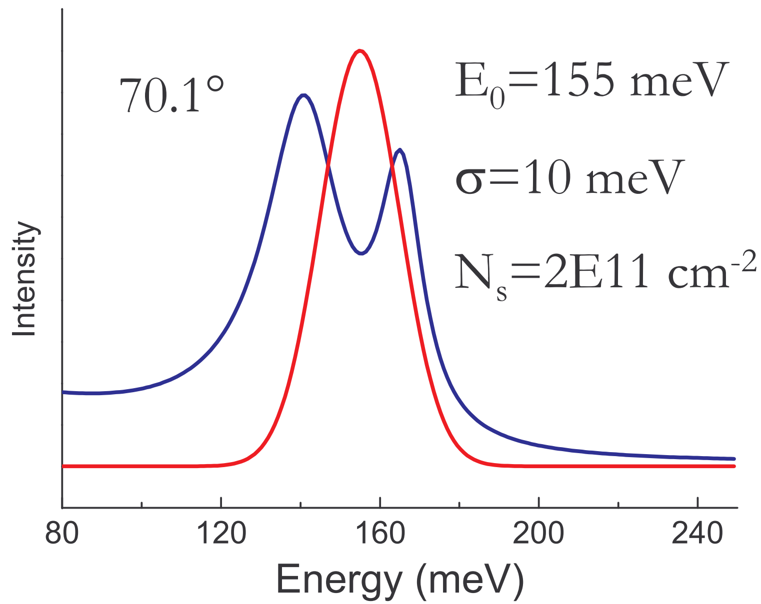
Tunnelling into polariton states



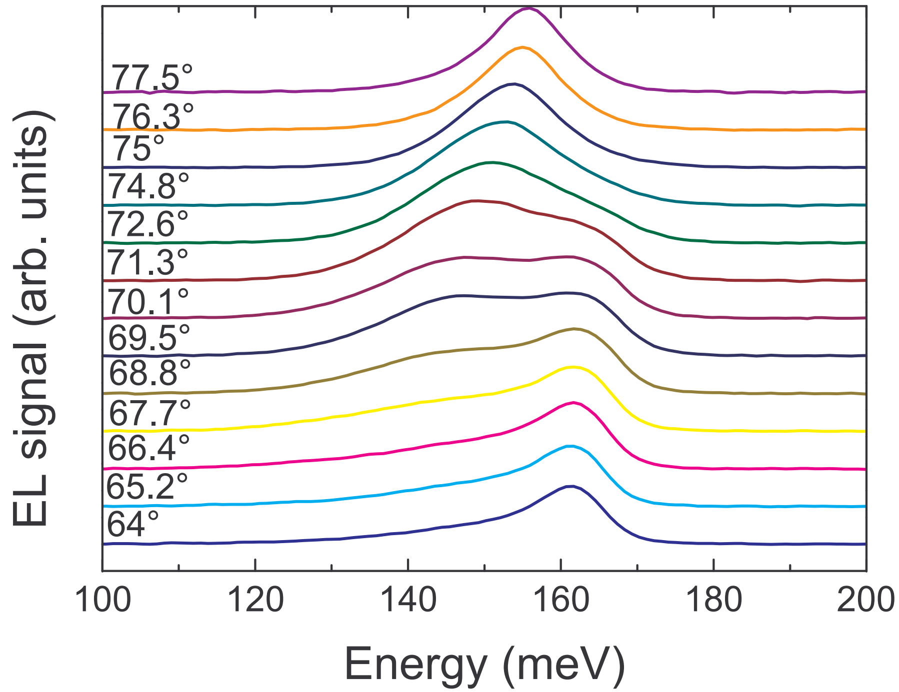
$$I_{exc}^{el}(E) = \exp\left(-\frac{(E-E_0)^2}{2\sigma^2}\right)$$

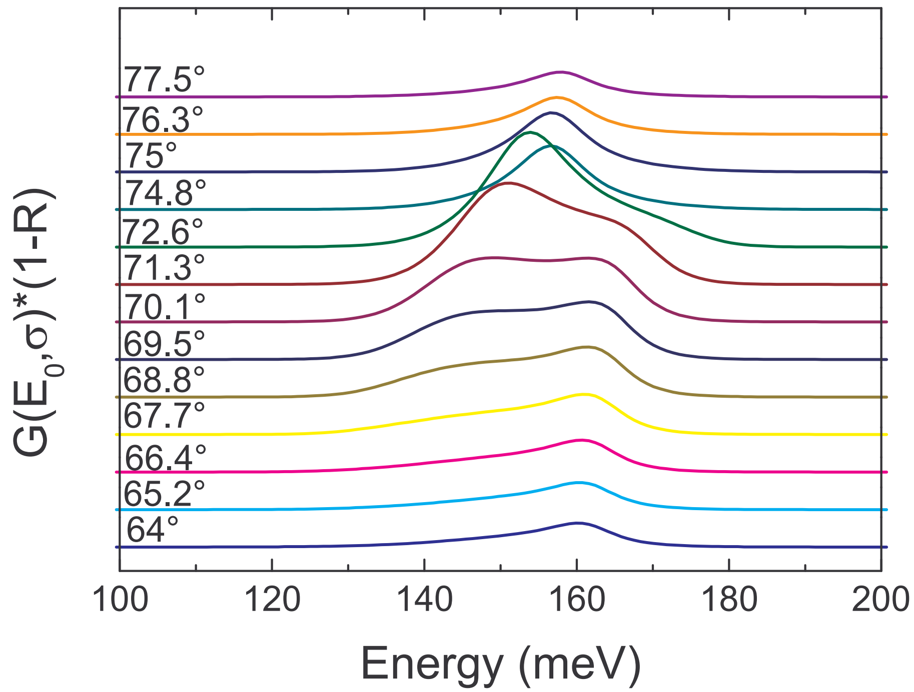






Comparison between simulated and measured spectra





Our model can reproduce the angular dependence of the EL spectra

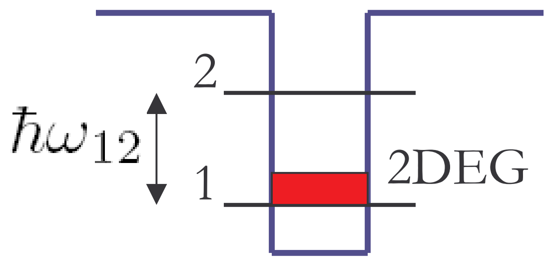
E_0 and σ are kept as fit parameters. Here E_0=155 meV, σ=10 meV

N_s=2E11 cm^{-2}

Excellent agreement at all temperatures (up to 300K)

Coupling to an electronic injector

The system can be considered as coupled to **an electronic injector**:



Electronic reservoir

Phonon emission or absorption, impurity scattering, alloy disorder, interface roughness

EL spectrum:

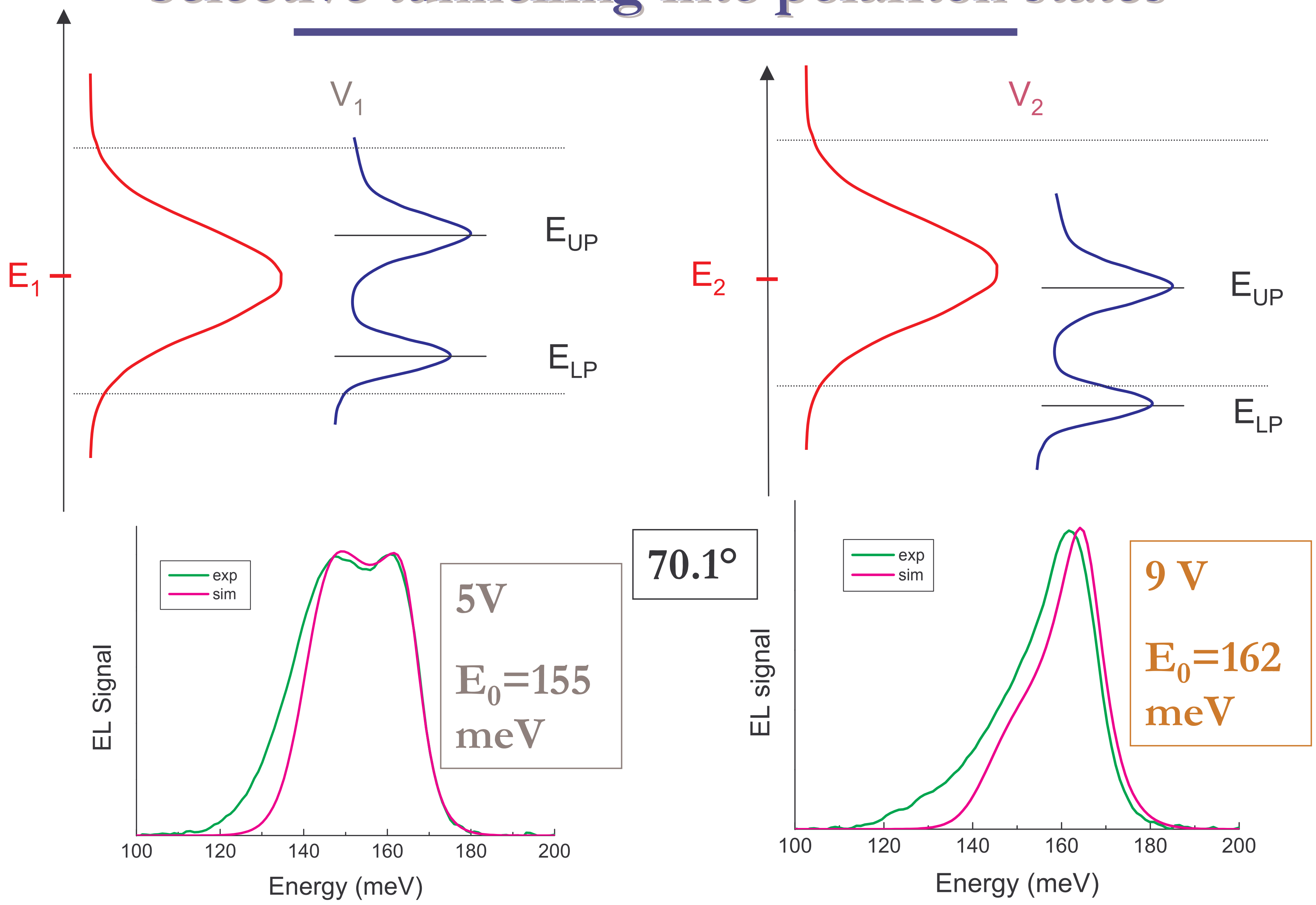
$$S(E) = I_{exc}^{el}(E)\left(1 - R(E)\right)$$

Spectral function depending on the electronic reservoir

Absorption spectrum

*C. Ciuti and I. Carusotto, PRA **74** (2006)*

Selective tunnelling into polariton states



Conclusions

✓We realized an electrically injected semiconductor intersubband device based on the strong coupling regime

✓The strong coupling regime has been observed in the absorption spectra up to room temperature

✓Polariton EL up to room temperature

✓EL spectra may be reproduced by taking into account the coupling between the 2DEG and the electronic reservoir

✓Efficient tunnelling into polariton states (selective with the applied voltage)