Harnessing light-matter interaction in intersubband microcavities

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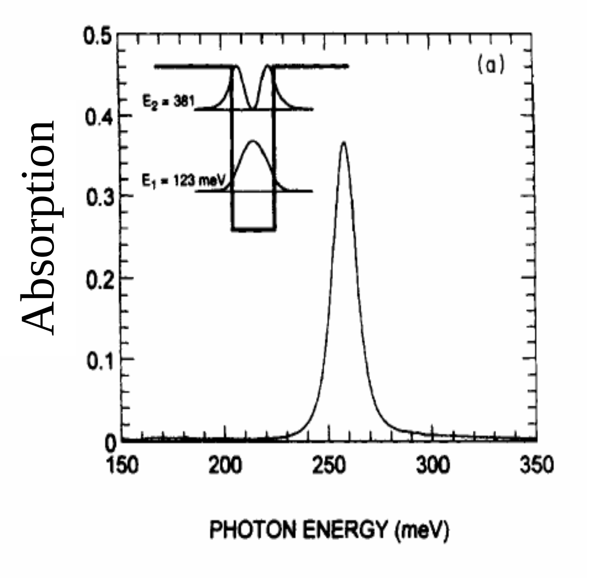
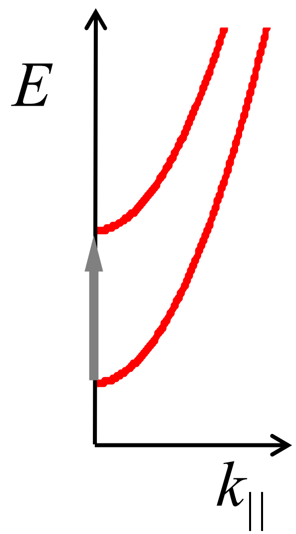
Outline

- *Introduction and motivation*
- *Strong-coupling regime using intersubband transitions*
- *Manipulation of cavity electrodynamics*
- *'Ultra-strong coupling regime' of light-matter interaction*
- *Attempts to realize ultra-strong coupling regime*
- *Conclusions*

Intersubband photonics





- *"atomic-like"*
- *ultrafast relaxation time (~ps)*
- *tailorable properties*

How intersubband transitions interact with confined electromagnetic field?

Cavity QED

Optical cavity $\Rightarrow$ *light resonator*

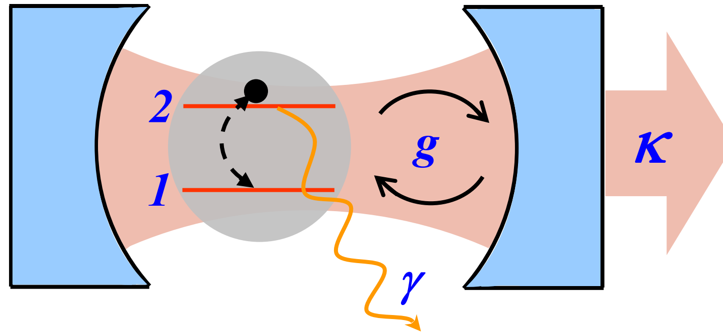
↕ *coupling*

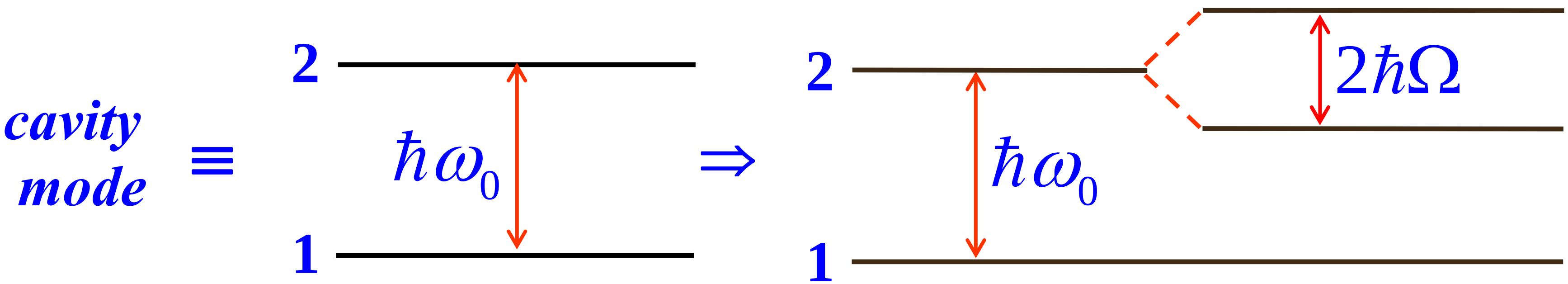
Electronic transition $\Rightarrow$ *material resonance*

Transition-photon coupling, $g = \frac{d}{\hbar} E_{cav}$

Weak coupling	Strong coupling
➢ Perturbative regime ➢ Purcell effect	➢ Rabi oscillations ➢ “cavity-polaritons”

Light-matter interaction





electronic transition *weak coupling* *strong coupling*

Strong-coupling regime

***Atomic physics*: atoms in metallic microcavity**

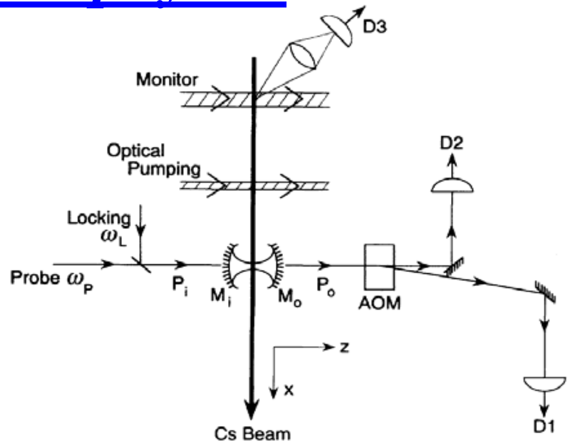
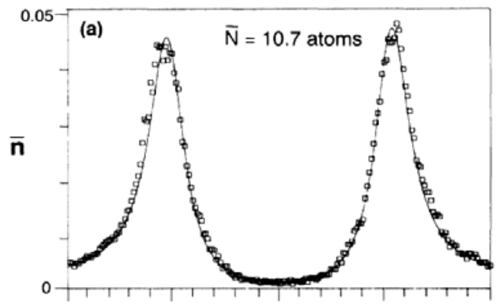


FIG. 1. Diagram of principal elements of the experiment.



R. J. Thompson et al., PRL.,68, 1132 (1992)

***Solid state physics*:**

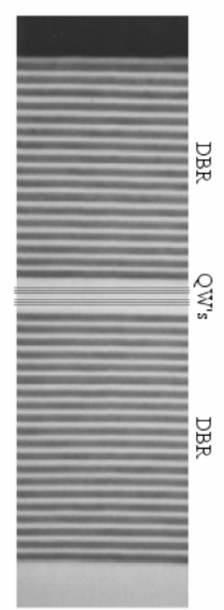
- ***excitons (bulk, QWs or QDs in semiconductor microcavities)***
- ***qubits (cooper pair quantum-box in microwave resonators)***

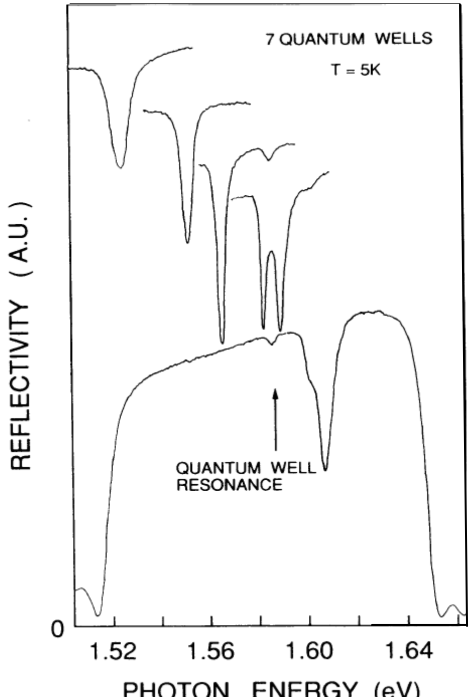
Exciton polaritons

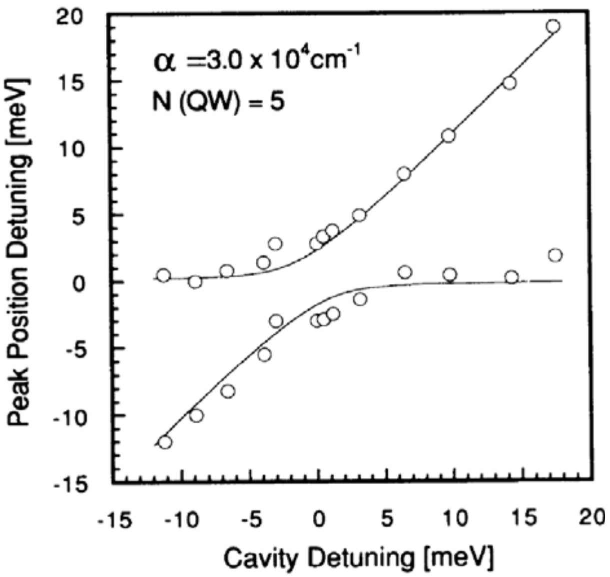
VOLUME 69, NUMBER 23 PHYSICAL REVIEW LETTERS 7 DECEMBER 1992

Observation of the Coupled Exciton-Photon Mode Splitting in a Semiconductor Quantum Microcavity

C. Weisbuch,[a] M. Nishioka,[b] A. Ishikawa, and Y. Arakawa
Research Center for Advanced Science and Technology, University of Tokyo, 4-6-1 Meguro-ku, Tokyo 153, Japan
(Received 12 May 1992)

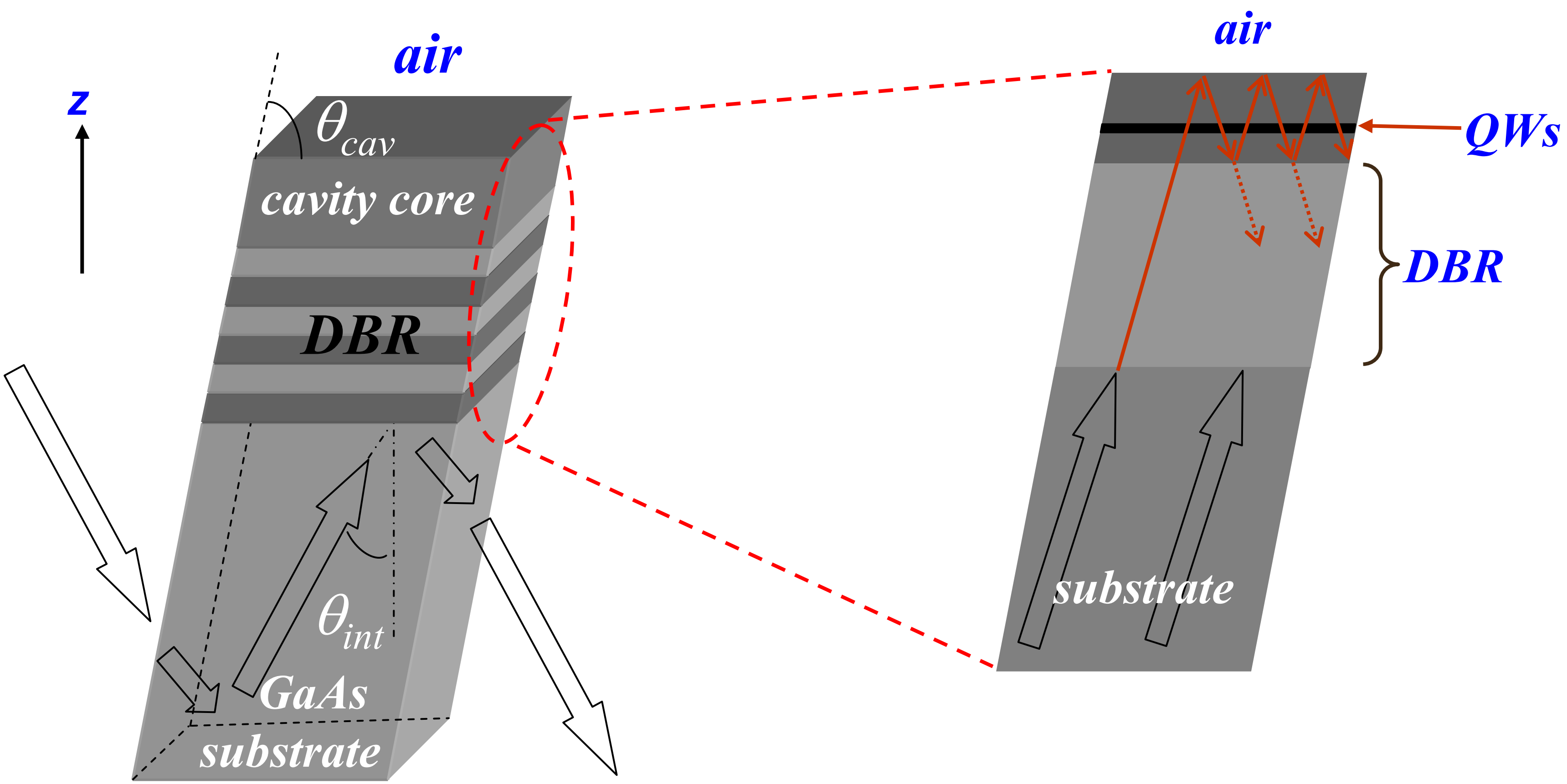






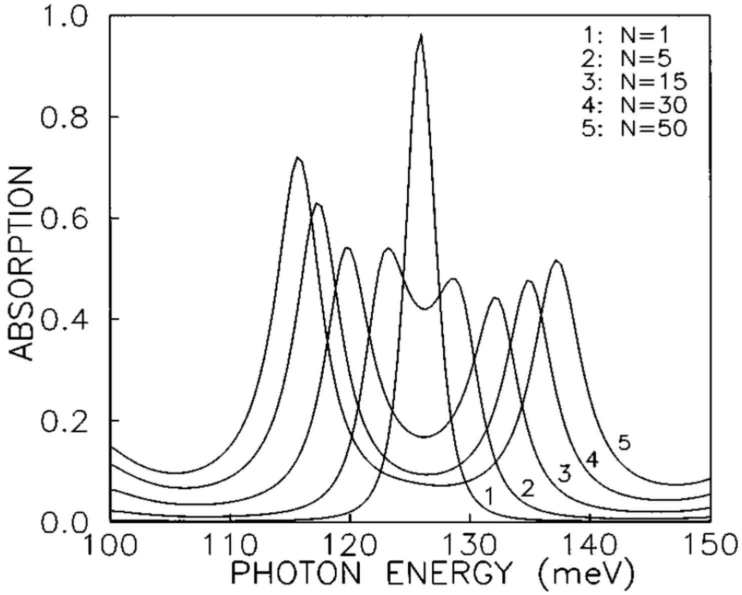
Intersubband resonators

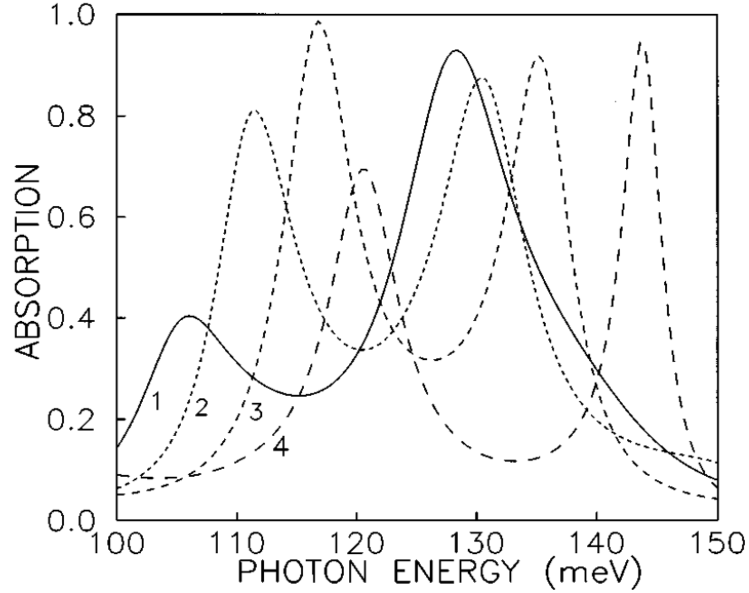
Theoretical predictions by Ansheng Liu, PRB., 55, 7101 (1997)



Intersubband resonators

L_{cav} = 3 μm; N_{DBR} = 3
GaAs/AlAs DBRs
Total thickness ~ 14 μm





Ansheng Liu, PRB 55, 7101 (1997)

Intersubband polaritons

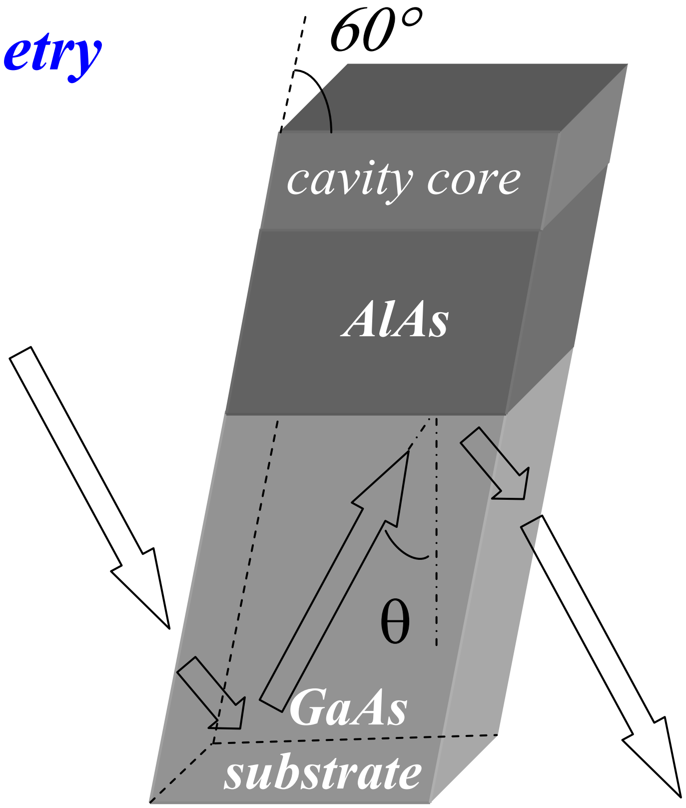
- *total-internal reflection geometry*
- *air as top-cladding*

$L_{cav} \sim 3 \mu m$; $\theta_{cav} = 60°$;

$N_{QW} = 18$, doped to $5 \times 10^{11} cm^{-2}$

$L_{AlAs} \sim 4 \mu m$;

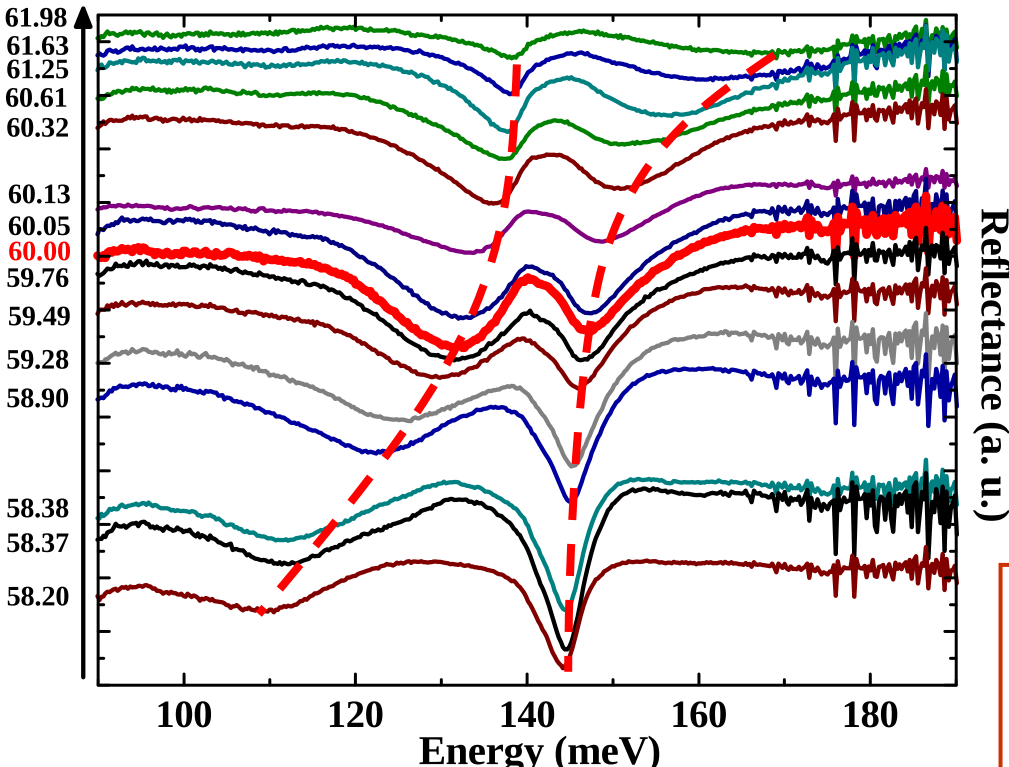
Total thickness $\sim 5 \mu m$

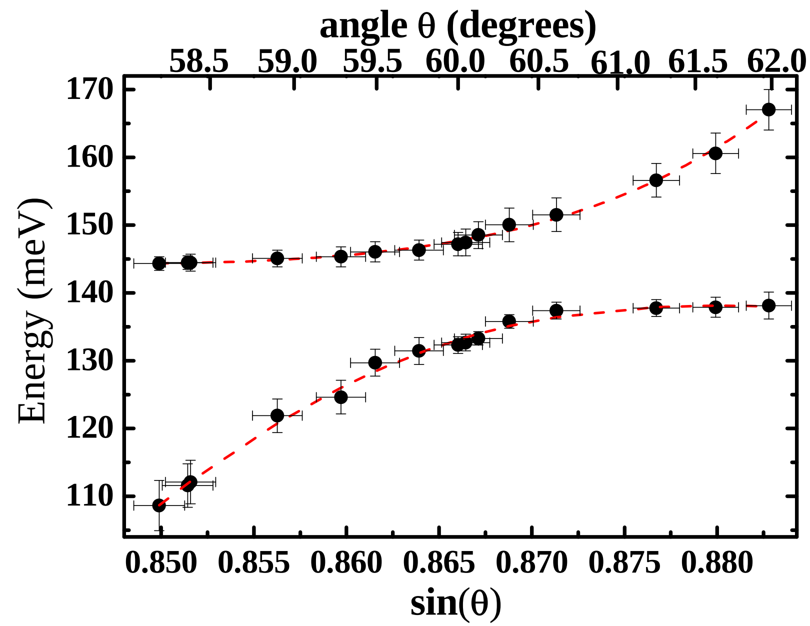


D. Dini et.al, PRL., 90, 116401 (2003)

Intersubband polaritons

measurements at 10K





Minimum splitting, $2\hbar\Omega = 14\,meV$

ISBT energy, $\hbar\omega_{12} = 140\,meV$

D. Dini et.al, PRL., 90, 116401 (2003)

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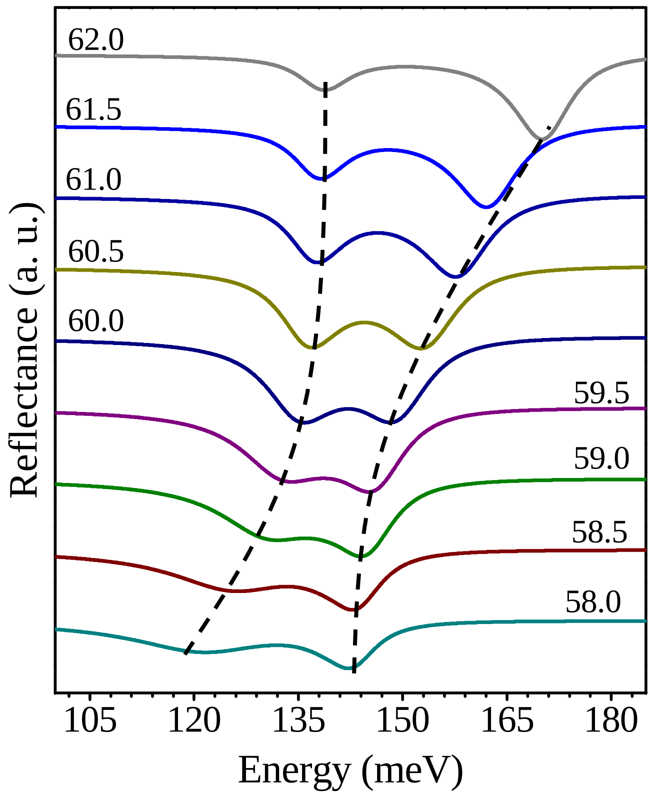
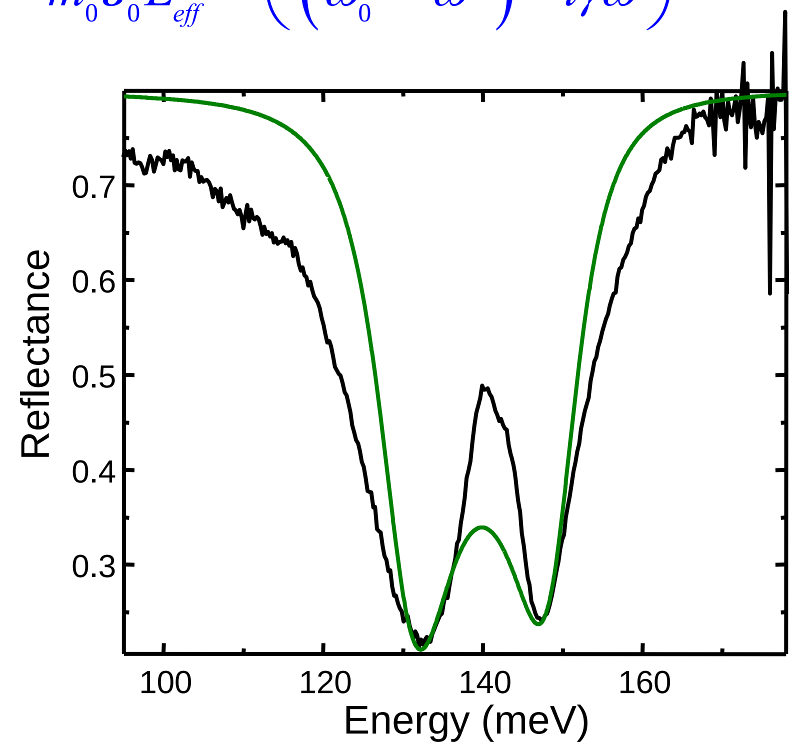
Coupled oscillators - simulation

Electromagnetic field propagation : Optical transfer matrix

Quantum well : $\varepsilon(\omega) = \varepsilon_\infty + \frac{Ne^2 f\, Sin^2\theta}{m_0 \varepsilon_0 L_{eff}} \left(\frac{1}{(\omega_0^2 - \omega^2) - i\gamma\omega} \right)$





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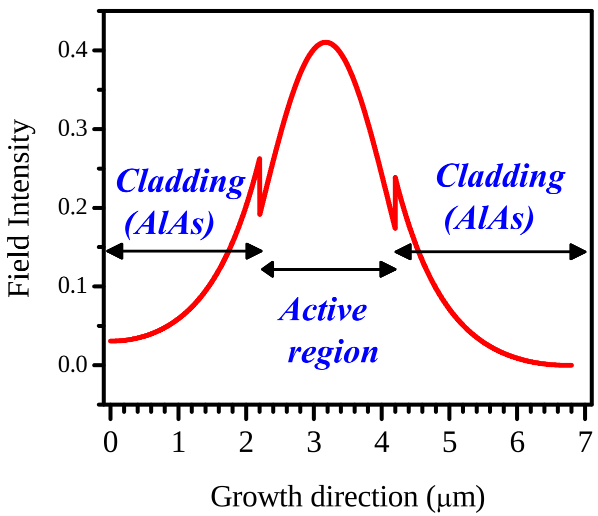
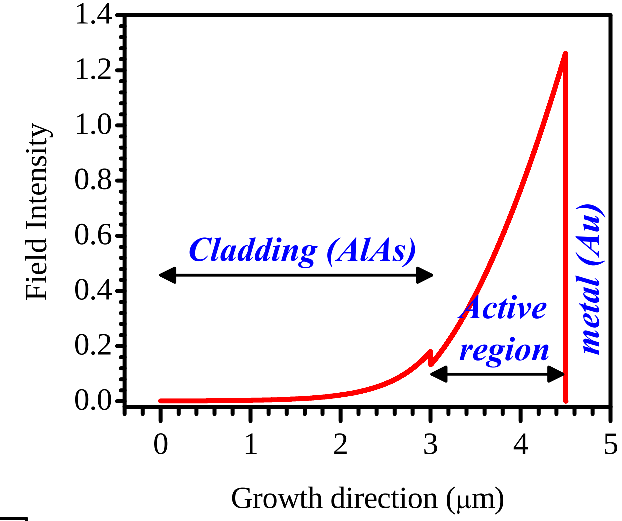
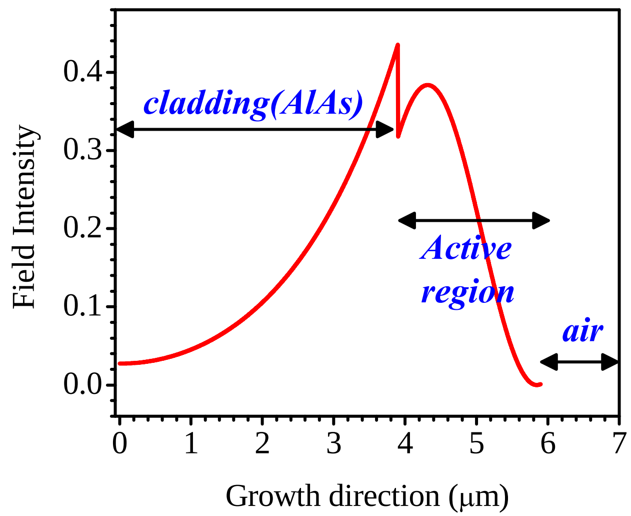
Intersubband resonators







Manipulation of cavity electrodynamics

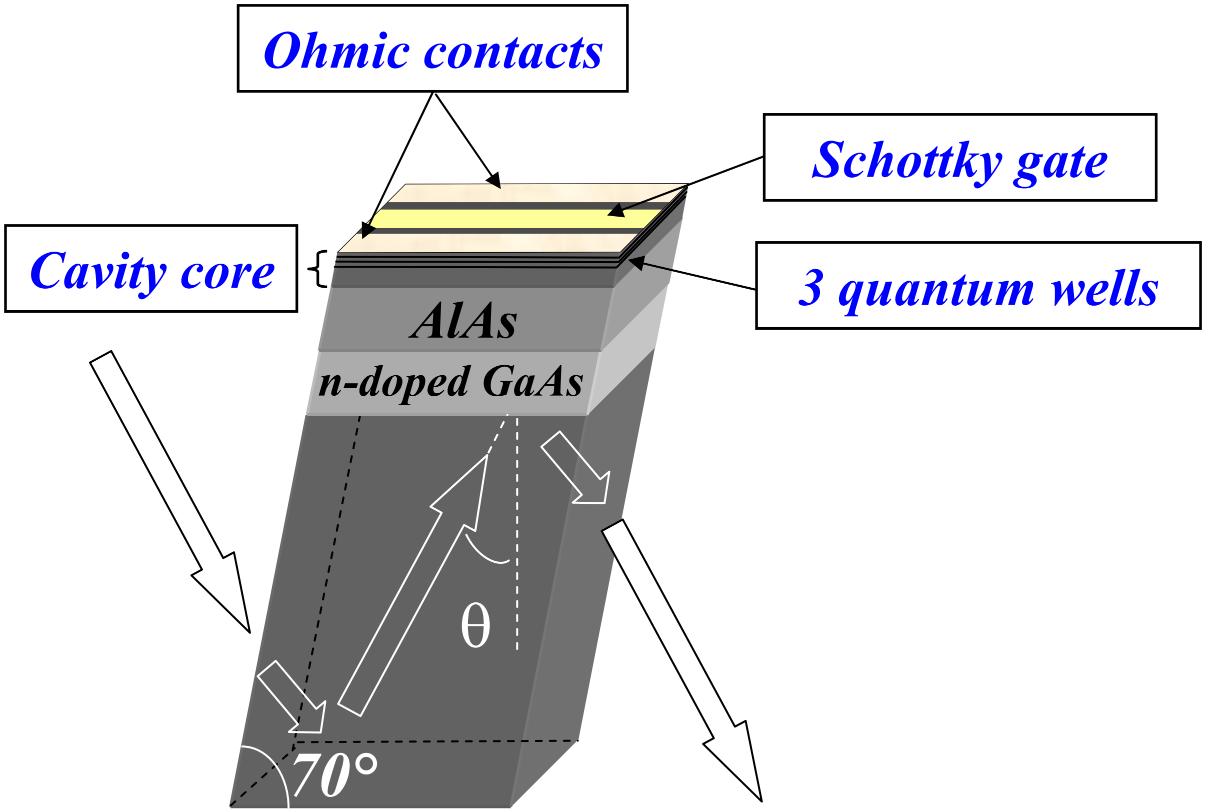
Rabi splitting, $\Omega \propto \sqrt{N}$

$N \rightarrow$ ***number of oscillators***

intersubband polaritons, $N \rightarrow$ ***electron density***

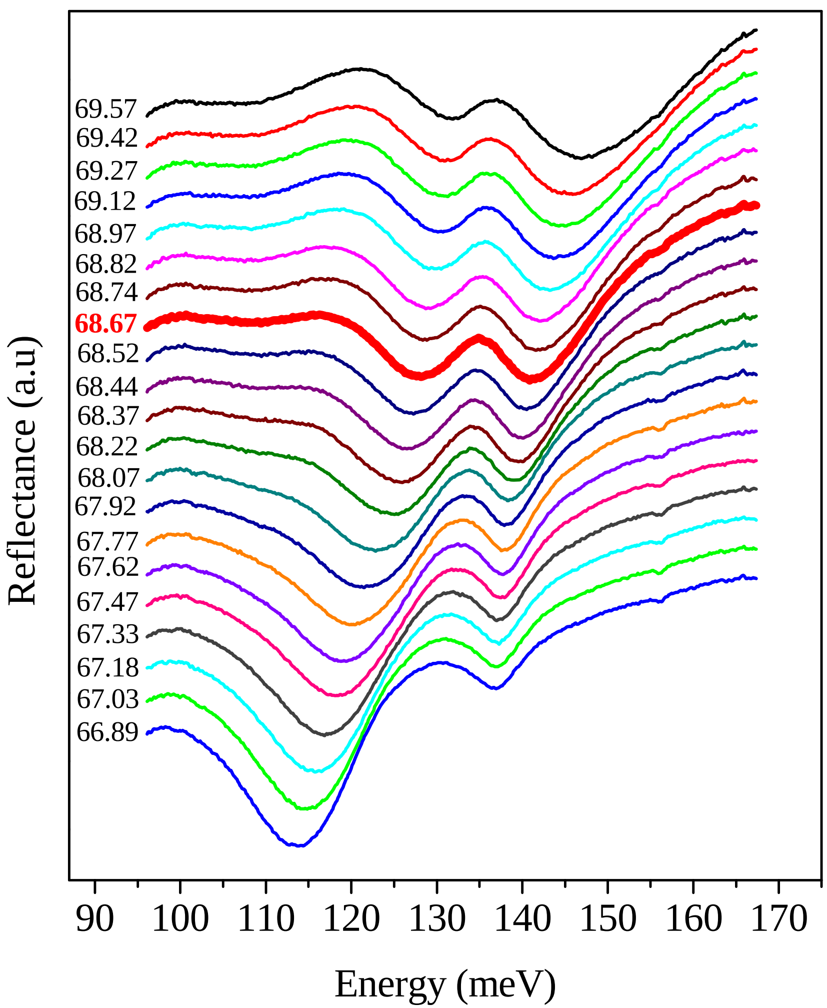
- can be tuned externally !!

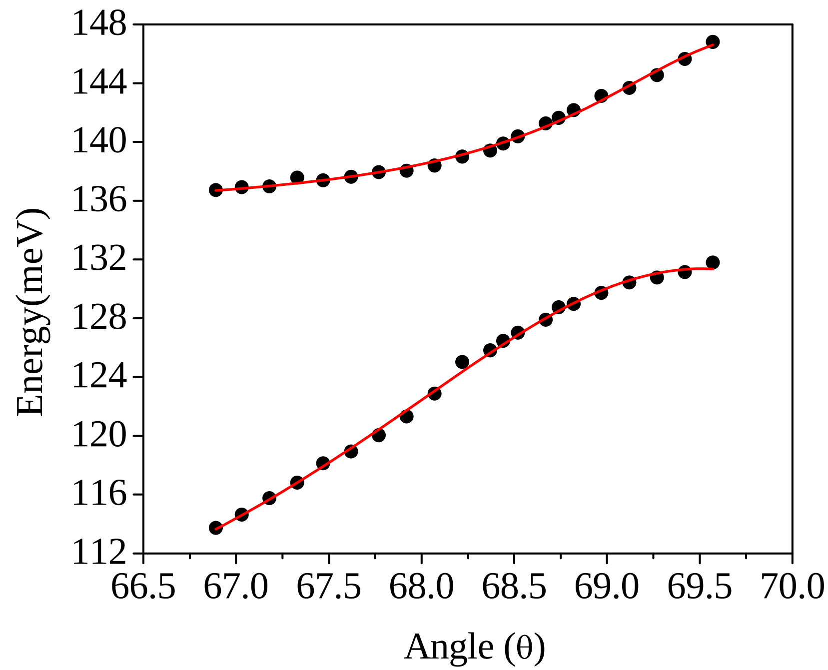
Depletion gating



A. A Anappara et al., APL., 87, 051105 (2005)

Normal-mode splitting and anticrossing





Minimum splitting, $2\hbar\Omega = 13\, meV$

ISBT energy, $\hbar\omega_{12} = 137\, meV$

$3\, QWs$

measured at $300K$

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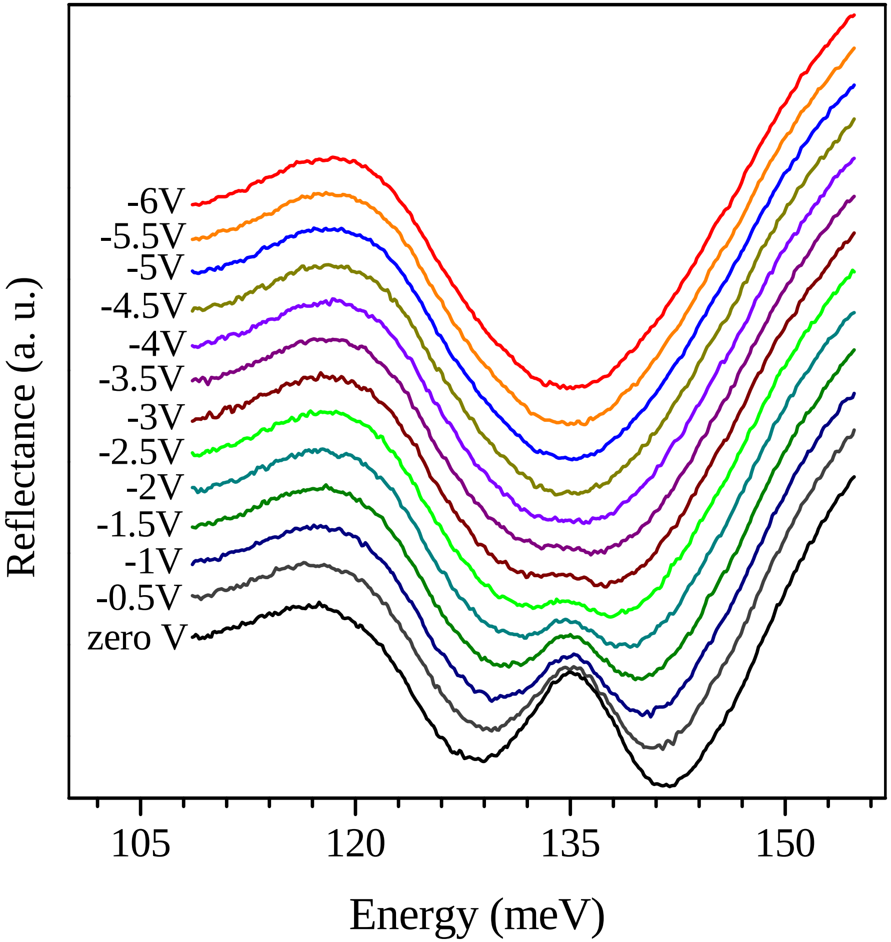
Strong coupling to weak coupling

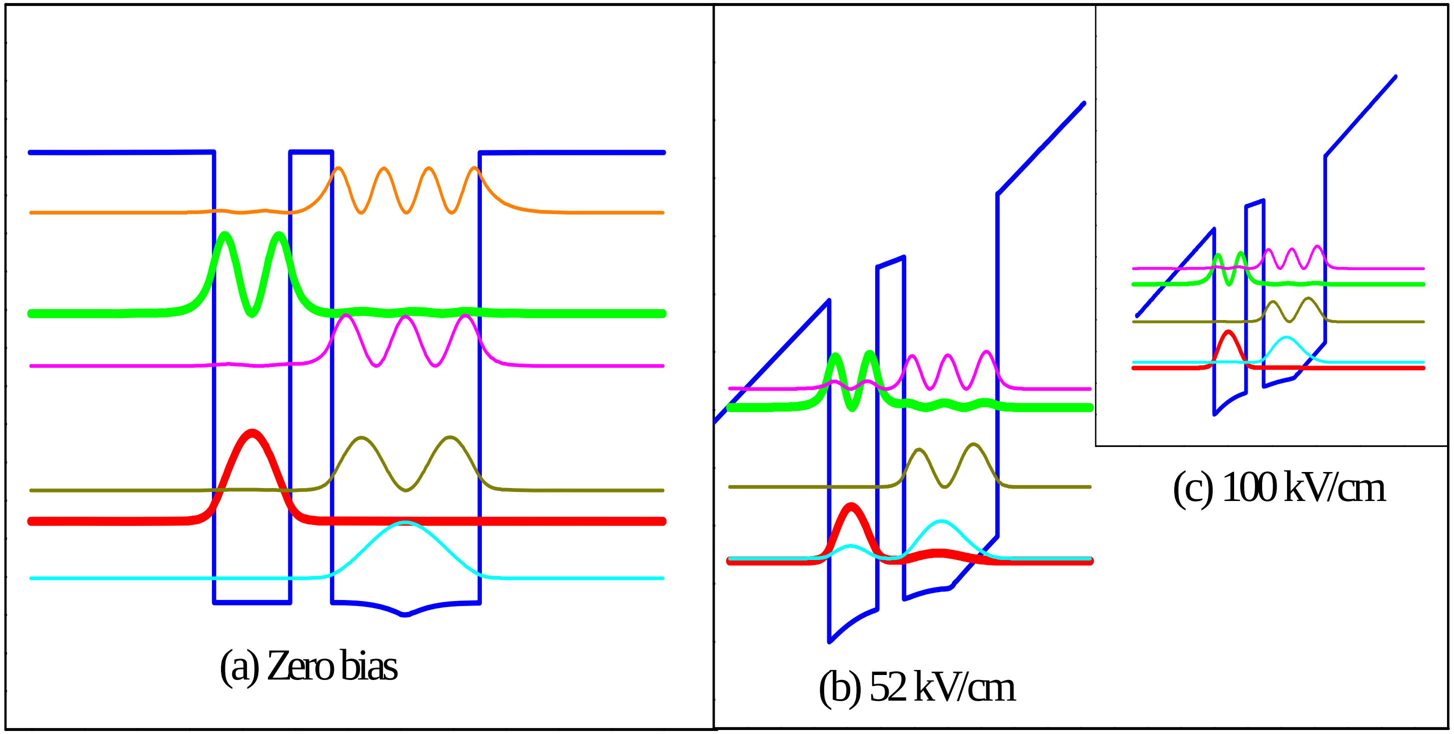


Room temperature measurements
Resonant angle, θ = 68.67°

A. A Anappara et al., APL., 87, 051105 (2005)

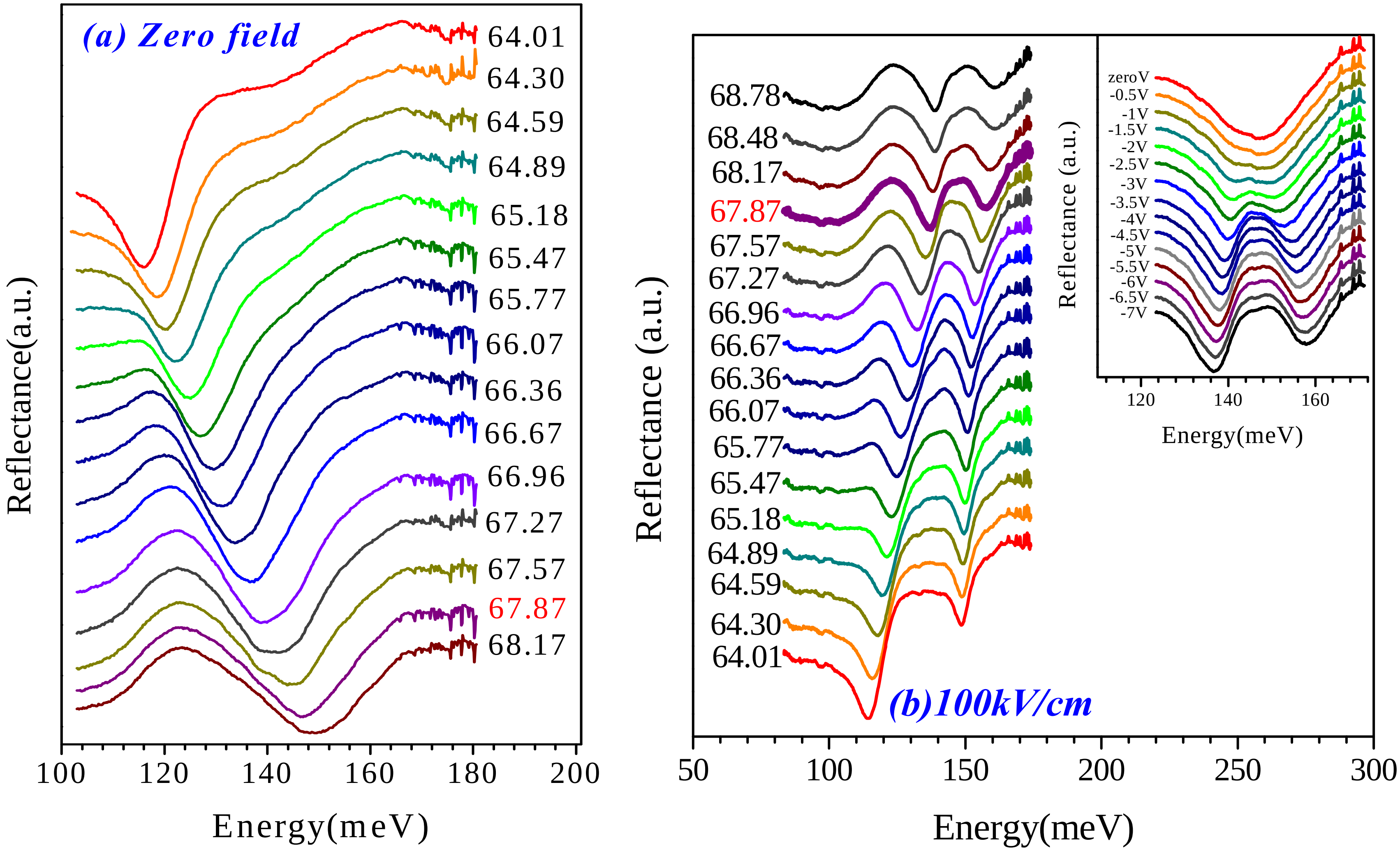
Tunnel-assisted control of splitting

Carriers are injected by tunneling



A. A Anappara et al., APL., 89, 171109 (2005)

Tuning by tunnel coupling



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Conclusions

- *Tailorability and manipulation of cavity electrodynamics in intersubband microcavities*
- *Intersubband microcavities are potential systems to realize the unprecedented 'ultra-strong coupling regime'*
- *Novel device applications – high absorption QWIPs, ultrafast optical switches, super luminescent devices*