Present status of polaritonic nonlinearities in planar III-nitride microcavities

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Motivations

Fundamental:
Study of bosonic condensation phenomena up to room temperature

Wide band gap semiconductors $\Rightarrow$ large effective masses
$\Rightarrow$ high threshold current density for lasing, best GaN edge-emitting QW LDs (Nichia/Samsung) $\sim 1\text{-}2\text{ kA/cm}^2$

What could be the next step?
$\Rightarrow$ GaN polariton LDs  
SST 26, 014030 (2011)
Cf. talk Marlene Glauser

Applied:
Achieve room temperature electrical injection of cavity polaritons characterized with an ultra-low effective mass
$\Rightarrow$ Low threshold “lasers” without population inversion

A. Imamoglu et al., PRA 53, 4250 (1996)
Outline

• Polariton condensation in planar microcavities: role of the detuning $\delta$ and temperature

• Impact of biexcitons on the relaxation mechanisms of polaritons

• A few hints on renormalization effects in III-nitride microcavities

• Conclusion and perspectives
Polariton nonlinearities in planar microcavities

GaAs
\[ \Omega_{\text{VRS}} \sim 15 \text{ meV}, N_{\text{QW}} = 12 \]
\[ T_C \sim 40 \text{ K} \]

CdTe
\[ \Omega_{\text{VRS}} \sim 26 \text{ meV}, N_{\text{QW}} = 16 \]
\[ T_C \sim 50 \text{ K} \]

- Relaxation bottleneck to overcome
- Key role of cavity photon lifetime to achieve spontaneous condensation
- Large QW number to reduce the exciton density per well

1. Thermod. Kinetics
2. Temperature-dependent optimum \( \delta \) but limited \( \Delta T \) range accessible

1. E. Wertz et al., APL 95, 051108 (2009);
Planar III-N microcavity for polariton studies

Large QW number to increase Rabi splitting
1- Fourier PL setup: Ar\(^+\) (244 nm, cw) or Nd:YAG (266 nm, quasi-cw)

Access to the polariton dispersion curve \(E(k_{//})\)

2- Time-resolved PL setup: Ti:sapphire (280 nm, 2 ps) + monochrom. + streak camera

Temporal evolution of the PL at \(k_{//} = 0\)
Polariton condensation phase diagram

$$(\delta, T, P_{thr})$$ diagram$^1$$^2$

GaN

Thermalized population in the vicinity of the ground state with $T_{eff} = 300 \pm 10$ K

$\Rightarrow$ signature of nonequilibrium polariton BEC at room temperature

$^1$ PRB 80, 233301 (2009); $^2$ PRB 81, 125305 (2010); $^3$ PRL 104, 166402 (2010)
Large negative detuning and low temperature
- inefficient polariton relaxation
→ increasing threshold (kinetic regime)

Less negative detuning and elevated temperatures
- enhanced scattering efficiency
→ decreasing threshold (toward/or thermodynamic regime)

Competition between kinetic and thermodynamic condensation regimes: impact of phonon scattering term ⇒ shift of $\delta_{opt}(T)$ toward more negative $\delta$ values with increasing $T(K)$\(^{1-2}\)

Extra kink observed in the evolution of $\delta_{opt}(T)$ once escape from parabolic region of the LPB is allowed\(^{1-2}\)
⇒ thermal detrapping from polariton ground state (specific feature due to matter-like character of polaritons)

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Fourier imaging spectroscopy: accurate farfield emission pattern

Cavity detuning $\delta = -55$ meV

$\Omega_{VRS} = 60$ meV

T = 10 K

Two unidentified PL lines!
Dark excitons in real multiple QW microcavities

In presence of disorder, redistribution of the oscillator strength from the polaritons to the dark modes


Dark excitons can bind to form cavity biexcitons

At quasi-thermal equilibrium \( 2X \leftrightarrow XX \implies I_{XX} \propto I_X^2 \)

Observation of “cavity biexcitons”

Do biexcitons play a role in the relaxation mechanisms of polaritons?

ESF polaritonics, Rome, March 22 2012
Possible cavity biexciton radiative dissociation channels:

- $XX \rightarrow \text{photon} + \text{LPB}$
- $XX \rightarrow \text{photon} + \text{UPB}$ (crossed out)
- $XX \rightarrow \text{photon} + \text{X}$

Uncoupled excitons get localized and recombine

LPs accumulate in the reservoir
LPB relaxation dynamics

\[ E_{LP} \geq E_{XX} - E_{LO} \]

\[ E_{LP} = E_{XX} - E_{LO} \]

\[ k_{//} = 0 \]

ESF polaritonics, Rome, March 22 2012
GaAs, CdTe and GaN
Increased LP relaxation efficiency when \( E_X - E_{LPB(k// = 0)} = \hbar \omega_{LO} \)

**GaN only**
Increased LP relaxation efficiency when \( E_{XX} - E_{LPB(k// = 0)} = \hbar \omega_{LO} \)

**Extra polariton relaxation channel mediated by cavity biexcitons**
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Renormalization of polariton branches: 
the standard picture

Renormalized dispersion curve

\[
\tilde{E}_{\text{LPB/UPB}} (k_{//}, \delta, n) = \frac{1}{2} \left[ E_C (k_{//}) + E_X (k_{//}) + \delta E_X (n) \right] \\
- \frac{1}{2} \sqrt{(E_C (k_{//}) - E_X (k_{//}) - \delta E_X (n))^2 + 4g^2 (n)}
\]

Nearly rigid blueshift of LPB and predicted linear shift of the LPB ground state with \(n\)
Renormalization of polariton branches: experimental facts

- Nearly no change observed at large $k_{//}$ $\Rightarrow$ saturation is the dominant renormalization effect
- $\Omega_{\text{VRS}}$ extracted from coupled oscillator model with constant $E_X$ and $E_C$ values
- $\Omega_{\text{VRS}}$ decreased by 20% between 0.15 and 1 $P_{\text{thr}}$
Renormalization of polariton branches: impact of $\delta$ and $T$

- Saturation effects seem to decrease with increasing $\delta$ values!
- Slow down of $\Omega_{VRS}$ decrease when crossing $P_{thr}$

- Blueshift at $k// = 0$ showing a clear deviation from linearity for $T < 200$ K
- Possible role of biexcitons ($E_{xx}^b \sim 22$ meV) in a system dominated by saturation effects (GaAs model not applicable)

$\Rightarrow$ several remaining open questions likely due to specificities of saturation effects in a system with small $\sigma_{B}^{2D}$!

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Conclusion and perspectives

- Polariton condensation phase diagram from 4 to 340 K in GaN MQW microcavity (access to kinetic and thermodynamic relaxation regimes)
- Experimental signature of biexciton-mediated polariton relaxation
- Anomalous renormalization behavior (sublinear blueshift of LPB), key role of saturation effects + biexcitons?

- Study the properties of polariton condensates over a wide range of temperatures including renormalization, biexcitonic effects
- Electrical injection of polaritons in III-N microcavities (Marlene Glauser)
- System a priori suitable for (i) investigating ultrafast OPA and OPO properties @ 300 K (solitons?), (ii) realizing coherent THz light emitters (nonpolar microcavities)
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Thank you for your attention!
Enhanced relaxation efficiency

![Graph showing P_{th} (arb. units) vs Detuning (meV) with temperature T = 4K and detuning labels XX-LO and X-LO.]