Scattering Dynamics of Exciton-polaritons in Different Material Based Microcavities

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***Abstract*- We present the numerical studies of exciton-polartion relaxation kinetics in different semiconductor microcavities including GaAs, CdTe, and ZnO. From semiclassical Boltzmann model, a bottleneck effect was found at low pumping rate. Above the critical density which is lower than the Mott density, the polaritons tend to condense at the lowest-energy states. Besides, the wide-band gap material like ZnO, could achieve polariton condensate even at room temperature (RT) due to the large oscillator strength and exciton binding energy.**

I. INTRODUCTION

Exciton-polaritons are quasi-particles, created from strong coupling between exciton and photon in the semiconductor microcavity (MC), which behave as composite bosons with very light effective mass and controllable dispersions [1]. Due to the bosonic properties, the polaritons tend to condense at ground state through several relaxation processes. The spontaneously decay of polaritons from the condensate radiates laser-like coherent emission, called polariton laser. The polariton laser needs no electronic population inversion, leading to a ultra-low threshold coherent light source. The relaxation dynamics of exciton-polaritons in MCs have been developed previously [2, 3], but the comparison of scattering features in different systems was still missing. With view of this, we present an overall comparison of polariton scattering dynamics in different materials at several distinct conditions.

II. SIMULATION MODEL

To simulate the scattering dynamics in the cavity, one can use the semiclassical Boltzmann equation [3]:

$$\frac{dN_k^{lp}}{dt} = W_k^{in} n_x^2 (1 + N_k^{lp}) - W_k^{out} n_x N_k^{lp} - \Gamma_k^{lp} N_k^{lp}$$
$$\frac{dn_x}{dt} = -\frac{1}{S}\sum_k dg_k^{lp}\left[W_k^{in} n_x^2 (1 + N_k^{lp}) - W_k^{out} n_x N_k^{lp}\right] - \Gamma_x n_x + p_x. \quad (1)$$

where N_k, S, n_x, p_x and Γ_x are the polariton distribution function, quantization area, reservoir exciton distribution function, reservoir exciton generating rate, and the reservoir exciton decay rate. In the small $k_{//}$ region, the photon-like polariton decay rate is mainly due to the finite cavity photon lifetime. In large $k_{//}$ region where exciton's fraction is higher, the exciton-like polariton decay rate should be related to the radiative decay rate of excitons. We calculate Γ_k by setting the cavity photon lifetime of 8 ps for GaAs, 1 ps for CdTe and ZnO. The exciton non-radiative decay time was set by 100 ps in all the materials. We have consider a pumping spot size R = 50 μm, so the quantization area was simply set by $S = R^2$. dg_k^{lp} is the two dimensional degeneracy for polariton at $k_{//}$. $W_k^{in} n_x^2$ and $W_k^{out} n_x$ are the rates of polariton scattering in and out from the state characterized by the wave vectors $k_{//}$ [2, 3]:

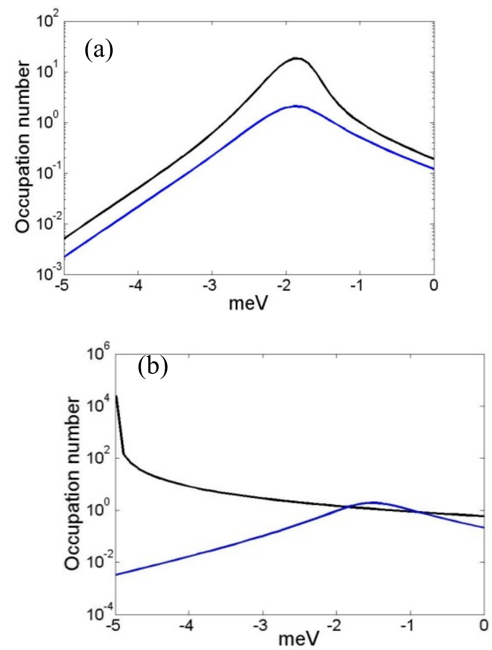

Fig. 1. Population distribution of polaritons versus the energy below bare exciton in (a) GaAs microcavity and (b) CdTe MC. The pumping rate are P=1, 5×10^{10}cm^{-2}/100ps (blue line and black line) for GaAs and P=1, 15×10^{10}cm^{-2}/100ps (blue and black line) for CdTe.

$$W_k^{in} = \frac{2\pi}{\hbar k_B T_x} M_k^2 e^{\varepsilon_k^{lp}/k_B T_x}$$
$$W_k^{out} = \frac{1}{\hbar} M_k^2 \rho_x e^{2\varepsilon_k^{lp}/k_B T_x}. \qquad (2)$$

M_k , ε_k^{lp} and ρ_x are matrix elements of polaritons, dispersion relation for polaritons and the excitons density of state.

III. SIMULATION RESULTS

Through the simulation model mentioned above, the population distribution curves of polaritons versus in-plane wavevector $k_{//}$ in GaAs and CdTe MC were summarized in Fig.1. We can observe a bottleneck in the high $k_{//}$ region. The bottleneck effect prevents polaritons from relaxing down to their ground-state at $k_{//}$=0 [2], which is the main obstacle for the realization of polariton lasers. However, the polariton-polariton scattering was very efficient when we applied a higher pumping rate, which was one of the ways to overcome the bottleneck effect. In Fig. 1, we can see the threshold pumping rate is about 10^{11} cm^{-2}/100ps for CdTe. The bottleneck effect disappears and the distribution function of polaritons has a Bose-Einstein distribution above the threshold. One should notice that the pumping density of GaAs QW was comparable to the saturation density (n_{sat} = $6.6\times10^{10}cm^{-2}$) when we increase the pumping rate. Polaritons in CdTe can relax to the ground-state way below the saturation density ($n_{sat} = 6.7\times10^{11}cm^{-2}$).

Due to the small exciton binding energy of GaAs and CdTe, which are much smaller than the thermal energy of RT (26 meV), the realization of RT polariton lasers is extremely hard to achieve in these material systems. We then consider the ZnO MC as an alternative candidate to achieve RT polariton lasing since the larger exciton binding energy of ZnO (E_b = 60meV) and the larger oscillator strength of excitons. Fig. 2 depicts the simulation result of the strongly coupled ZnO MC. The threshold pumping rate of ZnO microcavity is P = 10^{12} cm^{-2}/100ps at RT, which is smaller than the saturation density ($n_{sat} = 1.3\times10^{13}$ cm^{-2}) of ZnO QWs.

IV. CONCLUSION

At low pumping rate, most of the polaritons are accumulated in the high $k_{//}$ region before they reach condensate due to the lacking of ac-phonon scattering with the polaritons. The bottleneck effect is bypassed

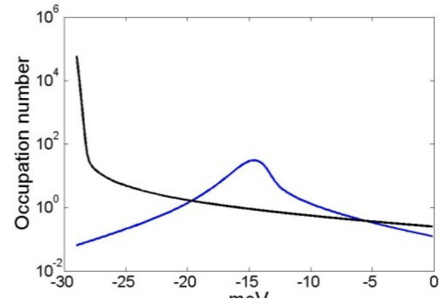

Fig. 2. Distribution function of polaritons in ZnO at RT. P=1, $10\times10^{11}cm^{-2}$/100ps (blue line and black line)

by the stronger polariton-polariton scattering at higher pumping rate. Furthermore, the large exciton binding energy and exciton oscillator strength enable the ZnO polaritons to survive at RT, which makes ZnO a promising material for the realization of the RT polariton laser.

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