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Dispersion Relation and Condensation of Exciton–Polaritons in ZnO Whispering-Gallery Microcavities

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*Abstract

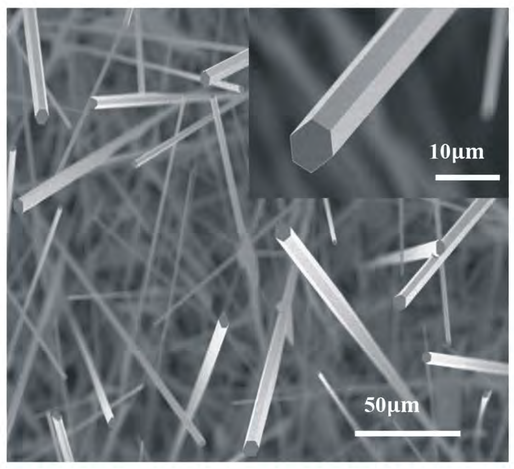
We construct a modified Lorentz oscillator model to extract the transverse and longitudinal exciton resonance energy and the damping term due to the scattering between LO-phonons and excitons in bulk Zinc Oxide at room temperature. The Rabi splitting energy and zero detuning point obtained by this method are accurate. The dispersion relations measured by angle-resolved photoluminescence agree well with the theoretical dispersion relation of exciton-polaritons, which further confirm the success of this modified model and the reliability of extracted parameters. The spectra of exciton–polaritons condensation are also observed at room temperature.

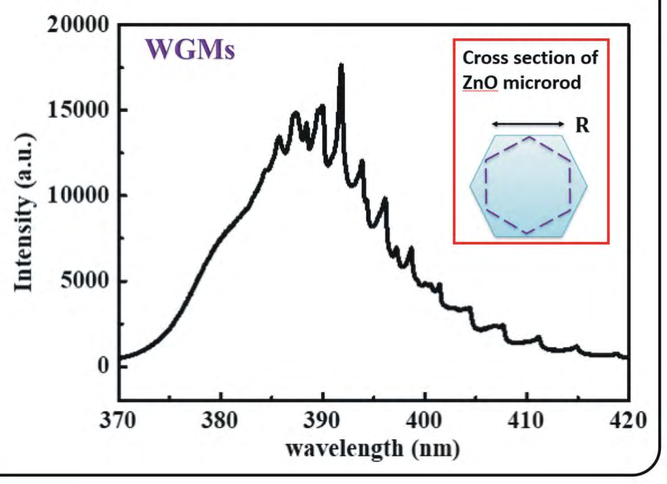
*Introduction

◆Zinc Oxide (ZnO) is a II-VI semiconductor material with hexagonal micro-structure, which can be exploited as a microcavity. The photoinduced excitons can couple with cavity photons to form exciton-polaritons, and propagate inside the cavity. The measured Rabi splitting energy also confirms exciton-polaritons are in strong coupling regime [1]. Because exciton-polaritons are bosons, we further observed condensations of these quasi-particles inside the ZnO whispering-gallery microcavities.

*ZnO MRs and WGMs

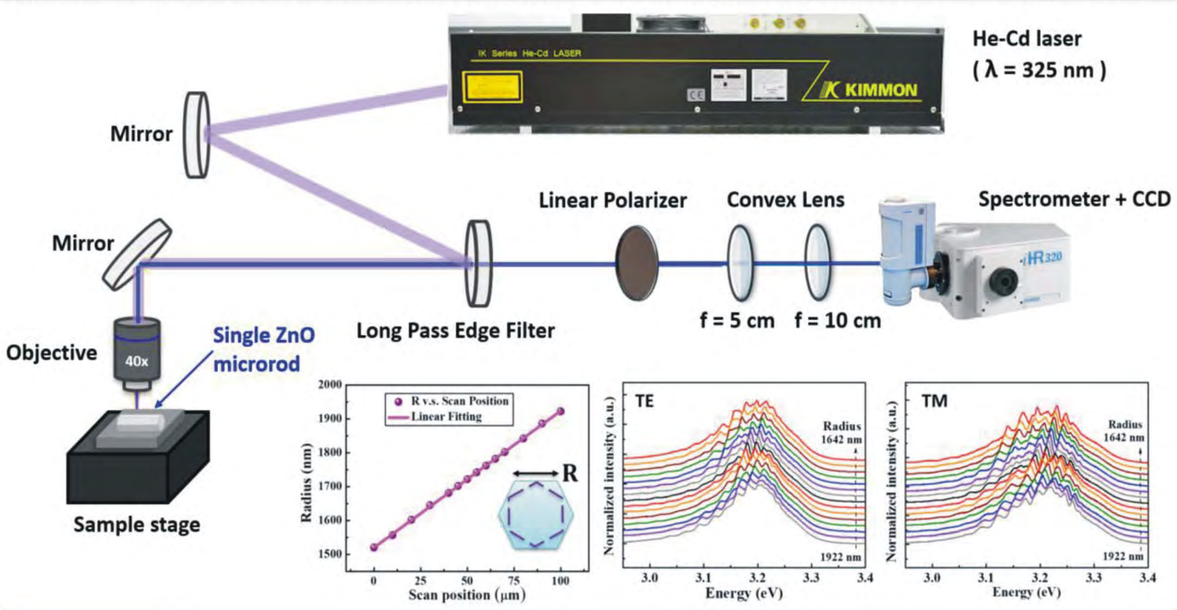
◆The high quality ZnO microrods (MRs) were grown by chemical vapor deposition method. The resonant optical modes corresponding to the whispering gallery modes (WGMs) in the hexagonal cross section can be determined by considering the phase matching condition due to the total internal reflection.



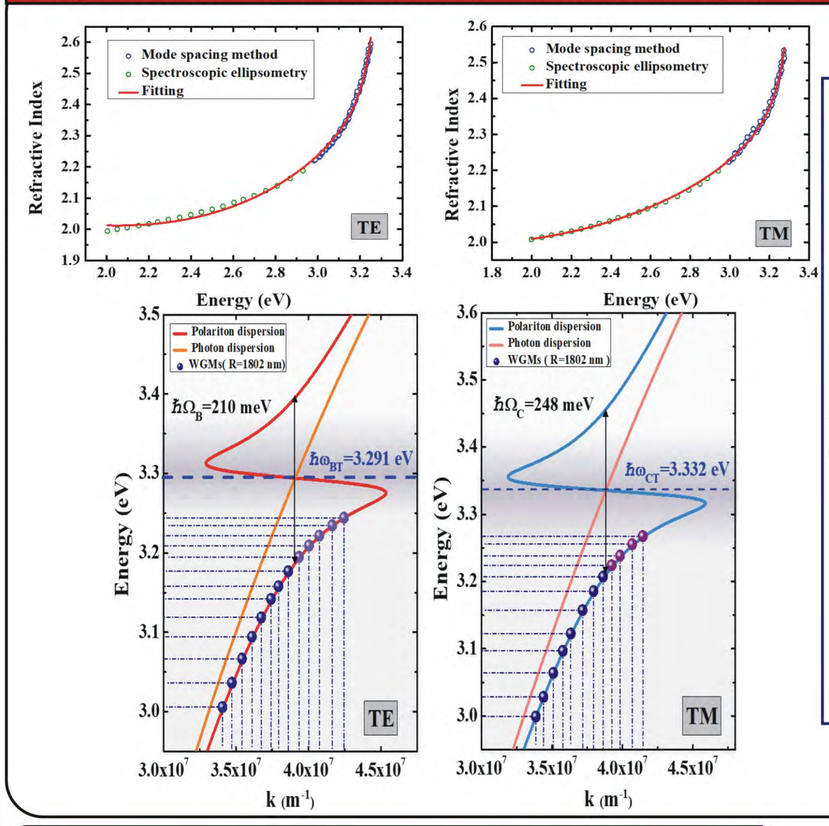


*micro-PL and the spectra of ZnO MR

◆The illustration shows the home-built micro-PL system in this work. A single tapered ZnO MR was excited by He-Cd laser. The emissions of sample was collected by the same objective, and then conducted to a spectrometer (Horiba-Jobin-Yvon iHR320) equipped with the liquid-nitrogen cooled CCD array detector.



*Dispersion relation and Exciton–Polariton induced parameters



	TE (i=B exciton)	TM (i=C exciton)
$\hbar\Gamma_i$(meV)	37.99	39.15
$\hbar\omega_{iT}$(eV)	3.291	3.332
$\hbar\omega_{iL}$(eV)	3.301	3.344
g_i	7.205	6.852
P_i	4.655	3.927
$Q_i(eV^{-2})$	-0.311	-0.055
$R_i(eV^{-4})$	0.0358	0.0159

$$\tilde{\varepsilon}(\hbar\omega) = \varepsilon_1(\hbar\omega) + i\varepsilon_2(\hbar\omega)$$

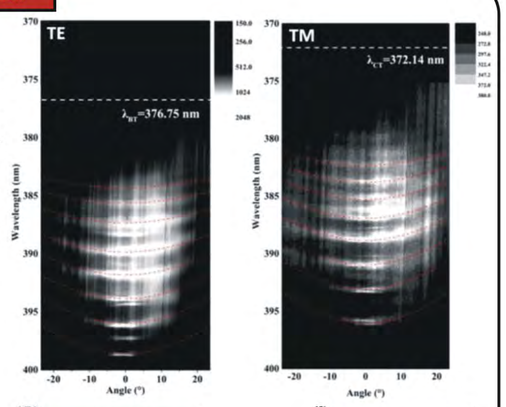
$$= \varepsilon_b(\hbar\omega) + g_i \frac{(\hbar\omega_{iL})^2 - (\hbar\omega_{iT})^2}{(\hbar\omega_{iT})^2 - (\hbar\omega)^2 - i(\hbar\omega)(\hbar\Gamma_i)}$$

$$= [P + Q \times (\hbar\omega)^2 + R \times (\hbar\omega)^4] + g_i \frac{(\hbar\omega_{iL})^2 - (\hbar\omega_{iT})^2}{(\hbar\omega_{iT})^2 - (\hbar\omega)^2 - i(\hbar\omega)(\hbar\Gamma_i)}$$

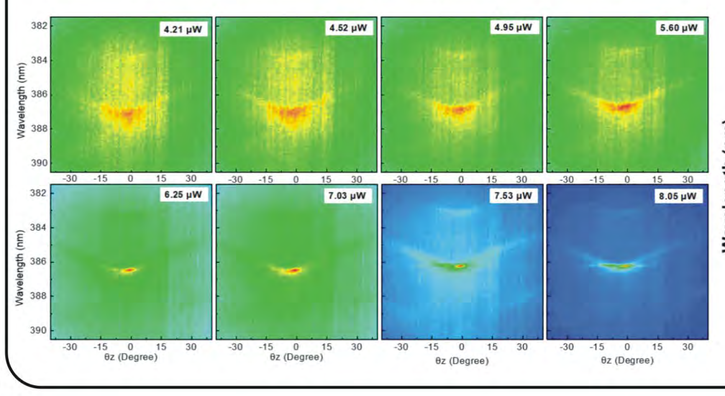
*ARPL spectra and Condensation of exciton-polaritons

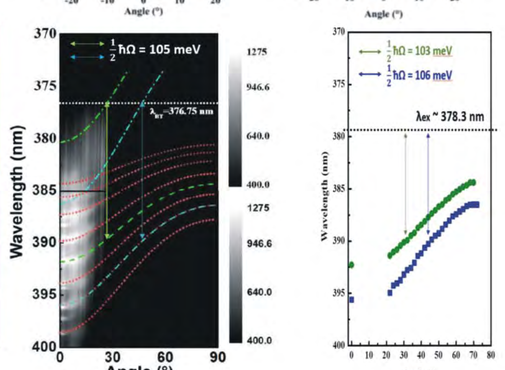
◆The theoretical prediction (red dash lines) and ARPL spectra (white signals) are consistent which implies the TE and TM refractive index dispersion obtained in this work are accurate.

◆While increasing pumping power, we further observed coherent photons generated from the condensation of exciton-polaritons in ZnO microcavity at room temperature.



Condensation of exciton polaritons at RT





*Conclusions

◆ We propose a concise and convenient methodology (an iterative method based on WGMs spacing and the modified Lorentz oscillator model) to calculate the refractive index dispersion of ZnO in a wide spectral range by using WGMs of ZnO microrod cavity. The important parameters for describing exciton-polaritons in the strong coupling regime can be extracted. ARPL spectra match the predictions of theoretical dispersion as well. The exciton-polaritons condensation are also observed at room temperature. Because of the many semiconductor microcrystals possessing a microcavity in nature, this methodology can be generalized to other semiconductor materials with a direct band gap and a large oscillator strength due to exciton resonance.

*References

[1] **S. C. Wu** et al., "Determination of dispersion relation and optical parameters induced by exciton-polariton effect in whispering-gallery microcavities using photoluminescence spectroscopy," ACS Photonics 8, 1413-1420 (2021).

*研究生活及心得

十年職場後，重返學校拾起書本、步進實驗室，迄今都不是容易的事情，況且研究工作是挑戰人類知識的極限並探索未知的世界，亦是人類智慧與自然複雜度的競衡。過程中無數次的失敗經驗，更是拼湊出背後真理的唯一途徑。期許自己能始終秉持這樣的信念和毅力，勇於面對人生未來的種種課題與挑戰，也要感念取之社會(中技社獎學金)，日後回饋於社會的責任。