PhD Proposal

Investigations on the intermediate regime between polaritonic and photonic lasing in ZnO based waveguides

Exciton-polariton results from the strong coupling between an electron-hole pair in coulombic interaction and a photon. Due to the bosonic nature of this composite pseudo-particle, condensation of excitons-polaritons occurs under an optical excitation and leads to a laser effect based on the stimulated emission by the final state; a lower threshold is expected in this regime which is interesting for optoelectronic devices. However excitons-polaritons only exist under a critical density of carriers named as Mott density for which the coulombic interaction between the electron and hole is not too much affected by the screening induced by the free carriers. For high carrier densities a classical emission based on the stimulated emission of radiation takes place.

It has been shown that an intermediate regime occurs between these two extreme situations known as the Barden-Cooper-Schrieffer (BCS) regime where emission comes from preformed electron-hole Cooper pairs [1]. The purpose of this thesis is to investigate this intermediate regime between polaritonic and photonic lasing in ZnO-based waveguides and microcavities.

Previous experimental experiments combined with calculations have demonstrated that the oscillator strength of excitons in ZnO waveguide is reduced under an optical excitation [2]. Moreover a signature of the existence of preformed electron-hole Cooper pairs has been identified in bulk ZnO [3]. This result has been recently confirmed through a research activity in our Optical Spectroscopy of Solids (OSS) group (PhD thesis to be defended before this end of 2024).

In the continuity of this thesis, we propose an in-depth spectroscopic study of the optical gain in ZnO based waveguides as a function of injected carriers and temperature in order to define the existence or the phase diagram of the BCS polaritons.

Spectroscopic experiments as a function of excitation intensity and temperature will be carried out in ZnO-based containing parallel cracks defining optical microcavities or in ZnO samples where designed cavities have been etched. First, the modification of the waveguide dispersion, extracted thanks to a designed grating deposited onto the surface, as a function of the excitation intensity, will allow to evidence the screening of the oscillator strength of the exciton. Second, the careful analysis of the cavity modes of the etched microcavities as a function of power will indicate the variation of the index. These

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experimental data will be compared in a first approach with a model developed by Banay and Koch which considers the screening of excitons by free carriers [4].

Time resolved photoluminescence experiments will provide decay times which are necessary to estimate the density of injected photo-carriers. Measurements of the decay time along the waveguide dispersion relation will contribute to a better knowledge of the dynamical recombination of the excitons-polaritons.

A new experimental set-up allowing to perform pump-probe experiments will be acquired at the end of 2024. It will allow to investigate the carrier dynamics in the band-edge region and the absorption changes under high excitation intensity at an ultrafast time scale - less than one picosecond. Exciton saturation and induced transparency at the bandgap due to electron-hole transient will be studied. These experiments will contribute to the measurement of the absorption or reflection coefficient as a function of the injected carrier density.

The whole set of the experimental data combined with calculations will contribute to a better understanding of the BCS lasing in ZnO-waveguides and microcavities.

The candidate should have a solid formation in solid state physics and in optics. He/She will have the ability to communicate (English required at minimum) for an efficient integration in the OSS group of the laboratory.

References:

[1] Jiaqi Hu et al., Physical Review X **11**, 011018 (2021)
[2] Geoffrey Kreyder et al., Physical Review B **107**, 125307 (2023)
[3] Marijn A. M. Versteegh, Physical Review B **84**, 035207 (2011)
[4] L. Banyai and S. Koch, **63**(3), pp283-291 (1986)

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