Hertzian stress-induced shifts of arbitrary exciton states in Cu_2O

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Exciton BEC in bulk semiconductors had not been observed until recently due to the losses associated with the two-body inelastic scattering between excitons. Recent experiments have been performed at the sub-kelvin temeperature region aiming at relatively low critical densities [1,2]. In 2022, real-space imaging of trapped 1s paraexcitons was performed by mid-infrared induced absorption using the 1s-2p transition, and the signal of the condensate itself was observed for the first time [3]. In the experiments at the sub-kelvin region, the BEC critical density was achieved by capturing and accumulating excitons with a strain-induced trap.

In future experimental studies, the 1s-2p transition can be used to visualize the formation dynamics and the coherence of the condensate. However, it is known that the 1s-2p transition energy is strain dependent and thus it is necessary to understand quantitatively the position dependence of the transition energy. This necessitates the development of a theoretical framework to evaluate the strain-induced energy shift of the 2p level, since only those of the even-parity states can be calculated at present [4].

In this study, we aim to elucidate the exciton states in a spatially inhomogeneous strain under the Hertzian contact, especially the 2p state, whose strain dependence has not yet been well understood. First, a theoretical framework is developed which can treat arbitrary exciton states in an arbitrary strain. This is based on the treatment of Schweiner et al. [5], which has succeeded in explaining the exciton spectra in the strain-free case, as well as on the Pikus-Bir Hamiltonian to incorporate the effect of strain. Then, we used the experimental data of the energy shifts of even-parity excitons under uniaxial stress [6] to determine the values of the deformation potentials of the valence band of Cu_2O. With this framework, we calculated the shift of the energy of 2p (Fig. 1) and 1s-2p transition energy under strain, which is in good agreement with our experimental data. This theoretical framework can also be utilized to calculate the energies and wavefunctions of any exciton states under strain, including the Rydberg excitons.

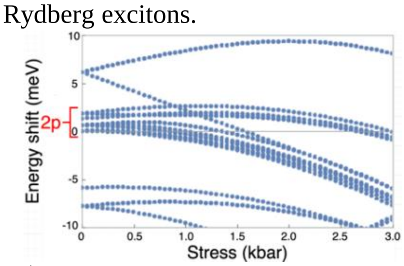

Fig. 1. Calculated energy dependence of 2p excitons under uniaxial stress (∥[001]) using our framework. Note that the energies of 2p states split even under no applied stress.

References

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