Cavity-controlled Moiré Excitons without a twist

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Abstract

2D materials like TMDs have attracted significant attention due to their unique electronic properties, such as the strong excitonic binding, which enables stable excitons at room temperature [1]. Considering TMDs heterostructures leads to even more interesting systems. Previous works [2] show that it is possible to tune the Moiré potential to control the localization of the excitons in such structures, which directly impacts the optical properties.
In the quest to understand and control excitons in novel environments, this study focuses on excitonic behavior for a twisted bilayer heterostructure in an optical cavity. Our materials of choice are $MoSe_2$ and WSe_2, and our goal is to produce an all-optical Moiré-like exciton confinement by tuning a cavity with a dielectric grating [Figure 1].
Optical cavities provide a promising approach to controlling material properties by strongly coupling the matter transitions in the material to the confined photons. Since the energy contribution of the interaction Hamiltonian is comparable to the other terms, one needs to go beyond the perturbative approach to treat the coupled light-matter problem. The new states resulting from this interaction are called exciton-polariton states, from the quasi-particle arising from the coupling of electronic and photonic states.
We find [3] that the cavity can induce optical confinement and emulate the Moiré potential in the classical limit [Figure 2], where the quantum fluctuation of the radiation field can be neglected. Similarly, we can confine the excitons even when such limit cannot be taken. In this case, cavity-induced exciton-exciton interactions arise.
This study utilizes the full diagonalization of the QED problem to address what happens to such twisted bilayer heterostructure when subject to the QED field. Starting from first principles, we solve the Wannier equation in k-space and then add the Moiré potential as well as the light-matter coupling terms. Finally, we diagonalize the Hamiltonian and compute the spectral and linear response functions to study the optical properties.

References

[1] A. Krasnok, S. Lepeshov, and A. Alú; Optics Express, 26, 12 (2018), 15972-15994
[2] S. Brem, C. Linderälv, P. Erhart and E. Malic; Nano Letters, 20,12 (2020), 8534-8540
[3] F. Troisi, H. Hübener, A. Rubio and S. Latini; Cavity-controlled Moiré excitons without a twist; in preparation

Figures

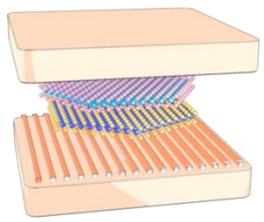

Figure 1: Representation of the bilayer Heterostructure in a Fabry-Perot optical cavity with grating.

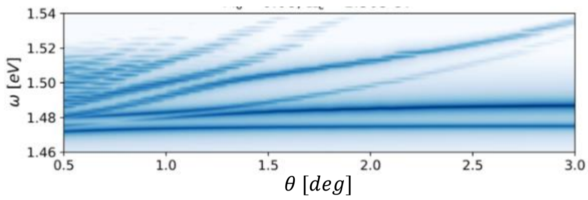

Figure 2: Linear response function for light-matter coupling $A_0 = 0.08$ and cavity frequency $\Omega_c = 1.303eV$, as a function of the twist angle θ and the probe frequency ω.