

Optical and cavity engineering of driven excitonic condensates

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Bilayer materials hosting interlayer excitons—comprising electrons in one layer and holes in the other—are a promising experimental platform for realising high-temperature condensates and studying their dynamical properties. Imposing a chemical potential bias through optical pumping or electrical contacts drives exciton condensates into distinct dynamical regimes. We investigate how these regimes manifest in emitted light and how they are influenced by placing the material within an optical cavity.

We show that in a bilayer system where the charge can tunnel between the layers, the chemical potential bias means that an exciton condensate is in the dynamical regime of the Josephson effect. By increasing the bias voltage, the system undergoes a transition from the phase-trapped to phase-delocalized dynamical condensation. Optical spectroscopy can identify these phases, with a strong response to weak fields near the transition due to the instability in the order parameter dynamics [1].

If such a system is placed in an optical cavity within the phase-trapped regime, coupling to photons favours a superradiant state. The phenomenon allows the device to convert DC currents into coherent photons at tunable frequencies determined by the bias and material thickness. These findings highlight mechanisms to control and harness excitonic condensates for optoelectronic applications [2].

[1] Alexander Osterkorn, Yuta Murakami, Tatsuya Kaneko, Zhiyuan Sun, Andrew J Millis, Denis Golež, *Physical Review Letters* 135 (10), 106902 (2025).

[2] Zhiyuan Sun, Yuta Murakami, Fengyuan Xuan, Tatsuya Kaneko, Denis Golež and Andrew J. Millis, *Phys. Rev. Lett.* 133, 217002 (2024).