Technische Universität Dresden

IFMP Institut für Festkörper- & Materialphysik

Master Thesis Opportunity

Lifetime enhancement of coherent order parameter excitations in excitonic insulators

Excitonic insulators represent an exotic quantum state of matter where excitons collectively condense into a macroscopic ordered phase. Unlike superconductors, excitonic condensate can exist at temperatures as high as room temperature, making them an attractive platform for studying macroscopic quantum phenomena at elevated temperatures. Although this concept was proposed more than 60 years ago in solids, many fundamental questions about the nature of the condensate and its dynamics remain unanswered. Among the various experimental techniques, ultrafast time-resolved optical spectroscopy has emerged as a powerful tool for studying excitonic insulators. By exciting a material with an ultrashort laser pulse and monitoring its response, these experiments allow us to observe coherent collective excitations that directly reflect the properties of the excitonic condensate.

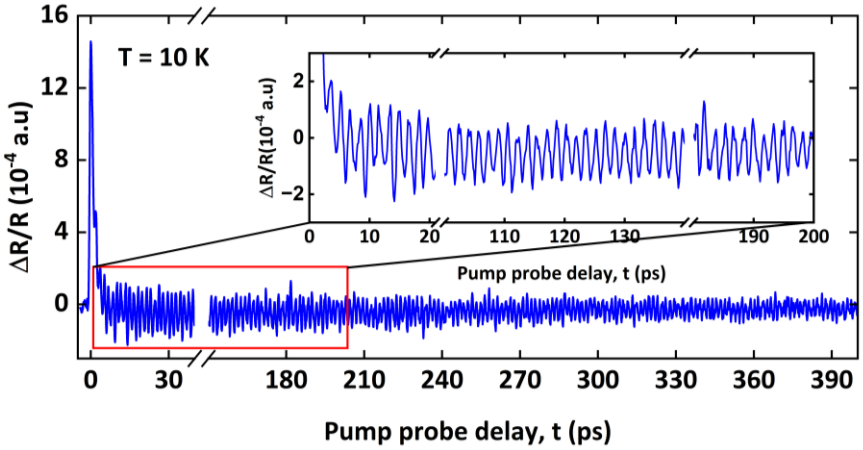

Figure 1: Photoinduced change in reflectivity as a function of pump probe delay measured on $Ta_2Pd_3Te_5$ at 10 K

Previous time-resolved studies of the prototypical excitonic insulator Ta_2NiSe_5 revealed coherent amplitude coupled phonon hybrid modes whose amplitude follows the excitonic order parameter and decreases when the condensate is optically suppressed [1]. More recently, our group identified a new dynamical signature in the excitonic insulator $Ta_2Pd_3Te_5$: exceptionally long-lived coherent oscillations (Fig. 1) associated with the condensed phase. Their lifetime increases markedly below the transition temperature and is strongly reduced as the excitation density increases. The physical origin of the remarkably enhanced lifetime remains an open question. This project aims to clarify the mechanism responsible for this behavior.

Thesis Project

The goal of this project is to investigate the temperature, wavelength, and excitation density-dependent dynamics of the long-lived coherent modes in prototypical excitonic insulators and related semiconductors, including $Ta_2Pd_3Te_5$ and the $Ta_2NiSe_{5-x}S_x$ family. In the $Ta_2NiSe_{5-x}S_x$ series, sulphur substitution gradually suppresses the excitonic instability, driving the system from an excitonic insulator to a normal semiconductor. This makes the material family an ideal model system for understanding how coherent collective excitations evolve with the strength of excitonic order.
This project combines ultrafast optical spectroscopy with the study of quantum materials. The student will work closely with members of the research group and will:

- Build and operate an ultrafast optical pump–probe spectroscopy setup and perform temperature, wavelength, and excitation-density dependent measurements on excitonic insulators.
- Analyse coherent phonons, hybrid amplitude modes, and long-lived coherent dynamics.
- Gain experience in time-resolved data analysis and the physics of collective excitations in quantum materials, with a focus on excitonic insulators and symmetry-breaking phase transitions.

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Dr. Anjan Kumar (anjan.naralapura@tu-dresden.de), Room REC/D 201 for further information and discussion

[1] Werdehausen, Daniel, et al. "Coherent order parameter oscillations in the ground state of the excitonic insulator Ta_2NiSe_5." *Science advances* 4.3 (2018): eaap8652.