Terahertz manipulation of exciton complexes in 2D semiconductors

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Rich physics of Coulomb-bound quasiparticles, such as excitons and trions in transition metal dichalcogenide monolayers, is currently under intense research in the condensed matter community. These quasiparticles feature high binding energies on the order of 100s of meV, exhibit strong light-matter coupling, and can store quantum information in spin-valley degrees of freedom [1]. Realizing strategies for external control of the excitonic states on ultrafast timescales thus has emerged as an important avenue of research.

Here we report the observation of transient trion-to-exciton conversion in hBN-encapsulated $MoSe_2$ monolayer (Fig. 1a) induced by intense THz pulses on picosecond timescales, generated at the infrared Free-Electron Laser facility (FELBE) [2, 3]. The exciton dynamics are subsequently monitored by recording time-resolved photoluminescence (trPL) spectra with a streak camera. Visible pulses (λ = 400 nm) excite a population of both excitons and trions (Fig. 1b, trPL spectra without THz pulses). By adding THz pulses after about 30 picosecond delay with respect to the visible excitation (Fig 1c), we observe a quenching of the trion emission and a temporary brightening of the exciton emission. Furthermore, by tuning the frequency of the THz pulses, we record the THz dissociation spectrum of trions (Fig. 1d). Importantly, efficient trion-to-exciton conversion is observed when the THz photon energy is equal or higher than the trion binding energy. Similar impact of THz radiation is observed in other materials such as WSe_2 monolayers and $MoSe_2/WSe_2$ heterostructures. Altogether, the results open up promising pathways towards external control of many-particle states in low-dimensional materials.

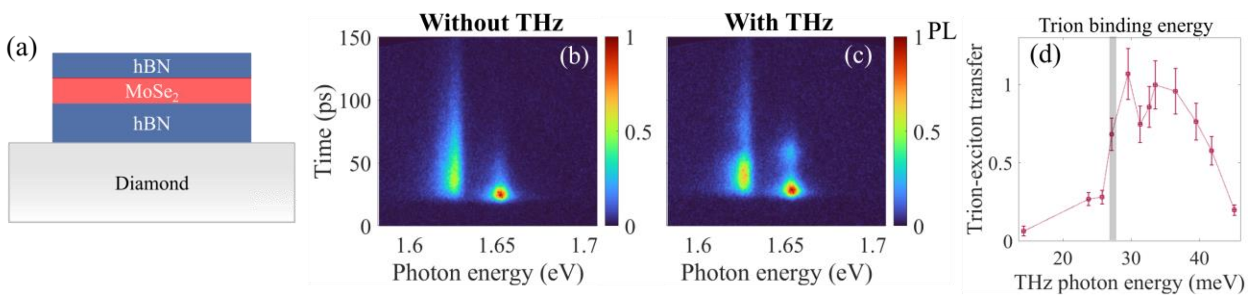

Fig.1. (a) Sketch of the sample: $MoSe_2$ monolayer encapsulated in hBN flakes on a diamond substrate. (b) and (c) Time-resolved PL spectra with and without THz pulses. (d) Fraction of trions transferred to excitons as a function of THz photon energy. This corresponds to the trion dissociation spectrum.

References

[1] G. Wang et al., Rev. Mod. Phys. 90, 021001 (2018)
[2] M. Helm et al., The European Physical Journal Plus, 138, 158 (2023)
[3] T. Venanzi, M. Cuccu et al., *Submitted* (2024)