Ultrafast studies of exciton dynamics in hBN/$MoSe_2$/hBN heterostructures by degenerate pump-probe experiments

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Semiconductor Transition Metal Dichalcogenides (S-TMDs) are subject to continuous interest due to a number of fascinating quantum phenomena that come from their specific electronic structure and strong many-body interactions.

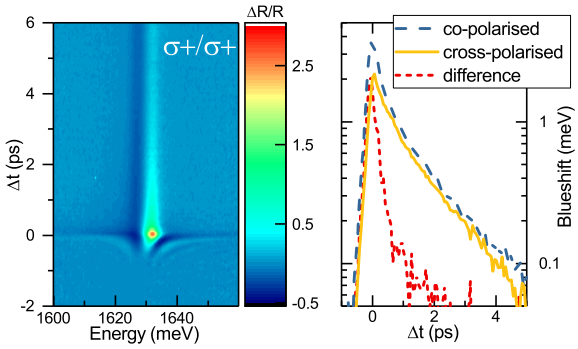

Figure 1: Differential reflectivity of hBN/$MoSe_2$/hBN as a function of time delay between pump and probe beams for co- and cross-circularly polarised light.

Due to the specific symmetry of the lattice, they offer a possibility to conveniently access individual valleys using circularly polarized light [1], making them ideal platform to explore properties of the valley pseudospin. However, extremely short lifetimes of excitonic complexes in these materials require experimental techniques of subpicosecond resolution, such as the ultrafast pump-probe measurements[2,3].

In our work we study single layer of $MoSe_2$ encapsulated in hexagonal BN by means of degenerate pump-probe spectroscopy. The rejection of the scattered pump signal is solely based on the geometrical arrangement of the experiment. This approach allows us to directly probe the exciton dynamics in a given valley by measuring reflection in specific polarisation with micrometer spatial resolution. The reflected probe beam is analyzed using a spectrometer with a CCD camera, which enables us to independently analyze the changes in energy and the oscillator strength of the exciton transition. We observe evolution of the exciton absorption after a pulse of spectrally broad femtosecond laser. The signal exhibits strong exciton blueshift and significant broadening while integrated intensity remains almost constant. The decay of the differential reflection shows different time-scales ranging from 200 fs to tens of picosecond. Interestingly, the differences between the signal in the cases of co- and cross-polarised pump-probe beams only weakly depend on the selection of polarisation basis (circular/linear).

We interpret our findings in the picture of phase-space filling of carriers in different K, K' valleys and strong exciton-exciton interactions. Moreover, an introduction of strong magnetic fields (up to 10T) which stabilizes the carriers within a single valley does not drastically affect the difference in the decay between the valleys, which points to a conclusion that the observed ultrafast phenomena are not directly related to intervalley exciton scattering.

[1] Ugeda, M. M. et al. *Nat. Mater.* 13, 1091–1095 (2014)
[2] Moody, G. et al. *J. Opt. Soc. Am. B.* 33, C39-C49 (2016)
[3] Jakubczyk, T. et al. *Nano Lett.* 16, 5333–5339 (2016)