Probing electronic excitations in atomically thin semiconductors: Unique insights from high magnetic fields

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Monolayer transition-metal dichalcogenides belong to a new class of atomically-thin semiconductors that show great promise for advanced opto-electronic applications, such as flexible displays and light harvesting devices (solar cells). As these materials are only three atoms thick, they are typically embedded with other materials in a host structure. However, being truly two-dimensional, it is expected that their electronic and optical properties will be strongly affected by the dielectric properties of the surrounding environment.

Magneto-optical spectroscopy is a powerful tool to determine the properties of electronic excitations in bulk and quantum - confined semiconductors. The exciton is one of these fundamental excitations, as it consists of an optically-excited electron that forms a Coulomb-bound pair with the positively charged hole that was left behind after the electron was excited from the Fermi sea. Key parameters that characterize an exciton include its binding energy and its physical size.

MagLab users have recently prepared high quality, atomically-thin samples of tungsten di-selenide, WSe_2, and systematically encapsulated them in different dielectric environments. Magneto-transmission spectroscopy in pulsed magnetic fields to 65 teslas revealed–for the first time–how the binding energy and size of the excitons depend on the dielectric constant of the surrounding material. This work shows that optical properties of 2D semiconductors can be tuned by design.

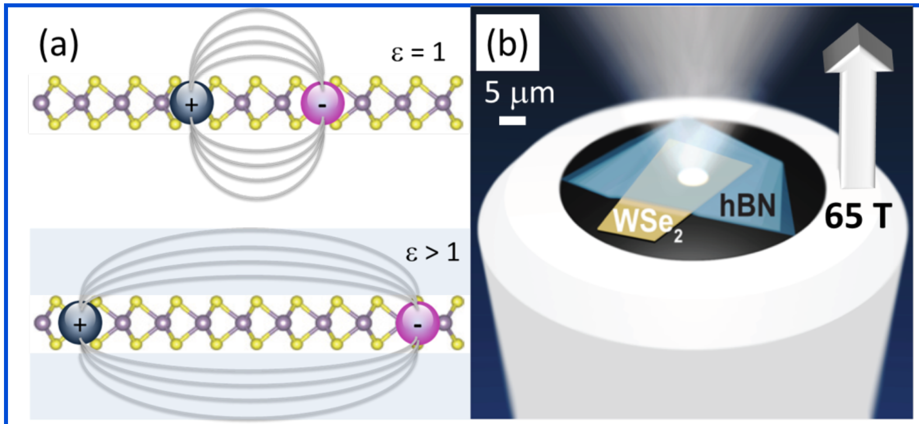

Figure 1: (a) 2D excitons in monolayer WSe_2: As dielectric screening from the surroundings increases, their size grows and binding energy drops. (b) The experiment: monolayer WSe_2 is affixed to an optical fiber and encapsulated.

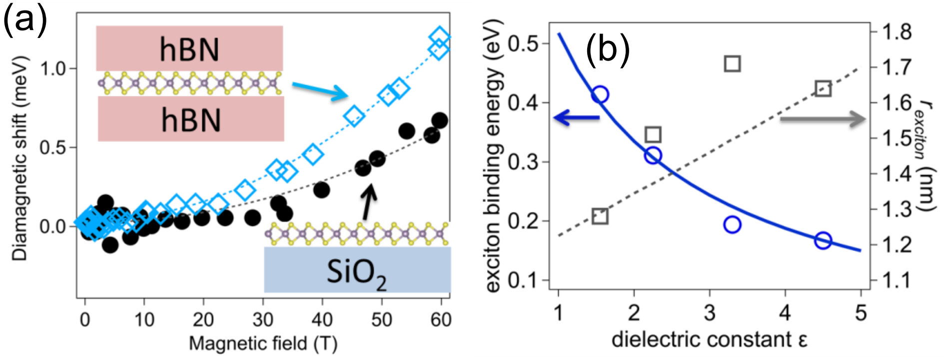

Figure 2: (a) Quadratic diamagnetic shift to 60T gives the exciton radius ($r_{exciton}$). (b) Calculated and measured exciton binding energy and $r_{exciton}$ versus average dielectric constant ε of the surrounding environment.

Facilities: NHMFL Pulsed Field Facility, Los Alamos National Laboratory; 65 Tesla capacitor-driven magnet.

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