Gate and Magnetic-Field Control of Dark Trions in Monolayer WSe_2

Liu, E., van Baren, J. (UC Riverside, Physics); Lu, Z., Smirnov, D. (NHMFL); Lui, C.H. (UC Riverside, Physics)

Introduction

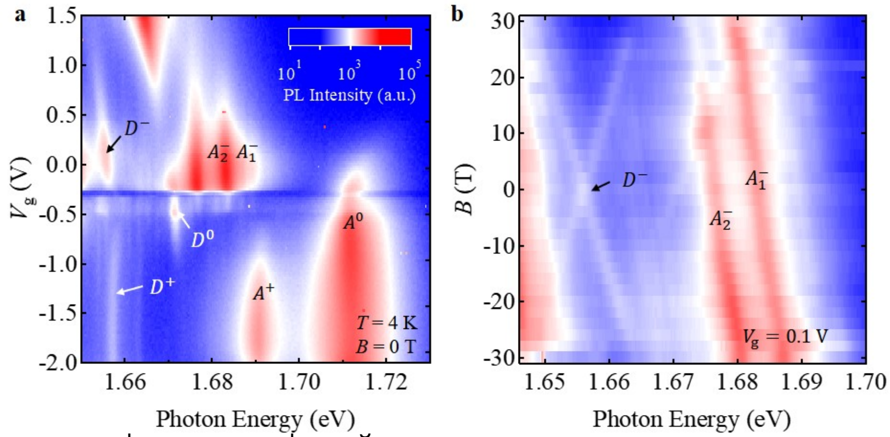
Dark trions, the bound states between a dark exciton and an electron (hole), are intriguing entities with novel applications. The long lifetime and finite net charge of the dark trions allow us to efficiently control the excitonic dynamics by electric field. Monolayer WSe_2 is an exceptional material to explore dark excitons. Unlike other semiconductors (e.g. $MoSe_2$) with bright excitons in the lowest energy level, monolayer WSe_2 hosts dark excitons well below the bright exciton level.

Experimental

In our experiment, we fabricate ultraclean monolayer WSe_2 gating devices encapsulated by boron nitride (BN). We excite the samples with 532-nm continuous laser and collect the photoluminescence (PL) at low temperature T = 4 – 10 K. We find that, in ultraclean samples, dark trions can emit weak but noticeable luminescence. Although such luminescence propagates in the in-plane direction, we can partially capture it with a wide-angle microscope objective (numerical aperture = 0.67) in the conventional out-of-plane detection geometry [1]. We also measured the PL of monolayer WSe_2 under strong out-of-plane magnetic field (B = –31 to 31 T), which is performed in National High Magnetic Field Lab with a 31 T DC magnet (cell 9) and a fiber-based probe.

Results and Discussion

By using ultraclean WSe_2 devices encapsulated by boron nitride, we can directly resolve the weak photoluminescence of spin-forbidden dark trions and continuously tune between negative and positive charged dark trions with electrostatic gating (**Fig. 1a**). The dark trions exhibit large binding energy (14-16 meV) and narrow line width (2.5 meV), signifying their high stability. The lifetime of dark trion measured by time-resolved PL technique could be longer than 1 ns, which is about 100 times that of the bright trion. We also reveal their spin triplet configuration and distinct valley emission by their characteristic Zeeman splitting under strong magnetic field (**Fig. 1b**). Our data results in a manuscript that was submitted to *Nature Communications*.



Conclusions

In summary, the characteristic gate dependence, long lifetime and large Zeeman splitting consistently confirm that the D^- and D^+ peaks correspond to dark trions in monolayer WSe_2. Our direct observation and gate manipulation of dark trions provides a promising route to develop trion electronics. Prior research has shown that trions can behave like free charge carriers with controllable motion under electric field. Given their controllable charge, spin, valley and layer degree of freedom, TMD trions are attractive carriers for quantum information technology. But so far, trion transport has not been achieved in 2D materials, primarily due to the short lifetime of bright trions. Our observed dark trions offer an effective solution. We can drive the motion of long-lived dark trions by in-plane electric field and image their spatial dynamics by their observable luminescence. Such combined transport and optical experiments of dark trions shall open a new path to investigate field-controlled trion transport in 2D materials.

Acknowledgements

The National High Magnetic Field Laboratory is supported by the National Science Foundation through NSF/DMR-1157490/1644779 and the State of Florida.

References

[1] G. Wang, *et al.*, Phys. Rev. Lett., **119**, 047401 (2017).