Brightened emission of dark trions in transition metal dichalcogenide monolayers

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The optical properties of atomically thin semiconductors based on transition-metal dichalcogenides (TMDs) are dominated by robust exciton complexes, such as the fascinating recombination processes of bright and dark trions [1]. The use of charge-tunable TMD monolayers fully encapsulated in hexagonal boron nitride (hBN) allows us to electrostatically dope the monolayers and significantly enhance the resolution of these complexes. Moderate electron doping of WSe_2 monolayers leads to the emergence of a strong luminescence peak just below the well-understood spectral lines associated with the recombination of negatively charged bright and dark trions. This peak has been observed by multiple research groups [2]. Two fundamental questions emerge: which exciton complex is associated with this optical recombination? What is the mechanism by which the recombination process works? In this work, polarization-dependent micro-photoluminescence (PL) experiments are performed at 4 K to demonstrate that this luminescence peak is the result of electron-electron assisted recombination that brightens the dark trion emission. Supporting evidence for this second-order recombination process comes from identifying the equivalent brightened emission of positively charged dark trions when the monolayer is electrostatically doped with holes. Remarkably, the discovered hole-hole-assisted PL peak emerges in the near infrared, about 500 meV below the well-studied spectral region of excitons and trions. Further, with magneto-PL experiments, we find that the g-factor of this new transition (g = +4) has an opposite sign compared to the well-known g-factor of neutral or charged excitons. This allows us to propose a brightening mechanism for the positively charged dark trion involving the Γ valence band [3].

References

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