Strain-Induced Exciton to Trion Conversion in Monolayer Transition Metal Dichalcogenides

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Abstract

In 2D transition metal dichalcogenides (TMDCs), strain has been used as an efficient tool for bandgap engineering. It has been proposed to use non-uniform strain as a tool to create a "funnel" for excitons, an excited bound electron-hole pair in TMDCs, to achieve a highly efficient broadband solar cell [1].
In this work we mimic the exact proposal in Ref. [1]. We construct an all-optical all-electrical atomic-force-microscope (AFM) and strain non-uniformly a monolayer of WS_2. Surprisingly, we do not see any "funnel" effect as we found that the diffusion of the excitons, an effect that is highly efficient at room-temperature, limits the "funnel" effect. On the other hand, we observe an efficient conversion of excitons into negatively charged trions (see Fig. 1) [2]. This is the first demonstration of electrostatic gating using mechanical deformation with external electric fields. This effect has been shown also with pressurized membranes with different geometries (circles and triangles) [3].
We analyze theoretically and numerically the influence of the diffusion for different temperatures and heterostructures and we find that the efficiency increases both at low temperatures and for long-lived indirect excitons in heterostructures [4]. This leads to the next generation of "funnel" devices with TMDCs heterostructures.

References

[1] J. Feng, X. Qian, C.-W. Huang, and J. Li, Nature Photonics 6, (2012), 866–872.
[1] M. G. Harats, J. N. Kirchhof, M. Qiao, K. Greben, and K. I. Bolotin, Nature Photonics, 14 (5), (2020), 324-329
[2] S. Kovalchuk, M. G. Harats, G. López-Polín, J. N. Kirchhof, K. Höflich, K. I. Bolotin, 2D Materials 7 (3), (2020), 035024
[3] M. G. Harats, K. I. Bolotin, 2D Materials 8 (1), (2020), 015010

Figures

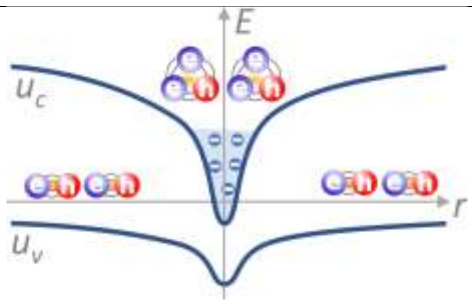

Figure 1: Description of the exciton to trion conversion. The non-uniform strain changes the band-structure and the density of free electrons in the center of the "funnel" increases, leading to increased trion density and decreased exciton density.