Substrate mediated control of exciton transport in atomically thin materials

V. Shahnazaryan[1,2*], O. Kyriienko[1,3], H. Rostami[4]

[1]ITMO University, St. Petersburg 197101, Russia
[2]Institute of Physics, Polish Academy of Sciences, Warsaw 02-668, Poland
[3]Physics and Astronomy, University of Exeter, Stocker Road, Exeter EX4 4QL, United Kingdom
[4]NORDITA, KTH Royal Institute of Technology and Stockholm University, SE-106 91 Stockholm, Sweden

We consider various schemes of governing exciton transport properties in atomic monolayers of transition metal dichalcogenide (TMD). Given by atomic thickness, the electronic properties of TMD monolayers can be essentially modulated by means of external impacts, such as electric field, strain, radiation, environment. Particularly, here we demonstrate a path for the spatially resolved control of single particle bandgap, exciton binding energy and exciton routing in TMD monolayer lying on a paraelectric substrate. The mechanism relies on the ultrasensitive response of the substrate dielectric permittivity to temperature changes, allowing for spatially inhomogeneous screening of Coulomb interaction in the monolayer. As an example, we consider the heterostructure of TMD and strontium titanate oxide $SrTiO_3$, where large dielectric screening can be attained (see Fig. 1). We study the impact of substrate temperature on the bandgap renormalization, exciton binding energy, Bohr radius and an exciton-exciton interaction. Applying local heating, we create spatial patterns with varying exciton resonant energy, resulting in a drift of excitons towards the energetically lower region of the sample [1].

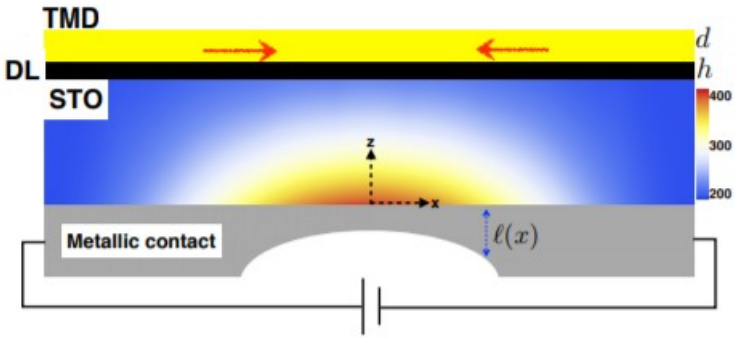

Figure 1: The sketch of monolayer TMD deposited on top of STO substrate. The substrate is inhomogeneously heated from the bottom by Ohmic contact of varying thickness. The color indicates the variation of temperature along STO substrate. In the highly heated region, the substrate permittivity is lower, resulting in strong bandgap renormalization and a higher value of exciton resonance energy. The spatially varying landscape of resonance energy routes excitons excited by optical pumping to the lower temperature regions of the sample, allowing us to create a controllable current of exciton cloud. The red arrows denote the direction of the exciton current flow.

A different mechanism consists in the use of ferroelectric material as a substrate. The latter can contain spontaneously polarized domains. The presence of such domains with normal to monolayer plane polarization will lead to emergence of spatially indirect excitons, possessing large dipole moment, allowing for long-range interactions. Such interactions between excitons in different areas of sample with antiparallel alignment of dipole moment results in macroscopic drifting force, generating an exciton current towards the boundary between the domains. Here we perform a microscopic modeling of this process, resulting in an appearance of nonlinear drifting term in drift-diffusion equation.

[1] V. Shahnazaryan, O. Kyriienko, and H. Rostami Phys. Rev. B 100, 165303 (2019).