Excitons in strained and suspended monolayer WSe_2

Burak Aslan[1,2], Colin Yule[3], Yifei Yu[4], Yan Joe Lee[1], Tony Heinz[3], Linyou Cao[4], Mark Brongersma[1]

[1]*Geballe Lab for Advanced Materials, Stanford U., Stanford, California 94305, United States*
[2]*Dept. of Physics, Bogazici U., Istanbul 34342, Turkey*
[3]*Dept. of Applied Physics, Stanford U., Stanford, California 94305, United States*
[4]*Dept. of Materials Sci. & Eng., North Carolina State U., Raleigh, N. Carolina 27695, United States*

We study suspended membranes of atomically thin WSe_2 as hosts of suspended excitons. We perform optical reflectance measurements to probe the exciton physics and obtain the peak energies for the 1*s*, 2*s*, and 3*s* states of the *A* exciton in suspended WSe_2 and consider supported membranes as a reference. We find that elimination of the influence of the dielectric environment enables a strong electron-hole interaction and a concomitant increase in the exciton binding energy in suspended monolayer WSe_2.

2D materials have been valuable systems for investigating the many-body physics of excitons. Dielectric screening offers a means to externally control and tune the Coulomb interaction between the bound electron and hole that constitute the exciton [1]. We perform linear optical spectroscopy on suspended WSe_2, as well as on reference supported WSe_2, samples to access the energies of the 1*s*, 2*s*, 3*s* exciton states. For the suspended films, the interaction of the electrons and holes are stronger, resulting in exciton binding energies significantly larger than those in supported samples. Based on the experimental results, we calculate the exciton binding energies by employing the recently developed quantum electrostatic heterostructure model and the commonly employed Rytova-Keldysh potential model [2,3]. We find that the binding energy of the ground state *A* exciton increases from about 0.3 eV (on a substrate) to above 0.4 eV (suspended) as shown in Figure 1.

We also exploit the tunability of the excitons in suspended samples via mechanical strain. We apply air pressure to achieve strain in the suspended membranes. In this fashion, we observe large and reversible band gap shifts. By applying external gas pressure of 2.72 atm to a 1L suspended over a circular hole of 8 μm diameter, we strain the WSe_2 and obtain a reversible 0.15 eV redshift in the exciton resonance. The linewidth of the *A* exciton decreases by more than half, from about 50 meV to 20 meV under 1.5% biaxial strain at room temperature (Figure 2). This line narrowing is due to the suppression of intervalley exciton-phonon scattering. By making use of the observed strain-dependent optical signatures, we obtain the two-dimensional (2D) elastic moduli of monolayer (1L) and bilayer (2L) WSe_2.

Our results exemplify the use of suspended 2D materials as novel systems for fundamental studies, as well as for strong and dynamic tuning of their optical properties [4,5].

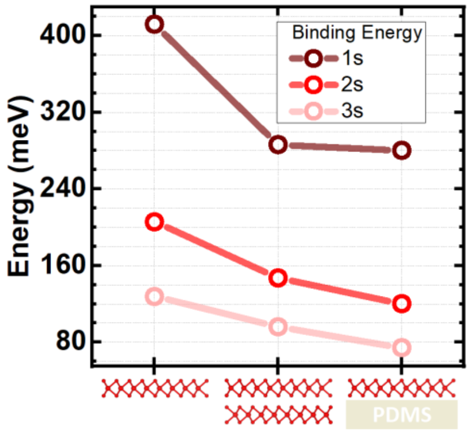

Figure 1: *Exciton binding energy in suspended 1L, suspended 2L, and 1L WSe_2 on PDMS.*

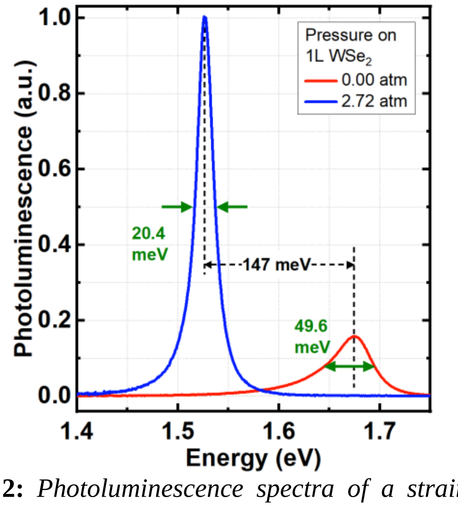

Figure 2: *Photoluminescence spectra of a strained and unstrained suspended 1L WSe_2 on an 8 μm diameter hole.*

Bibliograhpy

[1] A. Raja *et al.*, Nat. Commun. **8**, 1 (2017).
[2] L. V. Keldysh, Soviet Physics JETP **29**, 658 (1979).
[3] K. Andersen, S. Latini, and K. S. Thygesen, Nano Lett. **15**, 4616 (2015).
[4] B. Aslan *et al.*, 2D Mater. **9**, 015002 (2022).
[5] B. Aslan, M. Deng, and T. F. Heinz, Phys. Rev. B **98**, 115308 (2018).