Control of the valley lifetime in a suspended WSe_2 monolayer by opto-electro-mechanical tuning

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Two-dimensional (2D) transition-metal dichalcogenides (TMD) are emerging materials which exhibit novel physical phenomena related to their valley degree of freedom. Access and control of the valley information is challenging due to lattice defects, external contaminations, and contact with other materials which degrade the properties of 2D TMD and limit their tunability; monolayers suspended over empty spaces are an alternative. The contact-free nature of the suspended monolayers enables a precise control of the intrinsic valley lifetime and in future may unlock hidden valley phenomena.

Here, we report that the lifetime of the valley polarization can be controlled by tuning the optical, electrical, and mechanical properties of a suspended and undoped WSe_2 monolayer. In previous studies related to suspended monolayers, photoluminescence spectroscopy was used to probe bright and short-lived exciton dynamics as a function of the monolayer deflection produced by electrostatic gating [1]. However, since photoluminescence gives only a limited overview of the carrier dynamics, it does not reveal the contribution of neither "resident" carriers nor non-radiative excitonic species which are expected to have valley lifetimes on the order of nano- and micro-seconds [2]. In our study, we measured the valley polarization of a suspended monolayer by using a two-color and time-resolved Kerr rotation spectroscopy which allowed us to discuss the long lifetime of the valley polarization given by charged resident carriers as a function of a gate voltage V_g applied to the device shown in Fig. 1(a). Moreover, we strategically designed the mechanical, optical, and electrical parameters of our device to optimize the signal-to-noise ratio of the Kerr rotation spectroscopy conducted at a temperature of 7 K. As a result, we realized the control of the valley lifetime in range of 1-100 ns (Fig. 1(b)) by electrostatic gating in a low doping ($< 2\cdot10^{11}$ cm^{-2}) and strain (< 0.2 %) regime of the material [3]. The suspended configuration allowed us to exclude the influence of photo-charged defects at the interface which were previously shown to affect the Kerr rotation signal in encapsulated monolayers.

As a next step after these experiments, we have further improved our fabrication techniques to reduce the influence of other factors such as lattice defects or strain puddles on the intrinsic carrier dynamics in suspended monolayers. The obtained suspended WSe_2 monolayers have large area for optical access, high degree of tunability, and reduced spatial inhomogeneities compared to the monolayers directly exfoliated on substrates by using tape. Our goal is to obtain suspended monolayers with optical homogeneous linewidths which are expected to clearly answer open questions about valley dynamics and empower valley physics in TMD monolayers.

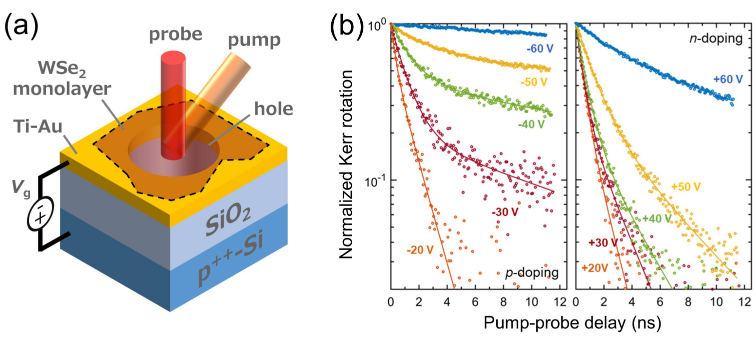

Fig.1: (a) Sketch of the device structure with the suspended monolayer. (b) Time-resolved Kerr rotation as a function of the gate voltage V_g.

References

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