Evidence of Single Photon Emitters from 1L WSe_2 under Electrostatically Induced Strain

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Strain engineering is a powerful tool that strongly influences electronic structure and exciton states in 2D transition metal dichalcogenides (2D TMDs). Among 2D TMDs, monolayer WSe_2 has gained attention as a host for quantum emitters due to its lowest lying dark exciton state that hybridizes with mid-gap defect states under tensile strain, giving rise to bright single photon emitters. The creation of a hybridized state consisting of dark excitons and mid-gap defect states results in the radiative recombination of dark excitons that is otherwise forbidden due to spin and momentum conservation. At cryogenic temperatures, the energetic alignment and coupling of the two abovementioned states results in localized defect emission which possess significant characteristics of single photon emitters. Strain-tunable devices are crucial for investigating the nature of TMD-based single photon emitters which can be beneficial for quantum information processing and secure communications.

In this study, we demonstrate strain modulation of monolayer WSe_2 suspended over a hole-patterned substrate via electrostatic deflection and characterize the resulting photoluminescence. This approach enables the creation of strain-tunable WSe_2 devices that can be operated at cryogenic temperatures, wherein strain fields are generated by applying a bias voltage to the suspended monolayer WSe_2 membrane. We observe a significant monolayer deflection of ~50 nm at 15V gate bias and a ~20 meV redshift of dark exciton peak as the applied is increased to 20V, corresponding to a 0.2% increase in tensile strain of WSe_2. Sharp localized emitters, typically associated with single photon emitters, were observed at 4K which showed less dependence on strain as the applied bias increased. Thus, we attribute these localized emitters to the presence of localized defects which are only weakly influenced by strained lattice environment. We also observe luminescence lifetimes of ~3ns and saturation of luminescence intensity with incident power, both of which are also characteristic of single photon emitters. These realizations are critical for understanding the origin of single photon emitters based on strained monolayer WSe_2.

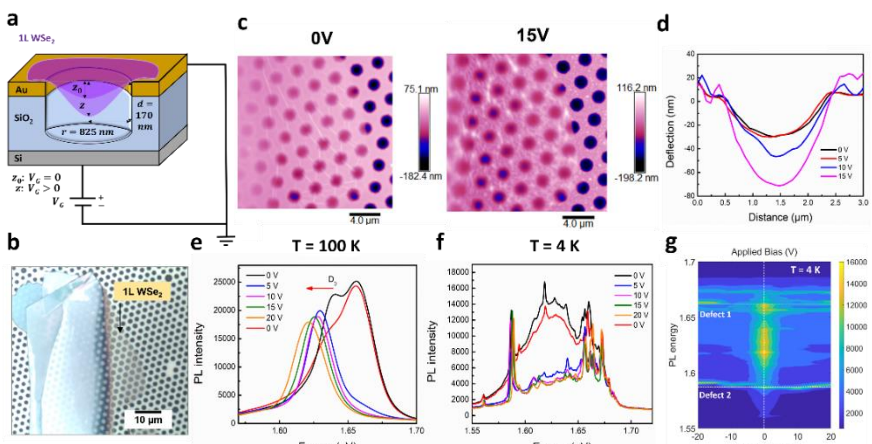

***Figure 1 a**. Schematic diagram of electrostatic straining approach. **b.** Optical image of 1L WSe_2 on hole-patterned substrate. **c.** AFM height images at different applied bias, showing a significant monolayer deflection as the applied bias is increased **(d).** Photoluminescence spectra measured at T = 298 K showing a redshift of dark exciton peak as a function of applied bias **(e)** and at T = 4 K showing the presence of sharp localized emitters **(f)** which are located at energies corresponding to defect level states **(g)**.*

Supplementary Pages

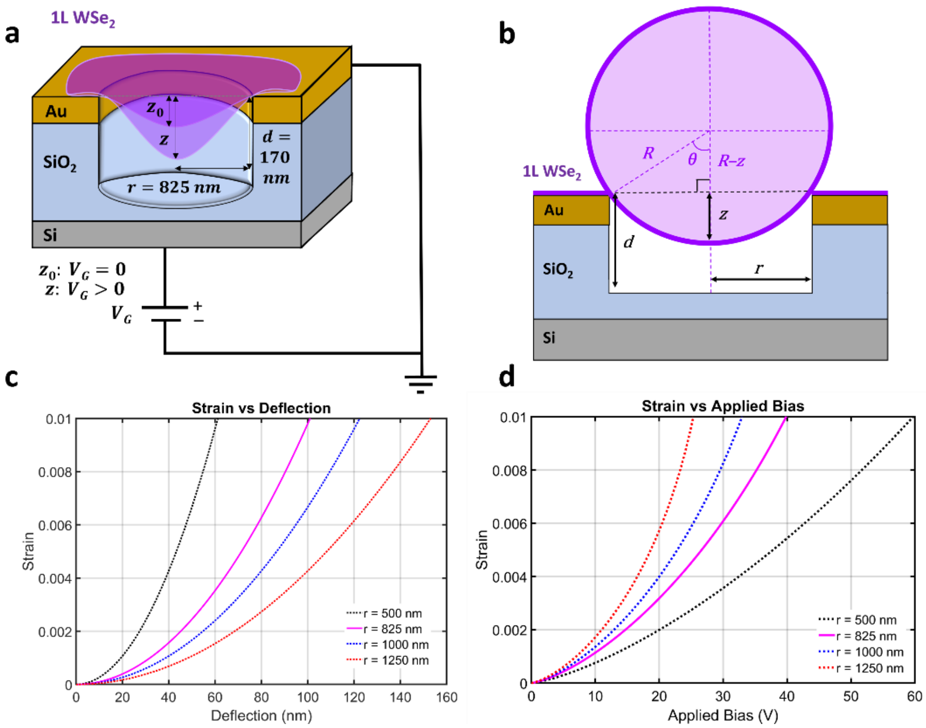

***Figure 2** Strain calculations from electrostatic-induced deflection of suspended monolayer WSe$_2$. Schematic diagrams of a suspended WSe$_2$ monolayer over patterned-hole substrate and straining approach (**a**) and a circumferential strain model* of suspended WSe$_2$ monolayer (**b**). Calculated strain as a function of monolayer deflection (**c**) and strain as a function of applied bias (**d**) assuming a semi-spherical monolayer deflection geometry.

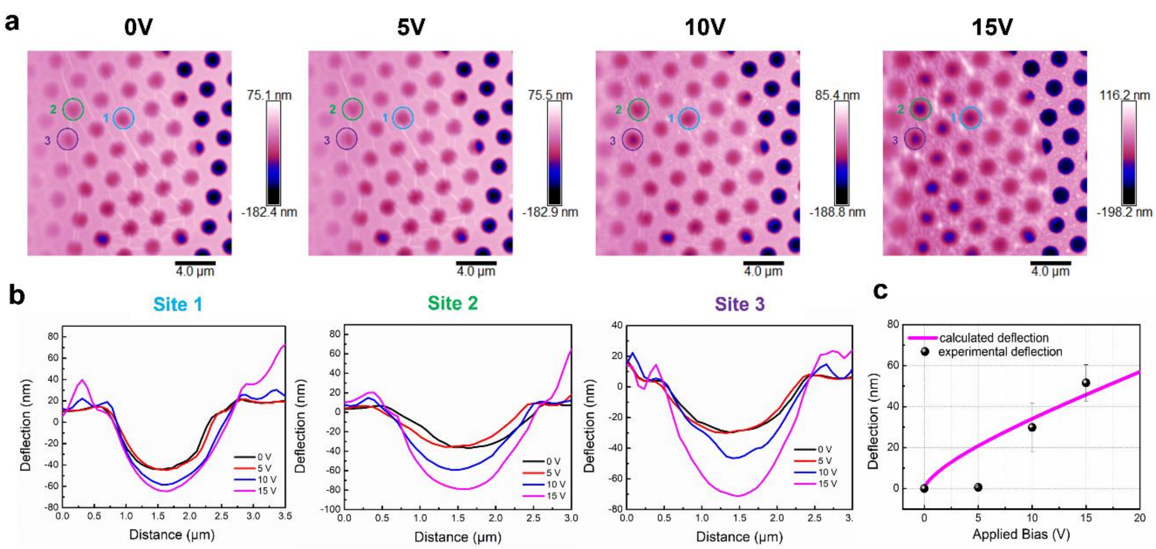

Figure 3 Electrostatic deflection of suspended WSe$_2$ monolayer at room temperature (T = 100 K). AFM height images taken using tapping mode at different applied biases: 0V, 5V, 10V, and 15V, showing monolayer deflection at increasing applied bias (**a**). Height profiles of monolayer WSe$_2$ at three different hole sites (b). Comparison between calculated (pink curve) and experimental (black sphere) deflection, showing that the monolayer starts deflecting in between 5V and 10V (c).

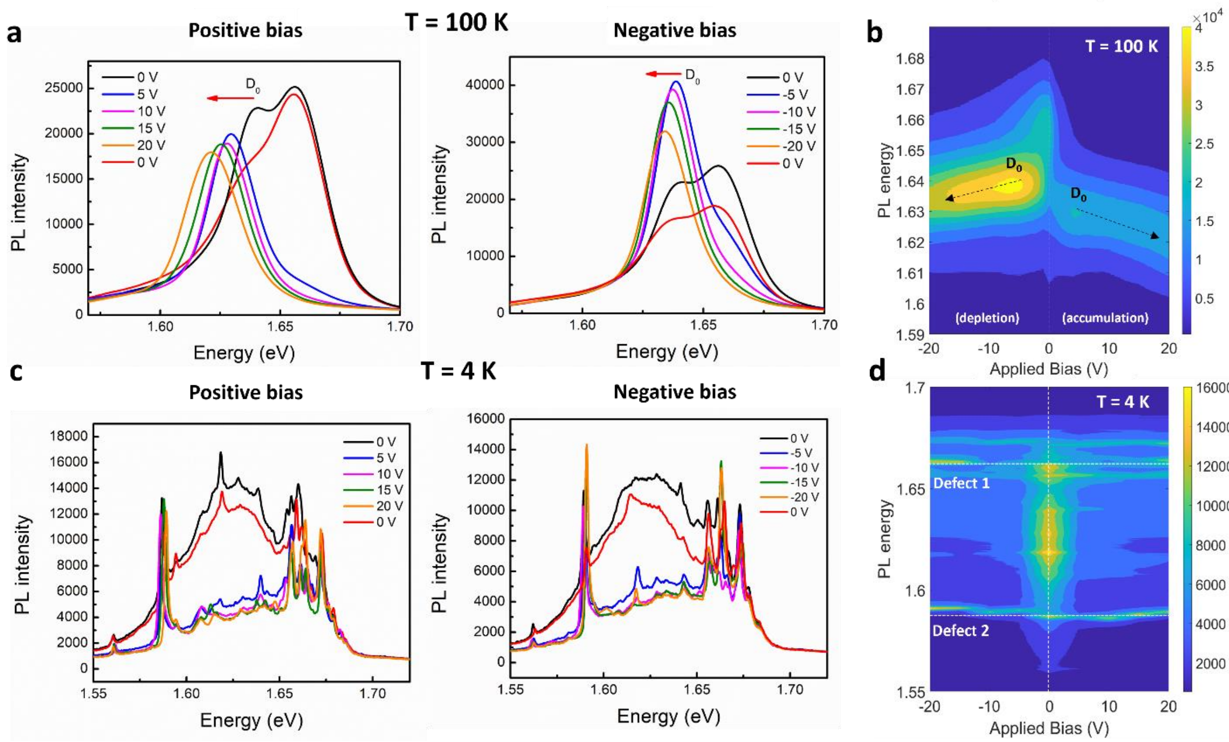

Figure 4 Photoluminescence spectra at different applied biases and their corresponding contour map measured at T = 100 K (a, b) and T = 4 K (c, d). PL measurements at T = 100 K showed a ~20 meV redshift of dark exciton peak, corresponding to ~0.2% increase in tensile strain on monolayer WSe_2. At T = 4 K, sharp localized emitters were observed corresponding to two defect energy regions of ~1.65 eV and ~1.57 eV which coincides with the previously reported defect energies of WSe_2 with selenium vacancies.