Thinning and doping of two-dimensional WSe_2 by vapour XeF_2

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Two-dimensional (2D) transition metal dichalcogenides (TMDs), such as MoS_2 and WSe_2, associated with an intrinsic bandgap, have attracted tremendous interest due to their thickness scalable down to a monolayer without surface dangling bonds and with promising carrier transport properties [1]. Besides, TMDs-based thin film transistors (TFT) are free of short channel effects [2]. Since the electronic, mechanical and optical properties of 2D TMDs greatly depend on the number of atomic layers, an effective method for thinning 2D TMDs is essential. Recently, several TMDs thinning methods, e.g., plasma etching, laser thinning and thermal annealing, have been reported [3-7]. However, these thinning methods cannot achieve a good balance between efficiency and thickness uniformity. Here, we report a controllable, efficient and uniform thinning of WSe_2 with high selectively by vapour XeF_2. Meanwhile, a p-doping effect on WSe_2 due to XeF_2 treatment has been found, which facilitates the fabrication of logical circuits and diodes on the same WSe_2 flake.

For our experiments, the exfoliated WSe_2 flakes have been treated with XeF_2 gas mixed with N_2 as carrier gas in a XeF_2 etcher under different pressures. Then, both the thickness and roughness of WSe_2 flakes before and after XeF_2 treatment have been characterized using atomic-force microscopy (AFM). Figure 1(a) shows the etched thickness and root mean square roughness for different etching times. It is noteworthy that the surface after thinning are smoother than using fluorine based plasma and thermal annealing method [3,4,6], which is crucial to restrain surface scattering and thereby enhance mobility. In addition, XeF_2 thinning is more efficient, compared with focused ion beam (FIB), laser, and annealing methods [5-7]. Figure 1(b) depicts the Raman spectra of pristine and thinned WSe_2 flakes with same number of layer, indicating that the crystal lattices of WSe_2 flakes remain intact after XeF_2 treatment. Figure 1(c) compares XPS spectra of W 4f core level of exfoliated WSe_2 before and after XeF_2 treatment. After XeF_2 treatment, the $4f_{7/2}$ and $4f_{5/2}$ doublet of WSe_2 shows a downshift of ~0.5 eV, which indicates a Fermi level shift towards the valence band edge, suggestive of the presence of p-doping. With XeF_2 thinning under different pressures, a 20-layer WSe_2 flake has been thinned down to bilayer and then patterned into a channel of a TFT successfully, as shown in Figure 1(d). The electrical properties of the thinned WSe_2 further confirm the p-doping effect due to XeF_2 treatment. The details of the TFT fabrication process and electrical characterization of the TFT will be presented. In addition, the mechanism of p-doping effect induced by XeF_2 thinning will be discussed and reported.

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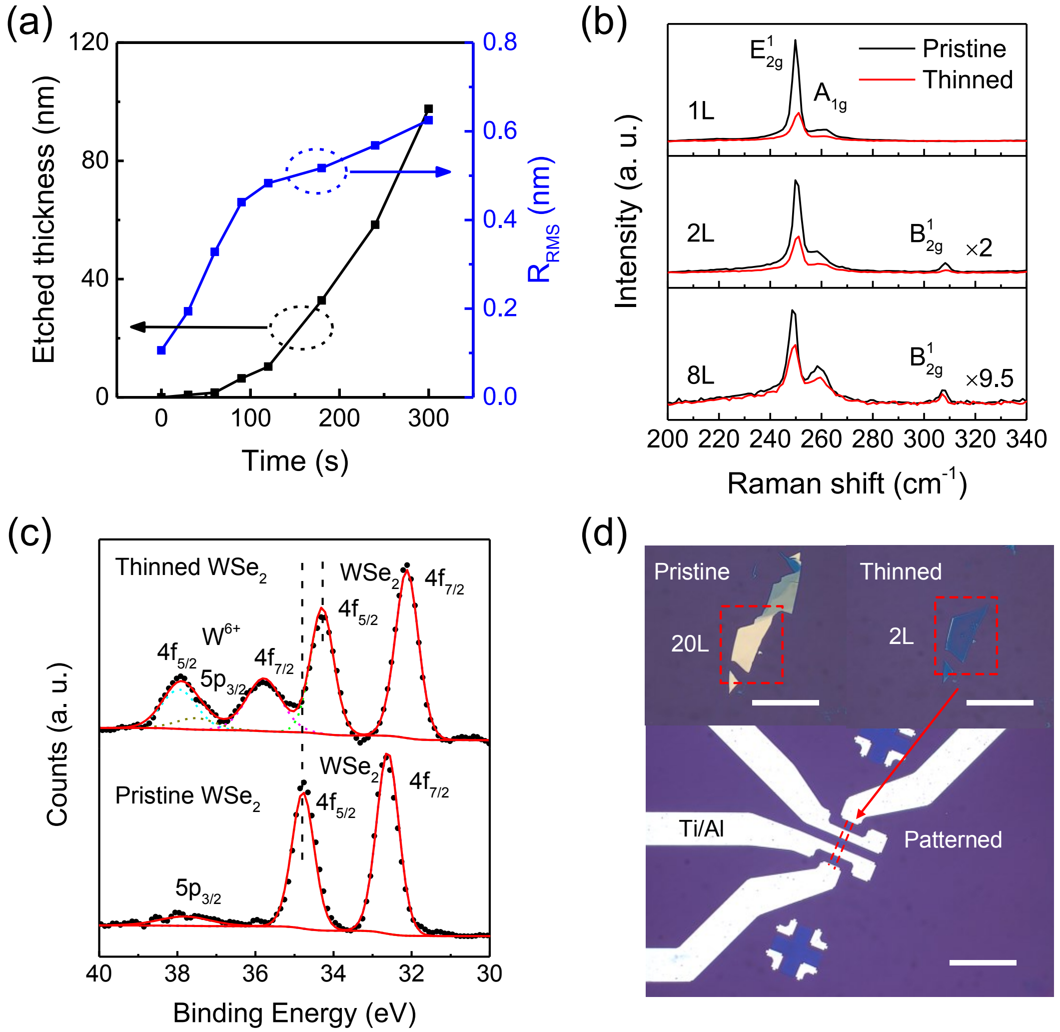

Figure 1: (a) Etched thickness (left axis) and surface roughness (right axis) of WSe$_2$ versus XeF$_2$ etching time. (b) Comparison of Raman spectra of pristine and thinned WSe$_2$ with different number of layers. (c) XPS spectra of W 4f core level of pristine and thinned WSe$_2$. (d) Optical image of thinning a 20-layer WSe$_2$ to bilayer with vapor XeF$_2$ and afterwards patterning the bilayer WSe$_2$ into a channel of TFT with Ti/Al as contacts (scale bars are 40μm).