Electronic Supplementary Material (ESI) for RSC Advances.

Supporting Information

Controllable Growth of Few-layer Spiral WS_2

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Contents:

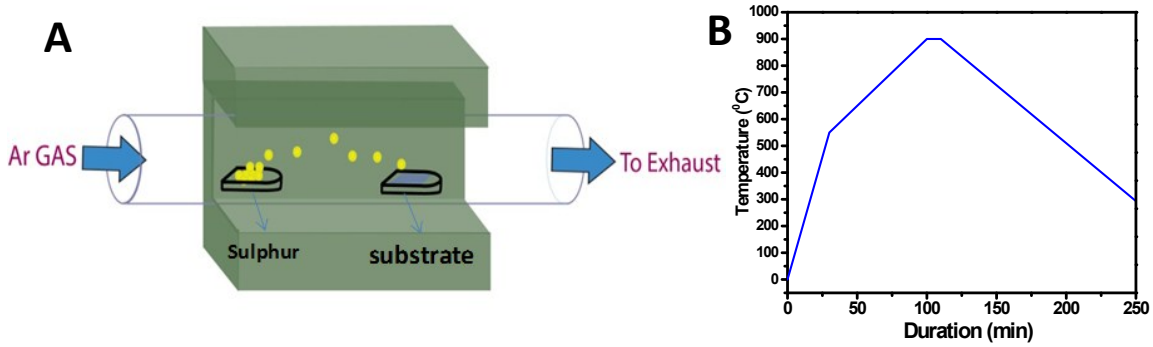

Fig. S1: (A) Schematic illustration of WS_2 chemical vapor deposition set up. WO_3 powder drop-casted on SiO_2/Si substrate is kept in alumina boat placed at the centre of heating zone, while Sulphur powder is kept at upstream end. (B) Temperature profile of chemical vapor deposition. After holding at 900 ^{0}C for 10 min, furnace is allowed to cool down to room temperature naturally.

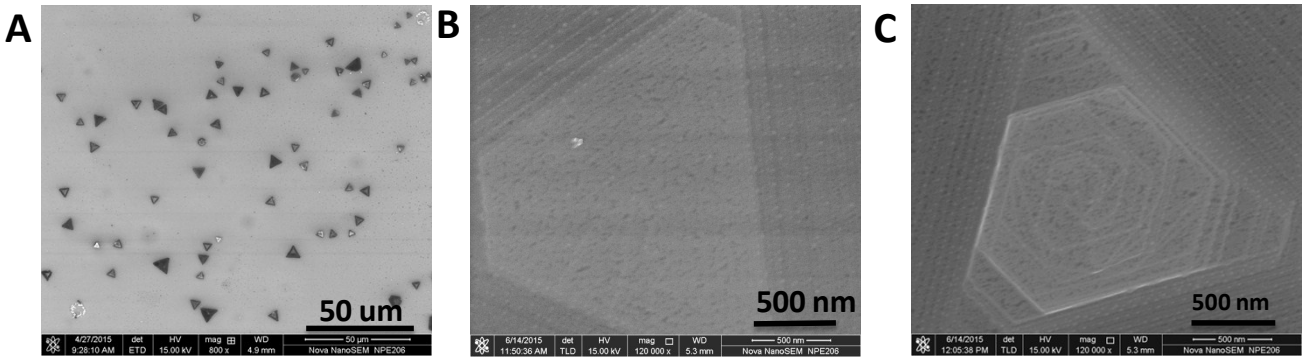

Fig. S2: (A) SEM image of CVD grown WS_2. High resolution SEM images of (B) LBL and (C) SDD grown WS_2 pyramid. (B) shows the flat surface on top of the domain and a clear image of spirals on top of another domain is illustrated in (C).

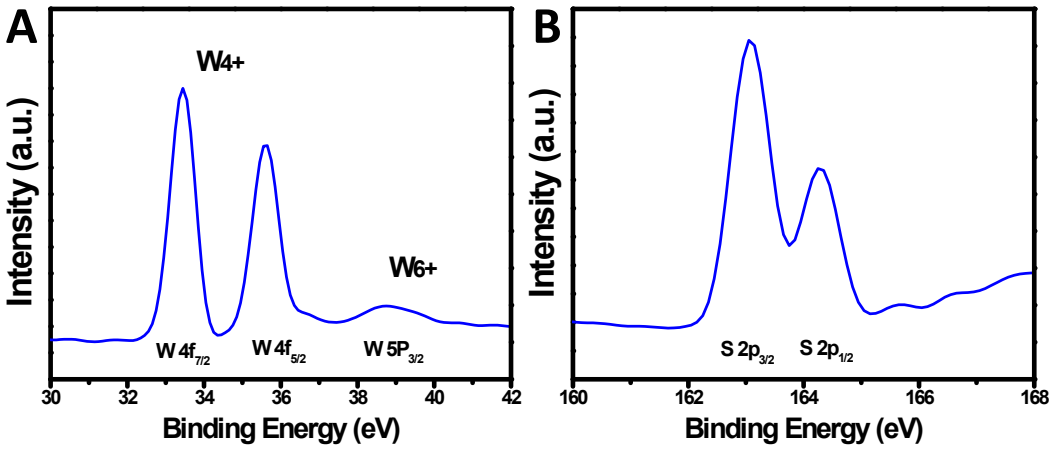

Fig. S3: XPS spectra of CVD grown WS_2. (A) shows characteristic XPS data from Tungsten that clearly illustrate peaks corresponding to W^{4+} oxidation state. The small intensity peak ~ 38 eV, in (A), attributed to 6+ oxidation state of Tungsten which could be due to the presence of WO_3. XPS spectrum from Sulphur is shown in (B) where characteristic peaks at 162.3 eV ($S\ 2P_{3/2}$) and 163.57 eV ($S\ 2P_{1/2}$) are present.

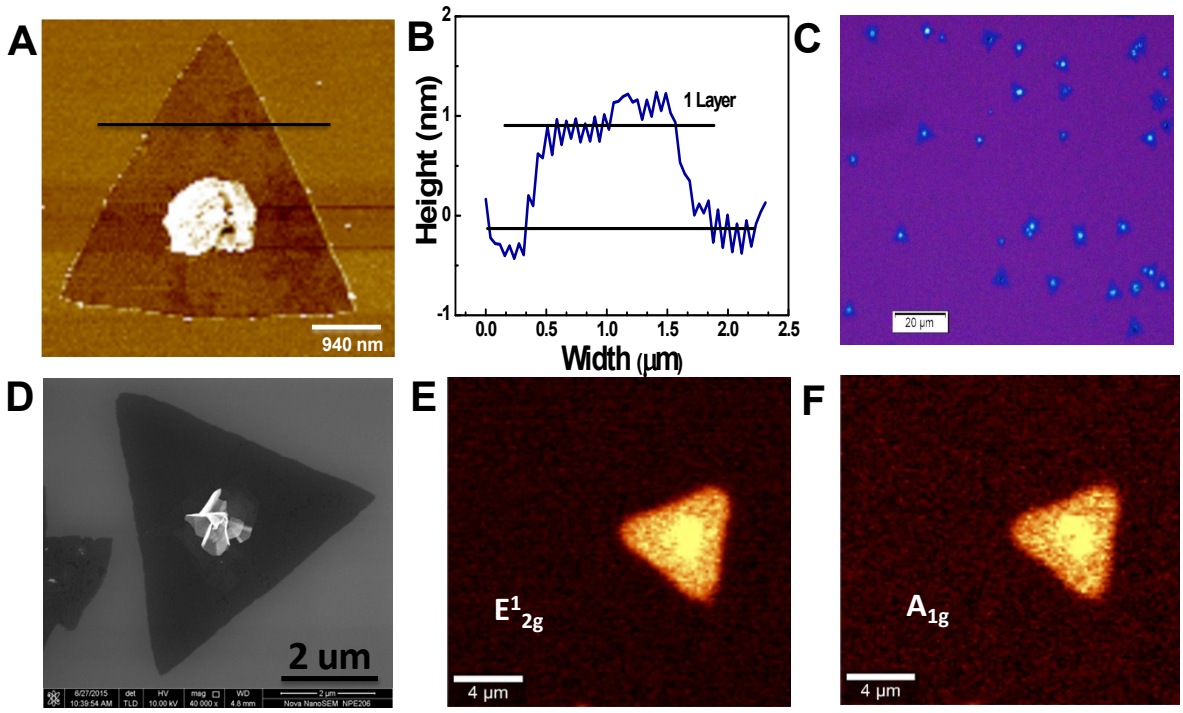

Fig. S4: Morphological and Raman characterization of monolayer WS_2 grown by using 0.1 mg/ml concentration of WO_3 precursor. (A) AFM and (B) corresponding height profile of monolayer WS_2. (C) Optical microscopy image and (D) SEM image of monolayer WS_2 flake (E), (F) Raman mapping of monolayer WS_2 by using 488 nm excitation. Here the domain size is around 4-6 μm. Optical image clearly demonstrate the uniform growth of monolayer WS_2 throughout the substrate. Raman mapping images show uniform Raman intensity throughout the domains except for the particle or cluster at the centre.

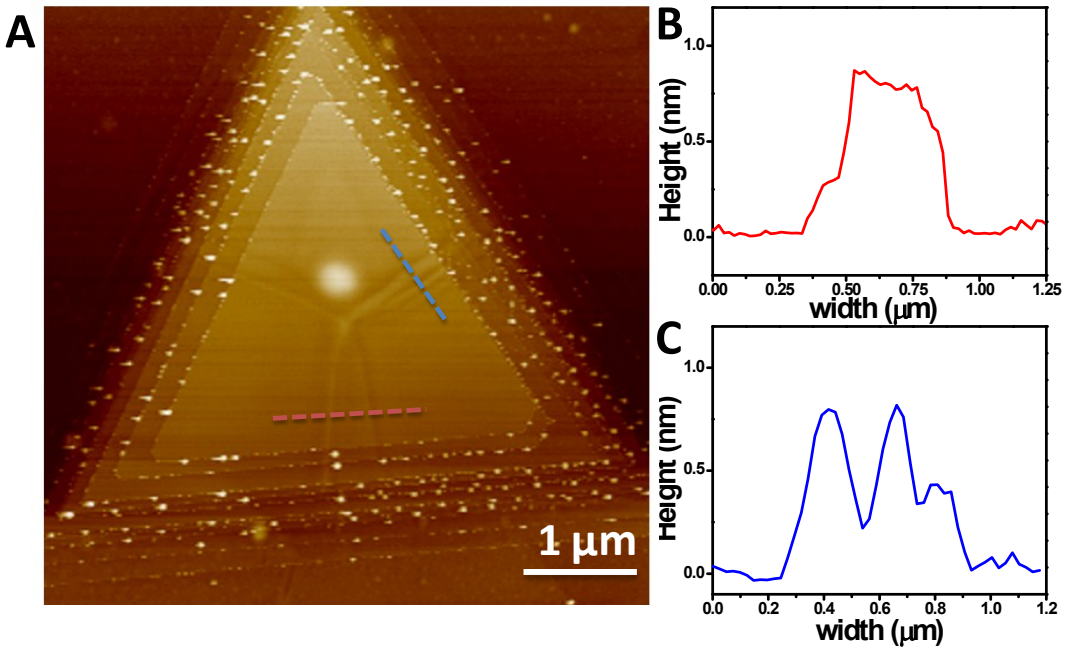

Fig. S5: (A) Ribbon-like morphology observed on top of WS_2 domains. (B), (C) shows the corresponding height profile along the marked lines in red and blue colors respectively. Heights of these ribbons matches with the thickness of monolayer WS_2.

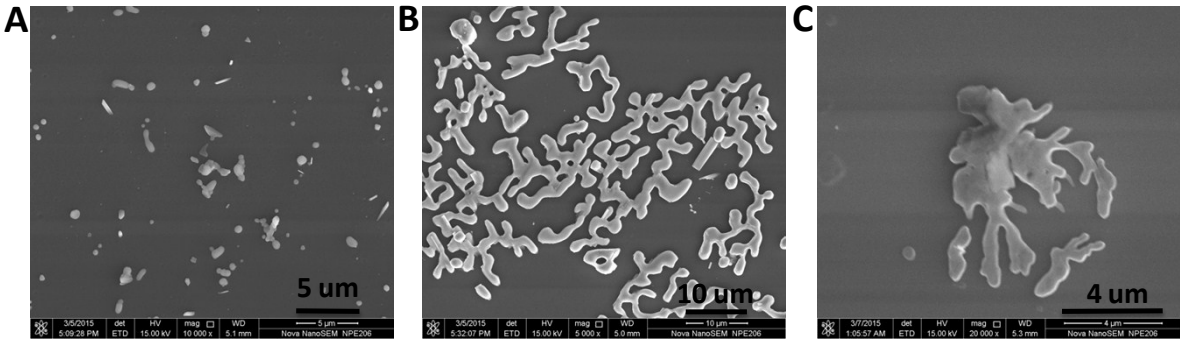

Fig. S6: (A) SEM image of WO_3 powder drop-casted (0.2 mg/ml) on Si/SiO_2 substrate before annealing (B), (C) SEM images of WO_3 drop-casted sample after annealing at 900 ^{0}C under controlled atmosphere of 200 sccm Argon flow. At this temperature WO_3 powder completely melts and island kind of morphology is formed.

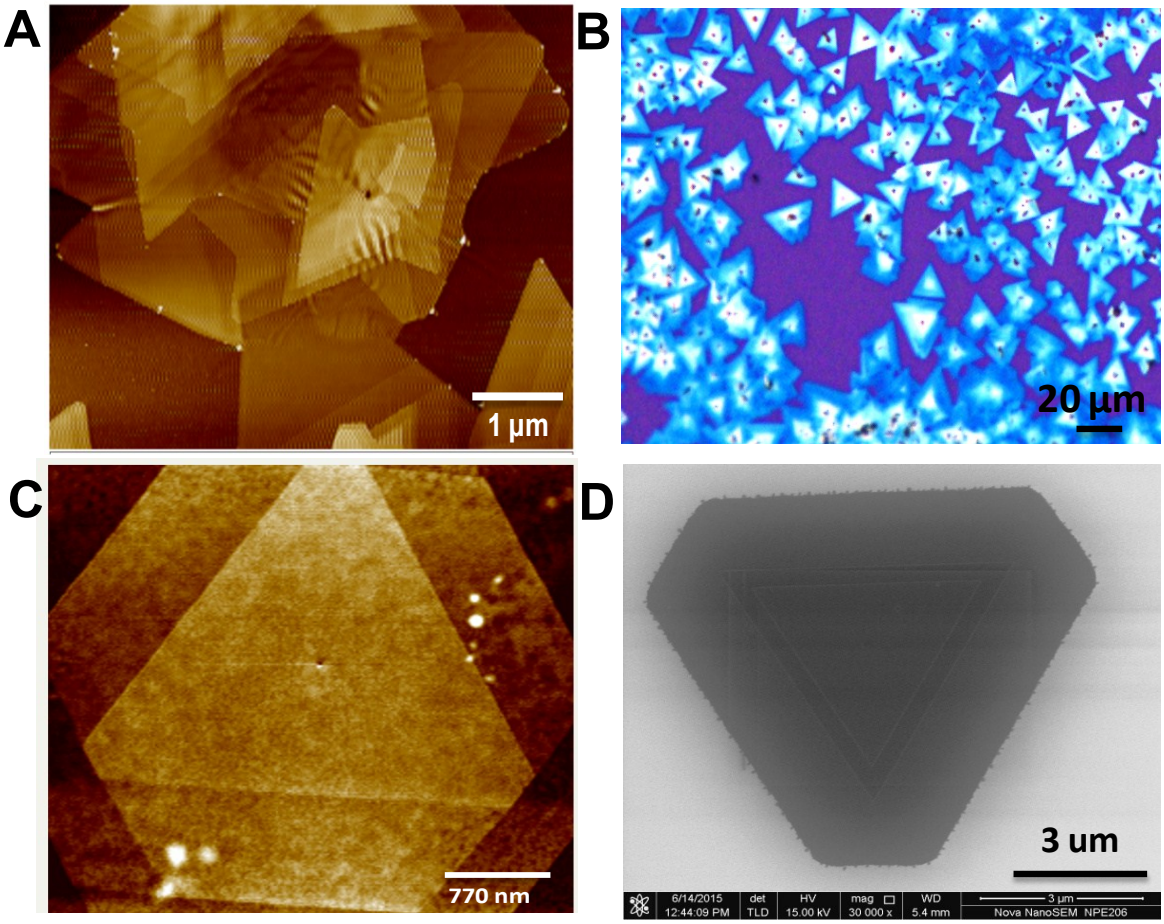

Fig. S7: AFM, SEM and optical microscopy characterization of CVD grown WS_2 flakes by using 0.5mg/ml concentration of WO_3 precursor. (A) AFM and (B) optical microscopy images clearly revealing cluttered growth. (C) shows the AFM image of pyramidal centre that follows LBL growth. (D) SEM image of a LBL grown WS_2 domain. Higher concentration of tungsten precursors triggers LBL growth and ends up in pyramids having flat faces on top.

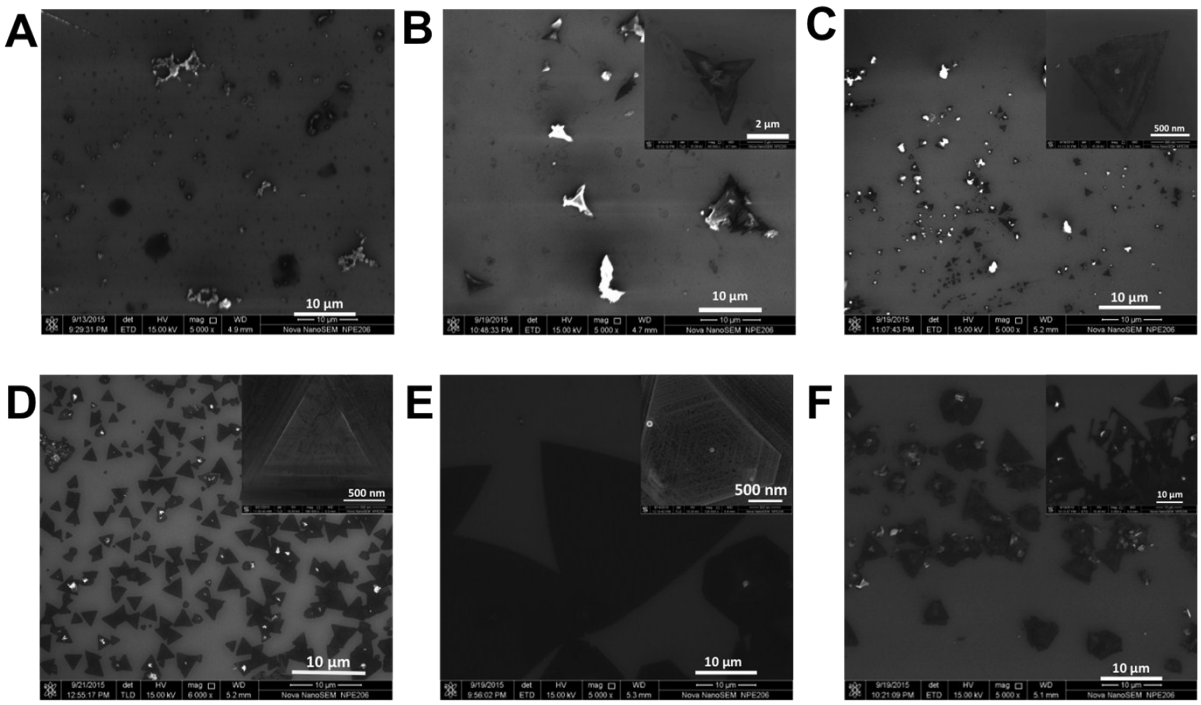

Fig. S8: SEM images of WS_2 flakes grown *via* CVD process at (A) 700 °C, (B) 750 °C, (C) 800 °C, (D) 850 °C, (E) 900 °C and (F) 950 °C. Inset shows respective magnified images. All other parameters in the CVD process, including Argon gas flow rate (200 sccm), sulphur amount (500 mg) and WO_3 concentration (0.2 mg/ml in ethanol), remain unchanged. Uniform growth of triangular domains is observed at 850 °C and 900 °C, with respective average domains sizes of 3-5 µm and 15-20 µm. Further increase in CVD temperature to 950 °C yields smaller and broken triangles, while the growth was seen incomplete at temperatures less than 850 °C. 900 °C appears to be the optimum growth temperature for few-layer spiral WS_2 domains, under the given conditions. At 850 °C, growth is mostly thick triangular domains.