# An effective approach to synthesize monolayer tungsten disulfide crystals using tungsten hexachloride

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The transition metal dichalcogenides (TMDs) based layered materials ($MoS_2$, $WS_2$ etc.) have attracted significant interest as two dimensional (2D) semiconductor with a direct band gap. Recently, $WS_2$ has gaining a lot of attention and it is constructed with a sandwich of two atomic layers of S and one atomic layer of W through covalent W–S bonds, respectively [1]. Here, we demonstrate a process to control the nuclei for growth of large $WS_2$ crystals by solution-casting the $WCl_6$ precursor on substrate.

In the developed process, a 0.05M solution of $WCl_6$ was drop-casted on the substrate, which was loaded in the center of small diameter tube sealed at one-end. A boat with 200 mg of S powder was placed in the center of low temperature furnace. Sulfurization experiments were performed at a temperature of 750 ˚C in 80 sccm Ar atmosphere. Finally, the furnace was cooled down to room temperature and samples were removed from the tube.

We observed the growth of triangular (more than 50 µm), star-shaped $WS_2$ crystals. Figure 1a shows a triangular monolayer $WS_2$ crystal of 50 µm size. Figure 1b shows a six pointed star-shaped crystal. Figure 1c shows an AFM image of the as-synthesized $WS_2$ crystal on $SiO_2$/Si substrate. Line profile at the edge revealed an approximate thickness of around ~0.9 nm, which is almost comparable to monolayer $WS_2$ crystal.

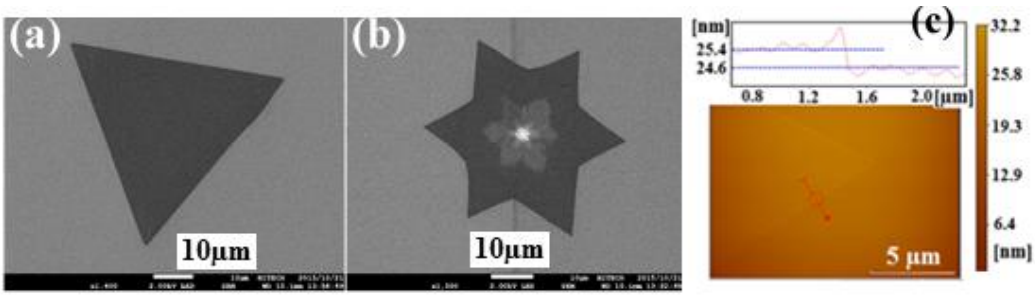


Figure 1 (a,b) FE-SEM images of triangular monolayer and six-arm star-shaped $WS_2$ crystal. (c) AFM image and line profile of the as-synthesized $WS_2$ crystal on $SiO_2$/Si substrate.

## References

1. Park, J., Lee, W., Choi, T., Hwang, S.-H., Myoung, J. M., Jung, J.-H., Kim, H. *Nanoscale*, *7*(4), 1308–1313 (2015).