# Limitations and opportunities of metal-organic chemical vapor deposition of $MoS_2$ and $WS_2$

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Group-VI transition metal dichalcogenides ($MX_2$), such as molybdenum- and tungsten disulfide ($MoS_2$, $WS_2$), emerge as two-dimensional (2D) semiconductors that can complement workhorse silicon as channel material in ultra-scaled nanoelectronic devices [1,2]. Manufacturable approaches to deposit highly crystalline $MX_2$ layers, tailor the layer number down to the atomic level, and remain compatible with temperature sensitive structures, are essential to unlock the desired material functionality. However, fundamental understanding is lacking on how to design Fab-compatible chemical deposition processes for 2D $MX_2$, such as chemical vapor deposition (CVD). This presentation focuses on metal-organic (MO-)CVD from metal hexacarbonyl and dihydrogen sulfide precursors using industry-standard, customized 200 mm and 300 mm epitaxial reactors. Based on a qualitative growth model, we review the limitations and opportunities of $MX_2$ MOCVD, such as poor diffusional transport of adsorbed surface species and undesired metal co-deposition (Figure 1). We describe how the $MX_2$ growth behavior depends on the starting surface by comparing the nucleation and growth evolution on an amorphous (e.g., $SiO_2$) and single crystalline (e.g., sapphire) substrate using complementary microscopy and spectrometry techniques [3]. From that insight, we reveal how these limitations can be overcome, yielding microcrystalline $MoS_2$ monolayers on sapphire with median mobilities at 30 $cm^2/Vs$ and drive currents up to 420 µA/µm [4].

## References

[1] Q. Smets et al., IEDM, 23.2. 1-23.2. 4 (2019)
[2] D. Lin et al., Symposium on VLSI Technology, 1-2 (2021)
[3] Y. Shi et al., ACS Nano, 15 (2021) 9482-9494
[4] Wu et al., IEDM, 7.4.1-7.4.4 (2021)

## Figures

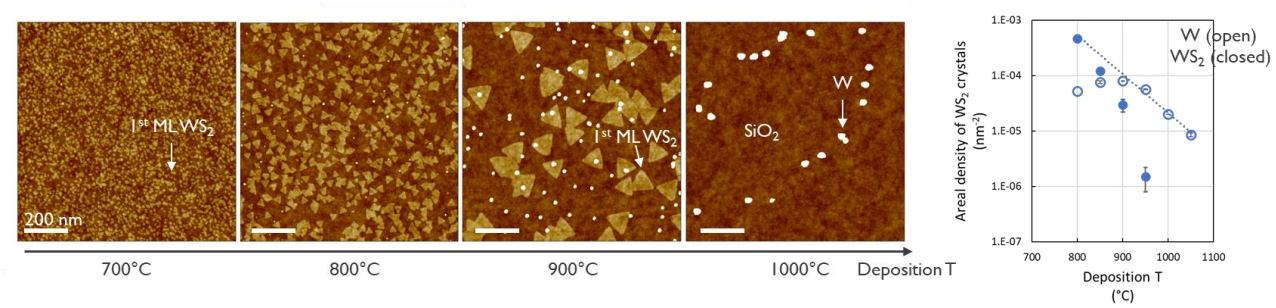


**Figure 1:** Growth evolution of $WS_2$ MOCVD on amorphous $SiO_2$ starting surface as a function of deposition temperature. W and $WS_2$ are simultaneously deposited. The areal density of $WS_2$ crystals decreases with deposition temperature but remains high at technologically relevant deposition temperatures introducing grain boundaries when neighbouring crystals coalesce.