Atomic Layer Deposition of Wafer-Scale Crystalline WS_2 Thin Films for Back-End-of-Line Applications

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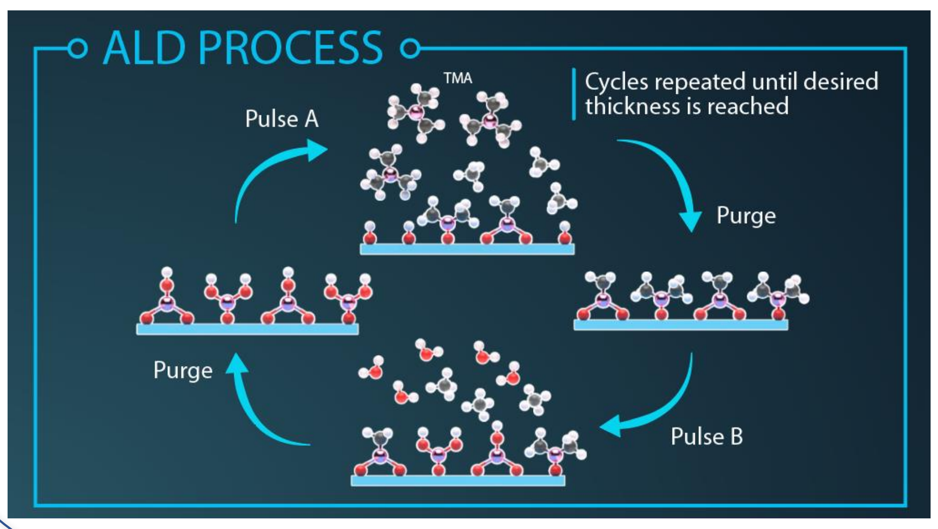
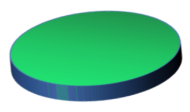
Introduction

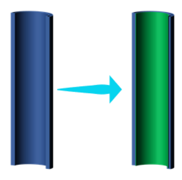
Growth of large-area 2D materials

- MOCVD, MBE, and ALD: large-scale synthesis of TMDCs
- CVD, MBE: Elevated growth temperatures (>700 °C) or high-temperature post annealing and crystalline substrates

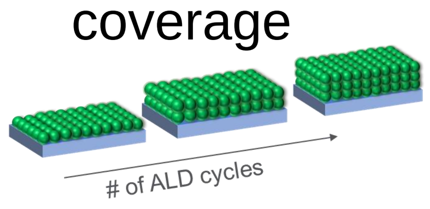




Large area uniformity



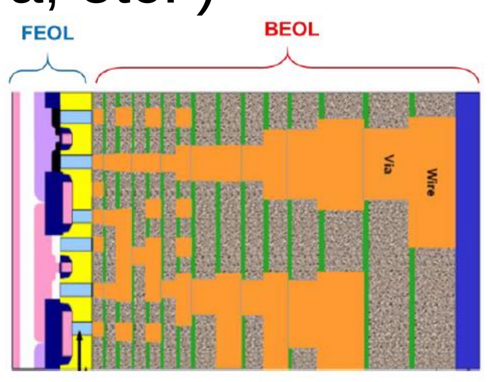
Excellent step coverage



Atomic scale thickness control

Aim

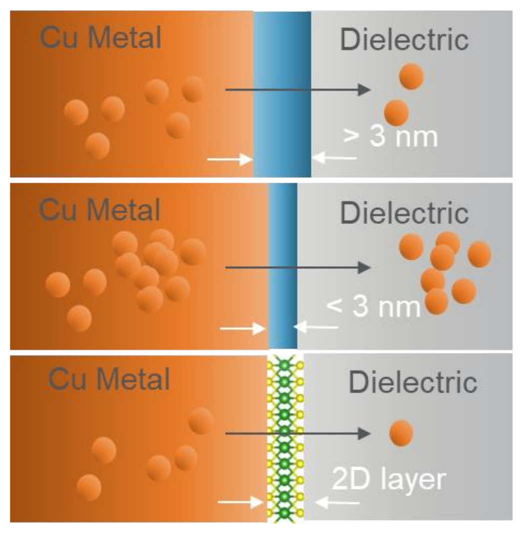
Low-temperature growth of WS_2 thin films without the assistance of plasma for metal diffusion barrier and liner applications replacing conventional materials (TiN/Ti, TaN/Ta, etc.)

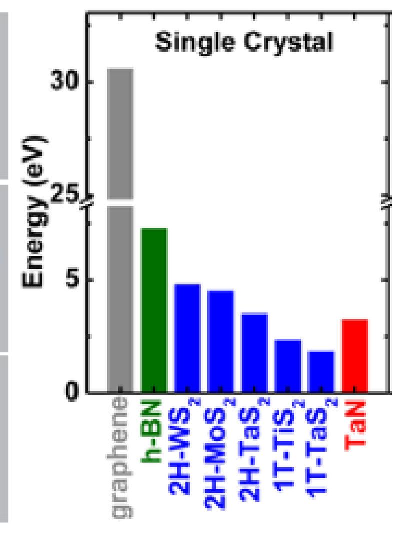


ITRS, (2011)

Applications

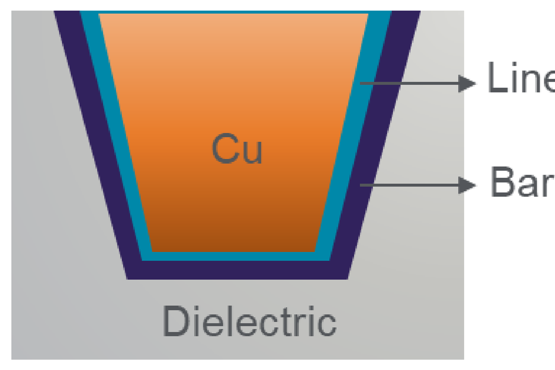
1. Diffusion barrier





Lo et al, JAP. 128, (2020)

2. Liner



Time delay of the structure

$$\tau = RC$$

Due to die-shrinking: Resistance of the interconnect increases, in turn increasing the delay in switching speeds

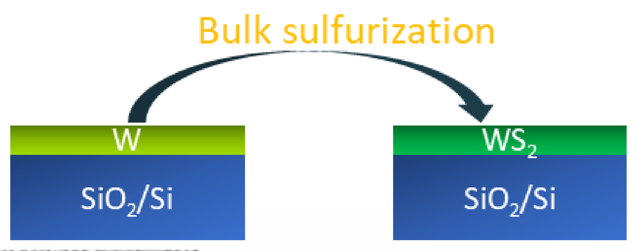
WS_2 *via* ALD

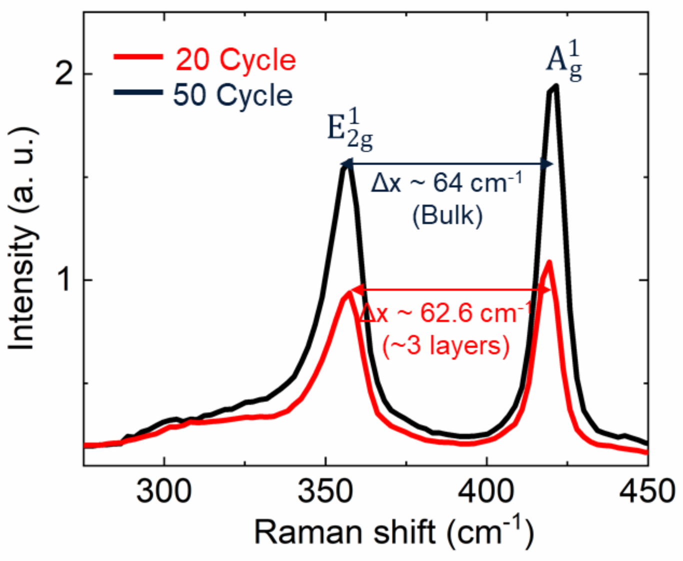
Process: 1 (bulk sulfurization)

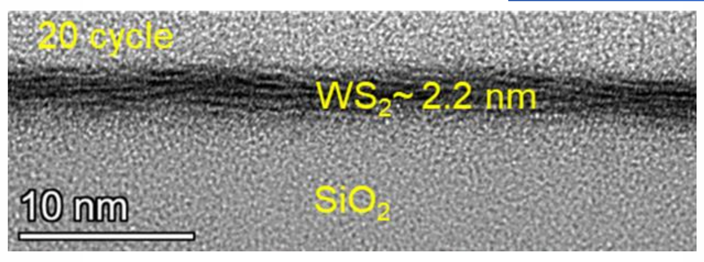
Grow of 1-2 nm tungsten film and consecutive sulfurization

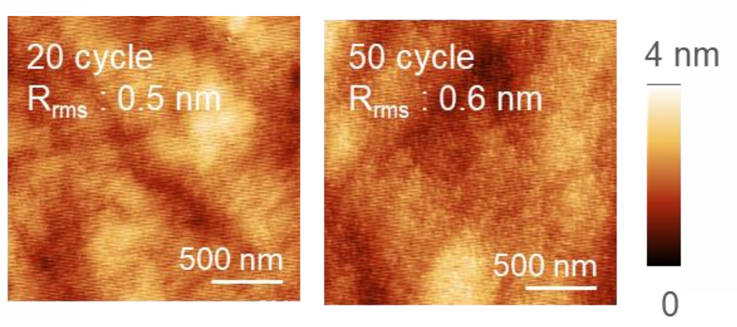
Step 1: W - precursor (T~ 350 °C)

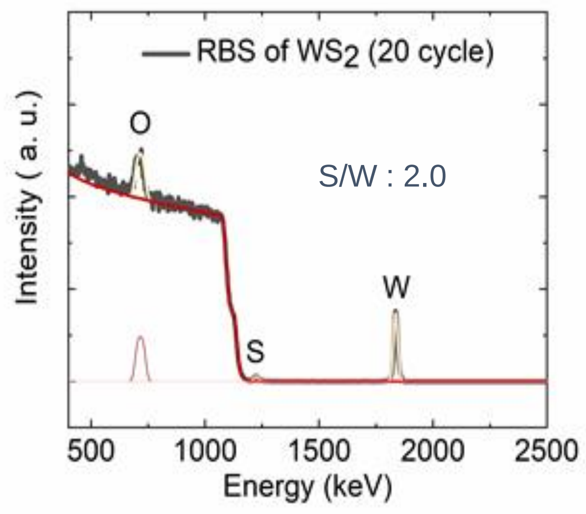
Step 2: Sulfur containing gas (T~ 430 °C)









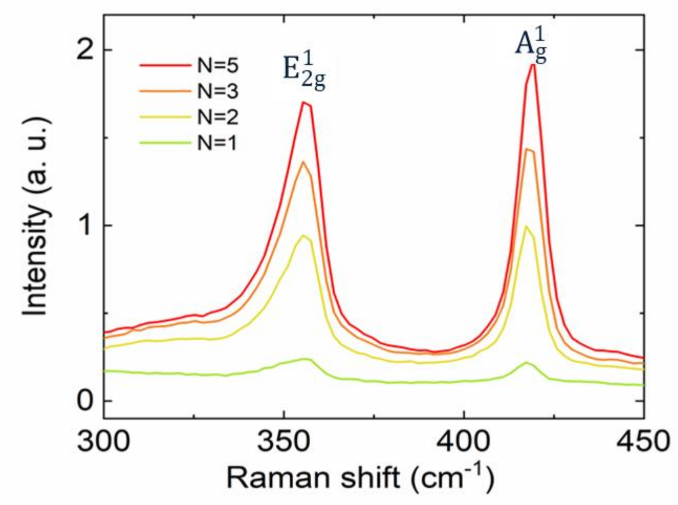


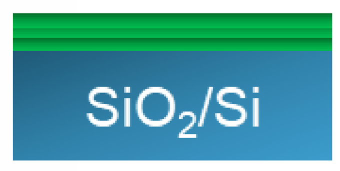
- Raman spectra shows the quality and number of layers of WS_2
- X-TEM shows the crystalline nature of WS_2
- AFM confirms the lower roughness of WS_2
- RBS shows the stoichiometry of the grown film

Process: 2 (layer by layer growth)

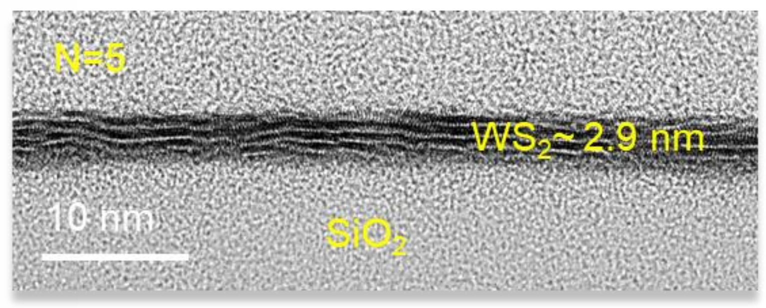
ALD WS_2 - layer by layer deposition at 350 °C

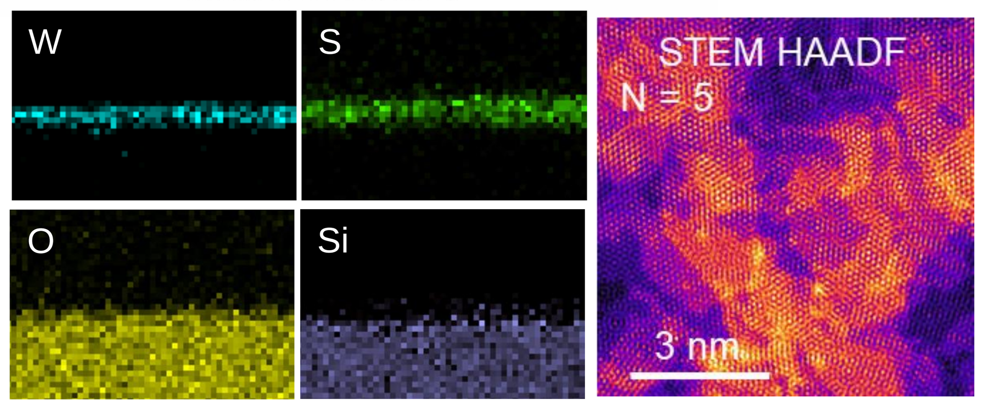
- W pulse and sulfurization processes at a single temperature
- N: number of ALD cycle
- Layer by layer growth





WS_2: Layer by layer sulf.

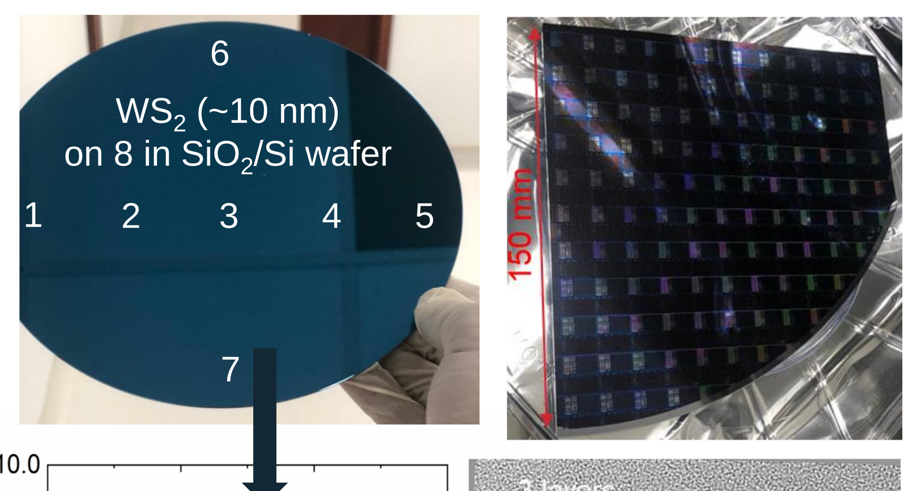


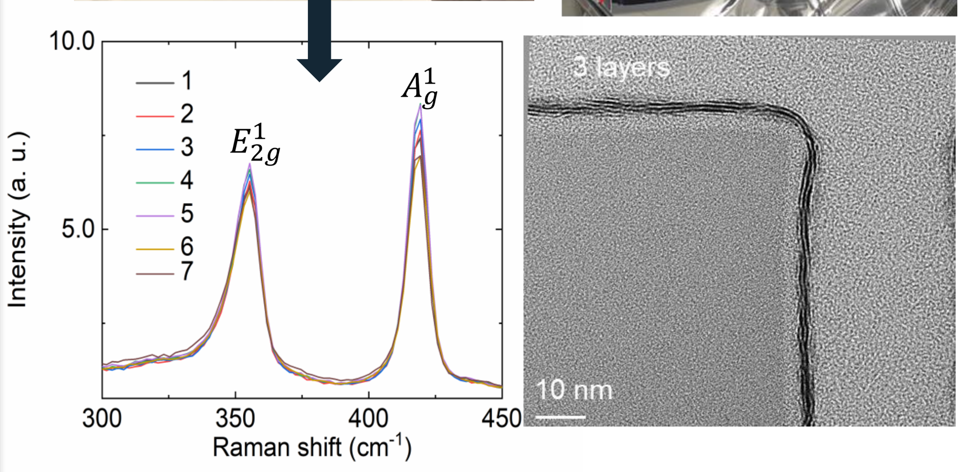


Raman spectra, AFM, X-TEM and EDX suggest the formation of crystalline good quality WS_2 films

Conformal growth

Process 2: wafer-scale and conformal deposition

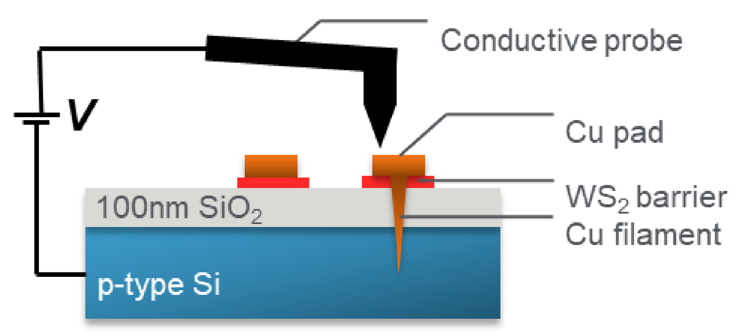


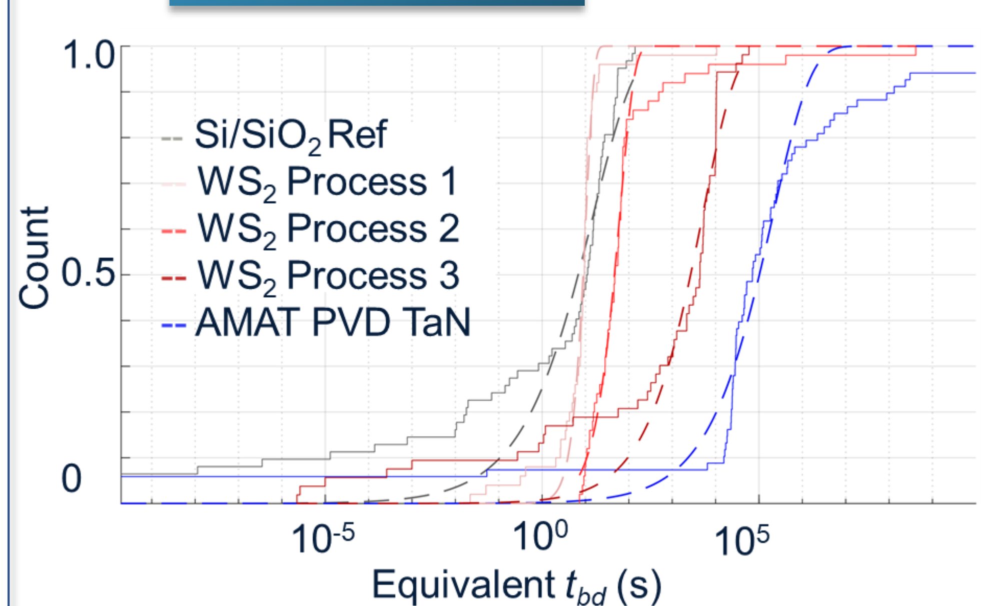


- Wafer-scale uniform deposition
- Achieved conformality > 95 % for WS_2 films of varying thickness

BEOL Applications

Diffusion barrier



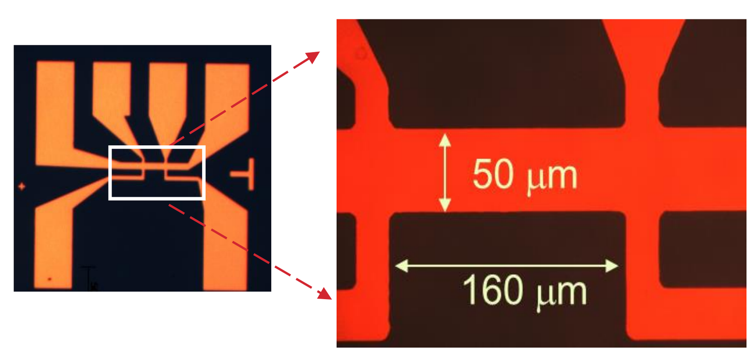


8 MV/cm	Barrier thickness	breakdown time t_{bd}
Si:SiO_2	No barrier	15 s
WS_2 Process 1	2.2 nm	10 s
WS_2 Process 2	2.9 nm	62 s
WS_2 Process 3	3.7 nm	5 x 10^3 s
AMAT TaN	~ 6 nm	2.1 x 10^5 s

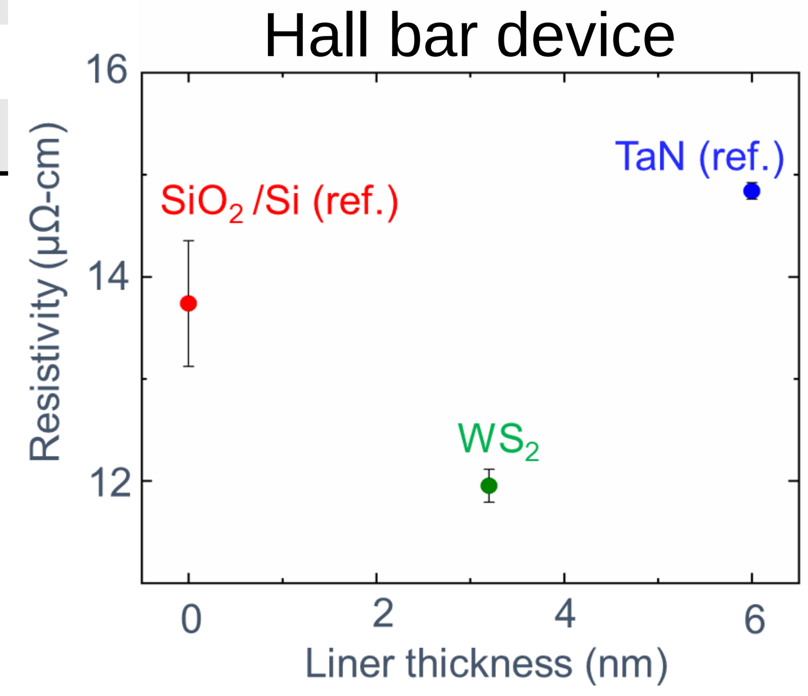
- Improved the time to failure values (300 x) by a modified growth recipe for WS_2

- TaN (~ 6 nm) shows better performance as compared to WS_2, TaN below 3 - 4 nm may exhibit severe Cu diffusion
- Works are on going on thinner TaN and WS_2 films (~ 2 – 3 nm) to evaluate the barrier properties

Liner measurements



Hall bar device



Cu film on WS_2 shows lower resistivity

Conclusions

- Large area conformal WS_2 films were grown by a low temperature ALD process without plasma
- WS_2 shows a better diffusion barrier properties (300 x improvement)
- WS_2 exhibits a good liner properties by reducing the resistivity of Cu

Acknowledgement

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