Tungsten Films by Hot-Wire Enhanced ALD

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Motivation

Metallic tungsten (W) films play a crucial role in manufacturing of semiconductor devices. The traditional technologies have some limitations in terms of achieving good film uniformity and step-coverage on patterned surfaces, as well as controlling film thickness with high precision. Atomic Layer Deposition (ALD) can be a good alternative. However, thermal ALD of single-element films such as W is difficult to achieve. As a solution, plasma-enhanced ALD (PEALD) can be utilized. Unfortunately, ions, radicals and UV light generated by plasma and coming to the surface can deteriorate film properties.

In our work, we propose an alternative method to generate radicals by means of a hot-wire (HW) instead of a plasma, enabling a HWALD process. Molecular hydrogen (H_2) can dissociate on the wire heated up to 1500-2000 °C, creating *atomic hydrogen* (at-H). These at-H can efficiently reduce the tungsten precursor (WF_6) pure tungsten, at a lower substrate temperature than usually used, and make the film metallic.

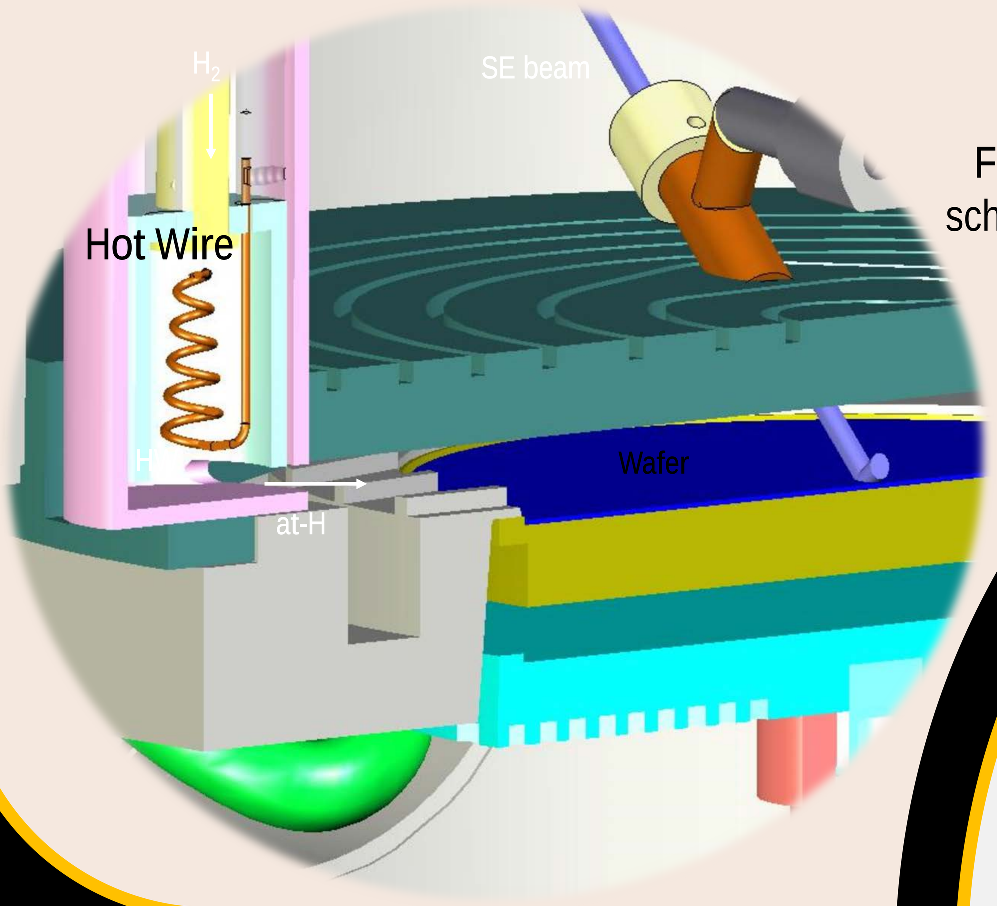
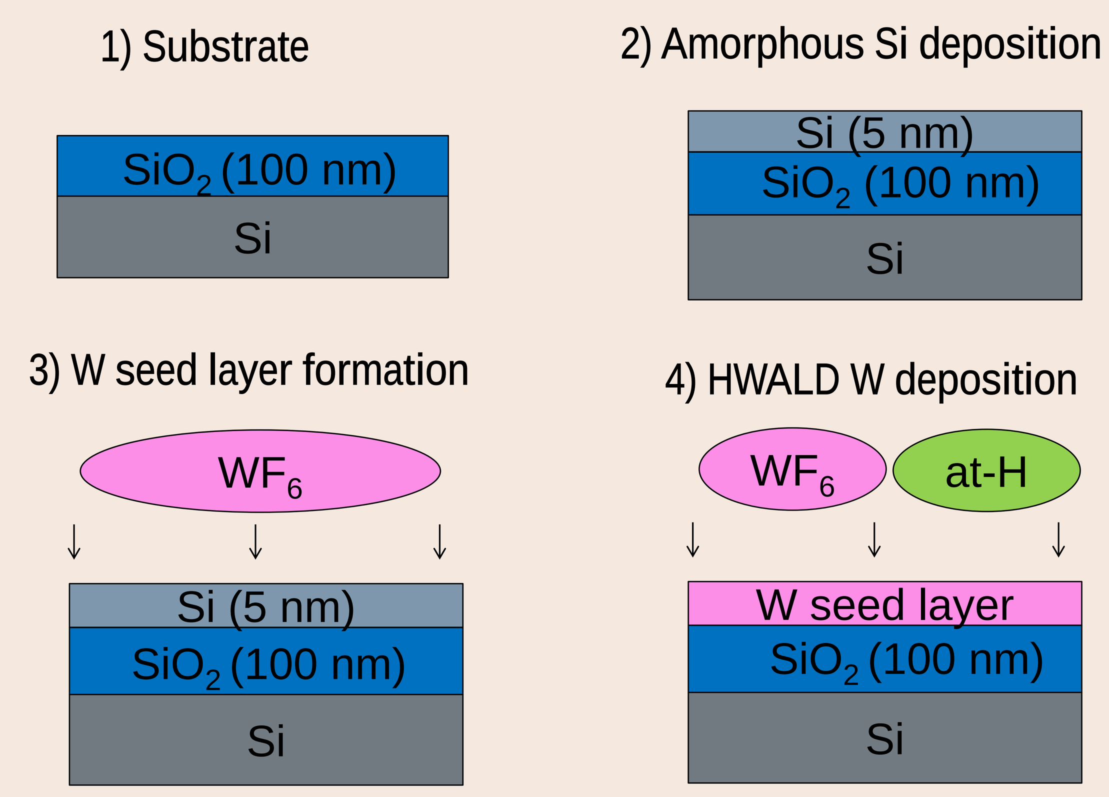


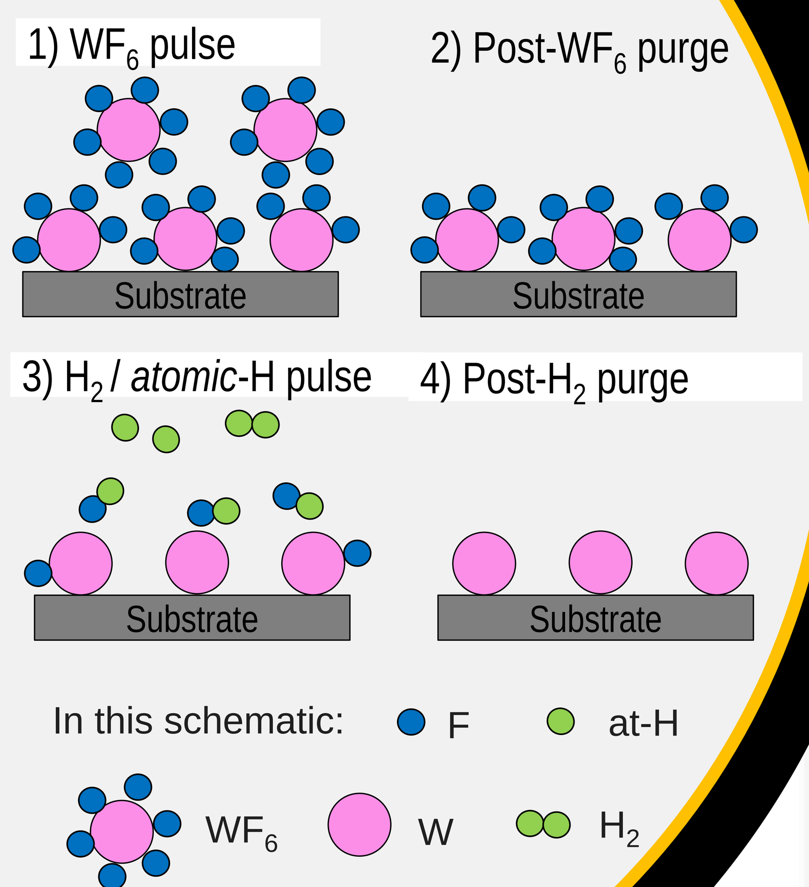
Figure: The rector schematic for HWALD

Process steps



Process fundamentals

During ALDThe substrate is exposed to alternate pulses of gaseous precursors. In each of these pulses the precursors ***cannot*** react with themselves but only with the surface in a self-limiting way. As a results, the reaction terminates once all the reactive sites on the surface are consumed. The four steps shown in Figure on the right make up an ALD cycle. By varying the number of cycles, it is possible to grow materials uniformly and with high precision on arbitrarily shaped and large substrates.



H_2 + HW → H + H

WF_6 + 6H → W + 6HF

Pure W films

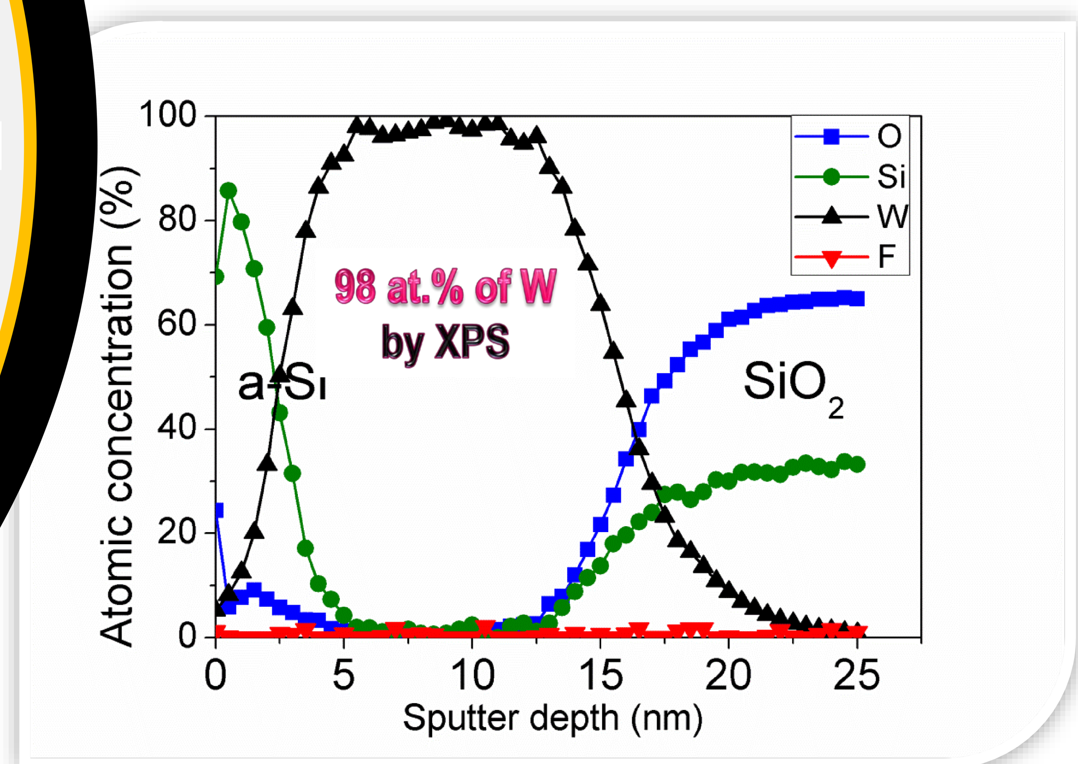


Figure: XPS compositional analysis of HWALD W films

Excellent step coverage

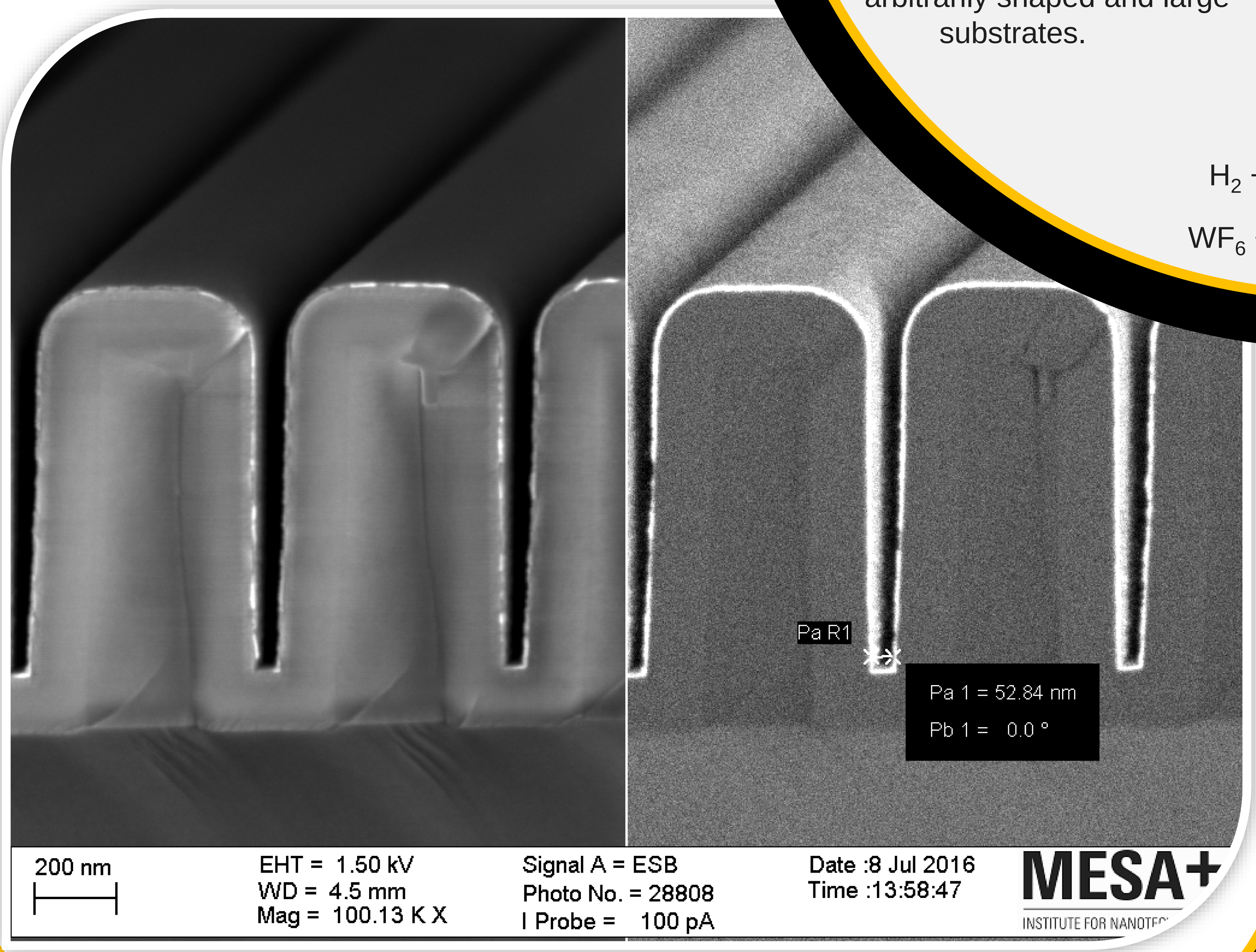
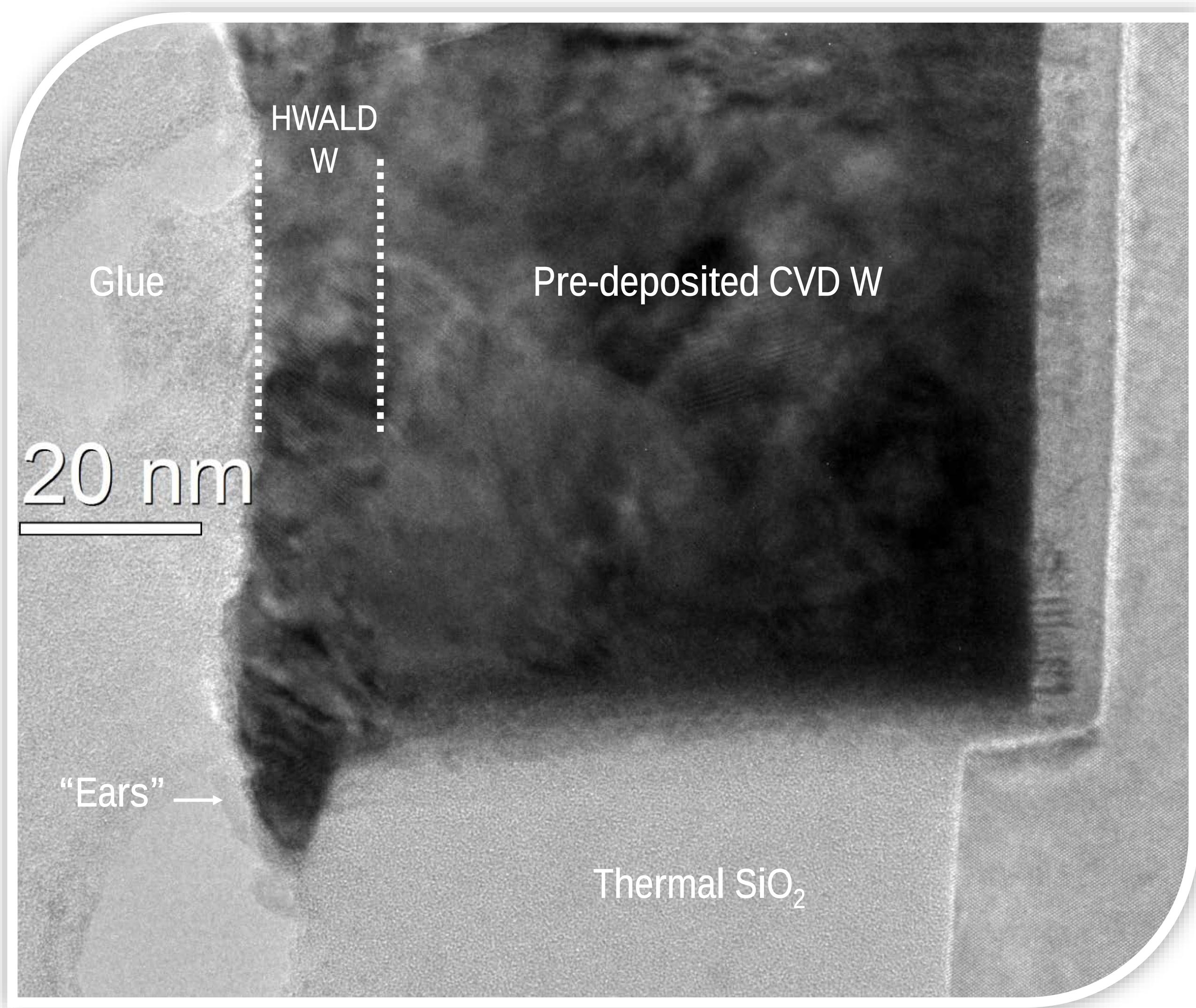


Figure: SEM cross-section of HWALD W films

Area-selective growth



Modern ultra-large-scale integration (ULSI) requires downscaling of devices and circuits with less than 10 nm dimensions.

Conventional patterning processes in combination with lithography become challenging due to the alignment issues.

Because of this, area-selective ALD attracts attention over the past several years, to enable nanoscale patterning and further downscaling of device dimensions.

Figure: Area selective deposition of low-resistivity α-phase W films by HWALD from at-H and WF_6 at a substrate temperature of 275 ºC. HWALD tungsten grows with little or no incubation time on W, Co and Si surfaces. On the other hand, no growth is observed on TiN, Al_2O_3 and SiO_2 surfaces.

Low resistivity

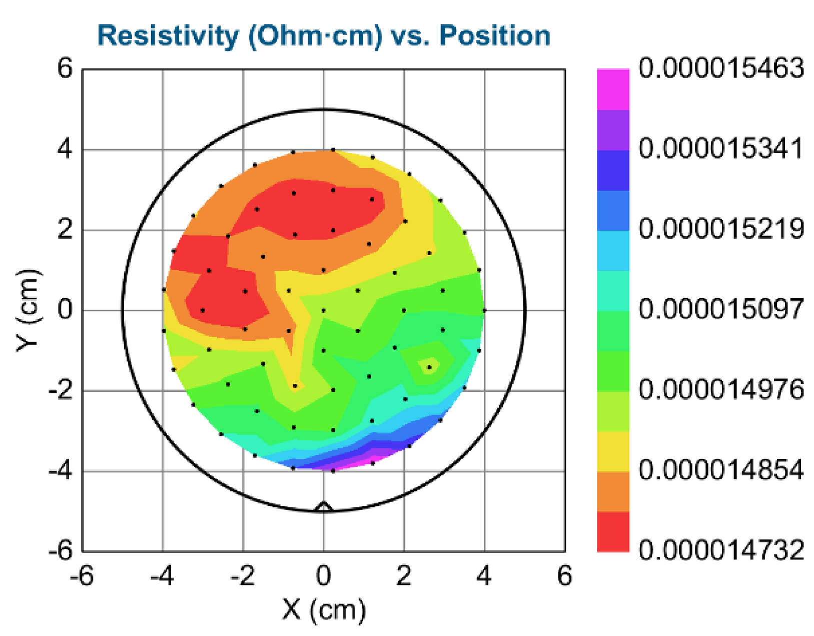


Figure: Measuring resistivity by four-point probe reveals 15 μΩ·cm with excellent uniformity across the wafer. This means growing **high-quality α-phase tungsten**. From the Figure, the resistivity slightly varies between 14.7 and 15.5 μΩ cm across the wafer.

Conclusions

- HWALD tungsten films have been deposited in a home-build reactor from at-H and WF_6 at 275 ºC.
- HRTEM analysis showed the uniform and conformal coverage, confirming the ALD with sufficient diffusion of both WF_6 and at-H into the deep trenches.
- Resistivity measurements revealed a low resistivity of 15 μΩ·cm
- XPS analysis indicated high purity, reaching 99 at.% of W.
- Area selective growth of HWALD W has been demonstrated.

References

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2. M. Yang, A.A.I. Aarnink, J. Schmitz, A.Y. Kovalgin, *Thin Solid Films* **646** (2018) 199–208.
3. M. Yang, A.A.I. Aarnink, J. Schmitz, A.Y. Kovalgin, *Thin Solid Films* **649** (2018) 17-23.