Integration of VR/AR with Nanoscale Data Visualization for Enhanced Semiconductor Manufacturing

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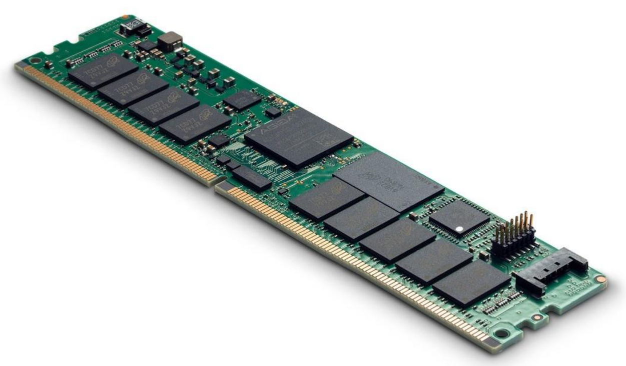
Abstract

This research aims to use Virtual and Augmented Reality (VR/AR) to navigate dataset from nanoscale characterization of semiconductor materials. By using advanced imaging and measurement techniques, this project will help better identify the properties and behaviors of these materials, making it easier to find and fix problems in semiconductor manufacturing.

Motivation & Future Work

Semiconductor devices, like RAM, are crucial for fast data storage and processing. Failure analysis is vital to ensure their reliability, identifying defects that impact performance. Metrology techniques such as AFM and SEM allow for nanoscale inspection of materials and structures, essential for refining semiconductor designs.



Non-volatile Random Access-Memory used in our daily computing devices [5]

In this study, we use niobium oxide, a material with complex properties suited for resistive switching in non-volatile memory, to explore AR/VR applications in metrology. Niobium oxide serves as a test case for 3D visualization techniques, while AR/VR can enhance failure analysis by providing an immersive view of AFM and SEM data, supporting defect analysis and design improvement.

In the future, we aim to fully automate 3D visualization of semiconductor metrology data. Advanced algorithms could directly convert AFM and SEM data into 3D models ready for AR/VR viewing, eliminating manual steps and speeding up analysis. This would enhance our current workflow, moving from human-driven data collection and processing to a system that automatically generates real-time, interactive 3D models. Our framework leverages AR/VR to transform 2D C-AFM data into immersive 3D visualizations, providing nanoscale insights into spatial and material properties. Devices like the HoloLens 2 and Meta Quest 2 enable hands-free, intuitive data exploration, enhancing defect analysis and interpretation. This automated approach could streamline semiconductor manufacturing, allowing faster, more accurate decision-making by simplifying the interaction with complex data in AR/VR environments.

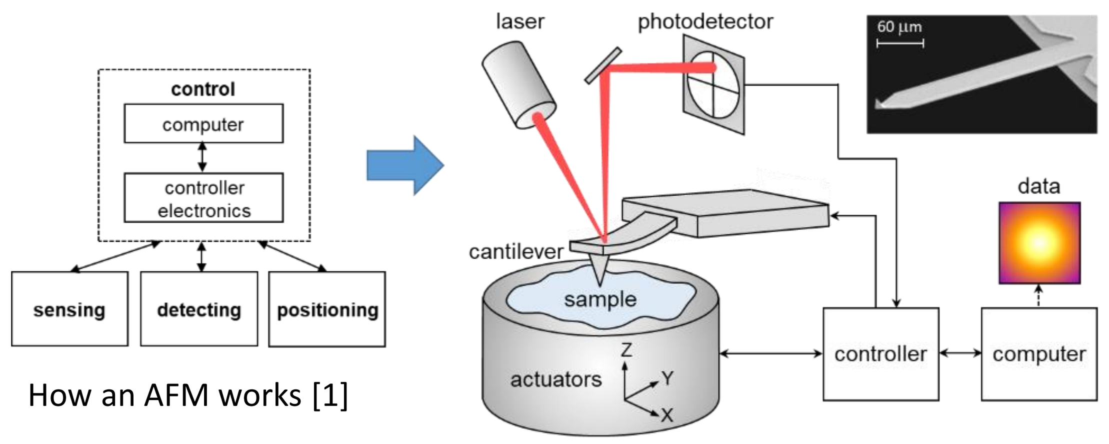
References & Acknowledgements

[2] M. A. R. Laskar et al., "Adaptive Scalpel Scanning Probe Microscopy for Enhanced Volumetric Sensing in Tomographic Analysis," Adv. Mater. Interfaces 2024, 11, 2400187.https://doi.org/10.1002/admi.202400187
[3] [4] M. A. R. Laskar et al., "Augmenting Metrology: A Framework for Interactive 3D Data Visualization and Contextual Analysis in Semiconductor Manufacturing," 2024 IEEE International Symposium on the Physical and Failure Analysis of Integrated Circuits (IPFA), Singapore, 2024, doi: 10.1109/IPFA61654.2024.10691140.
[1] What is Atomic Force Microscopy. (n.d.). [5] https://afm.oxinst.com/outreach/atomic-force-microscopy.
[5] Micron NVDIMMS 2017. [n.d.] https://www.tomshardware.com/news/nvdimm

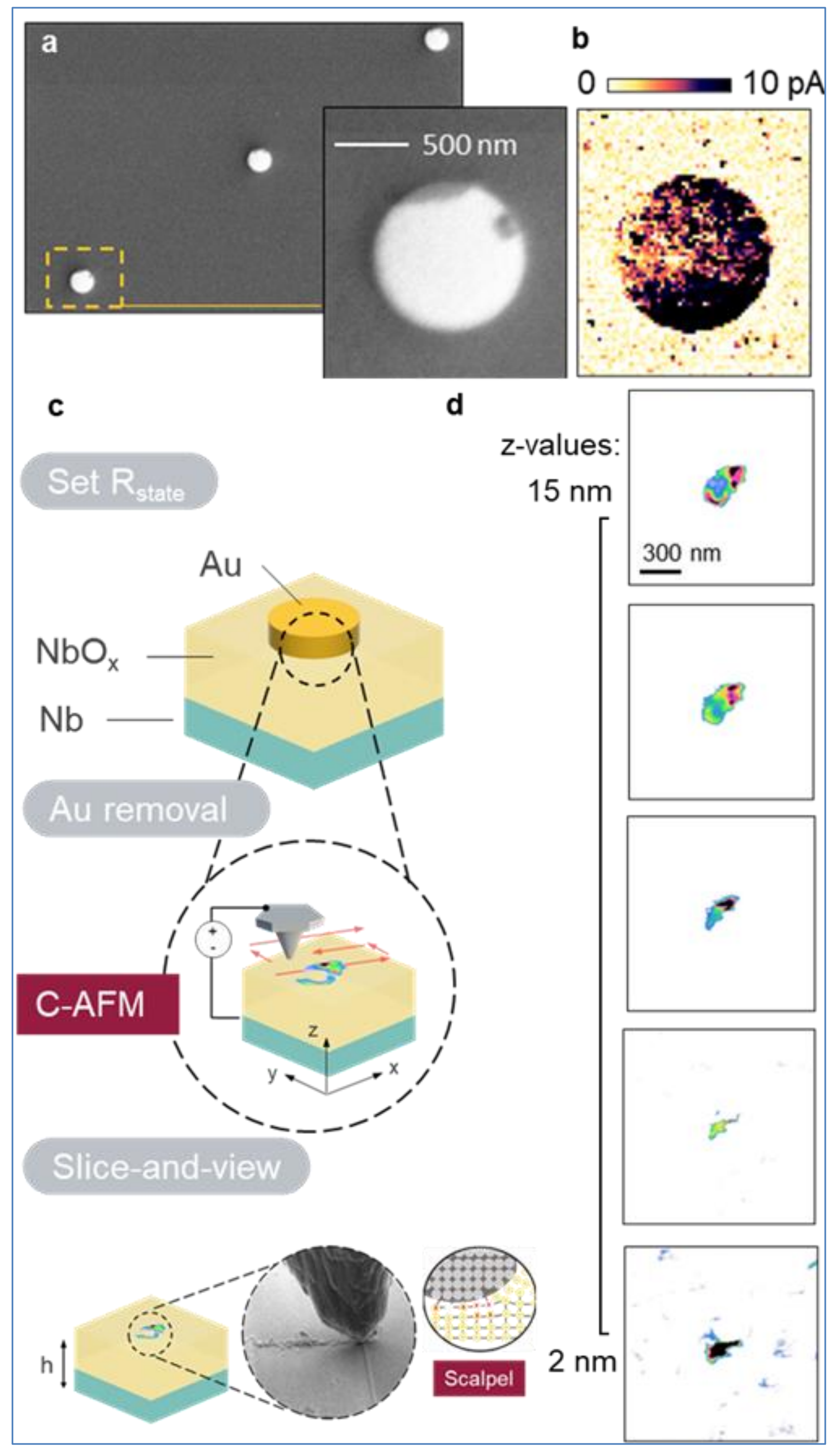
Research Methods & Instrumentation

1) Data Collection:
Experts in our lab begin by manually collecting raw 3D metrology data from semiconductor samples, using precise instruments such as atomic force microscopy (AFM) or scanning electron microscopy (SEM). It was ensured that the data accurately captures the detailed features of microstructures critical for analysis.

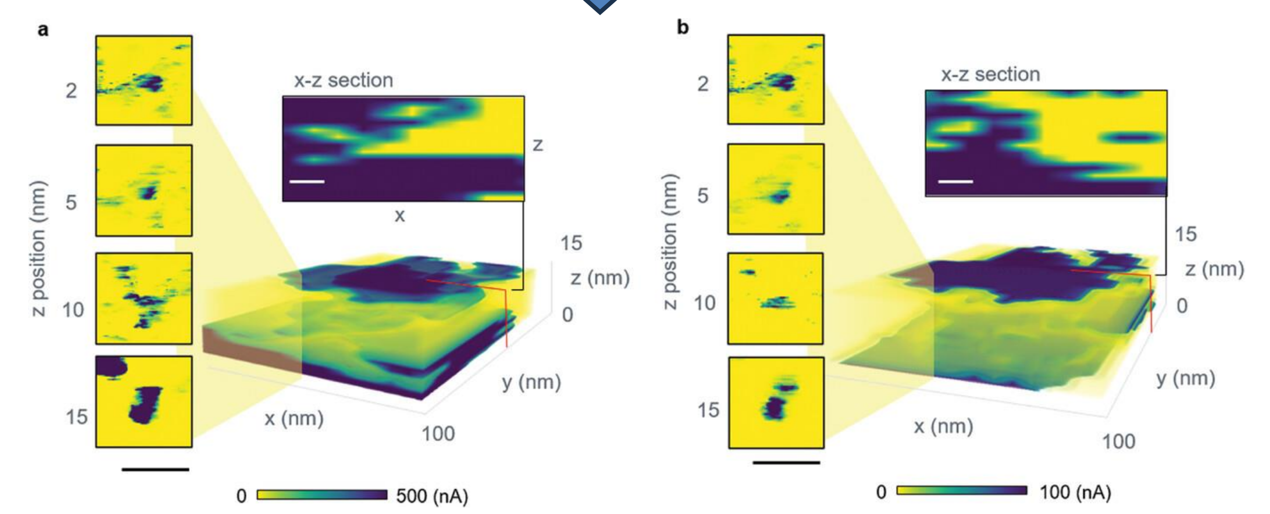
The Bruker Multimode 8 C-AFM (conductive atomic force microscopy) system, using conductive diamond probes (CDT-CONTR), was employed to scan semiconductor samples. The scanning rate was set at 0.9 Hz with 256 samples per line, where each pixel in the image represented a 7.88 nm² area on the actual semiconductor samples.



How an AFM works [1]

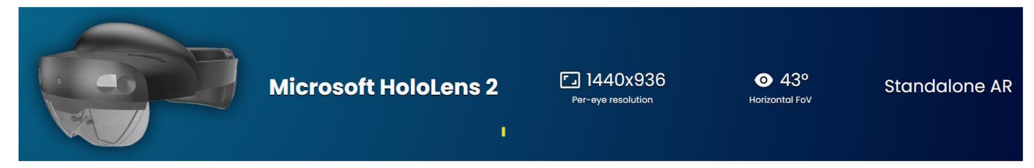


Data collected from AFM [4]

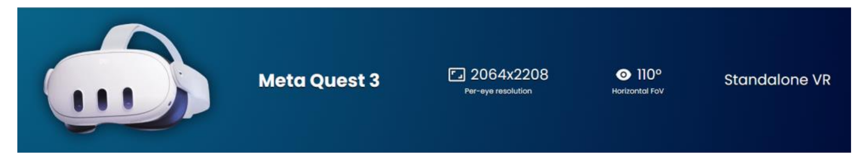


3d interpolation of Data [2]

2) Data Processing and Model Generation: Once collected, the data is carefully processed and segmented to remove any noise or irrelevant details. Through advanced software, models are constructed from this processed data, ensuring that each model accurately represents the structural intricacies and contextual elements of the semiconductor sample. For our project, Dragonfly software was utilized to convert the 2D C-AFM images into a 3D tomogram



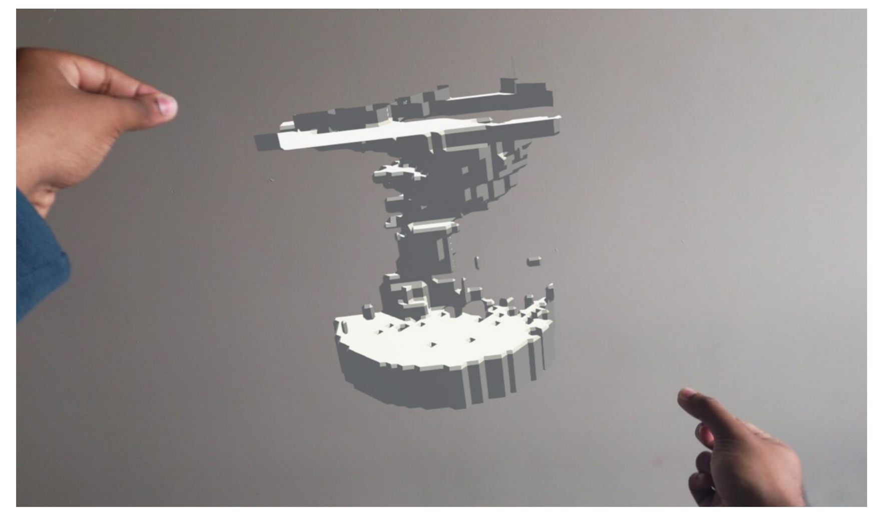
AR headset used for Visualization



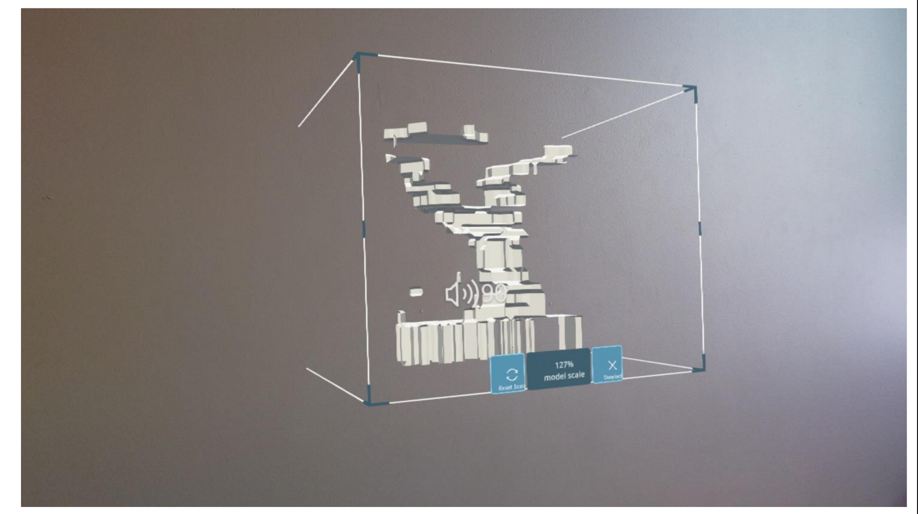
VR headset used for Visualization

New AR/VR headsets that can be used for Visualization

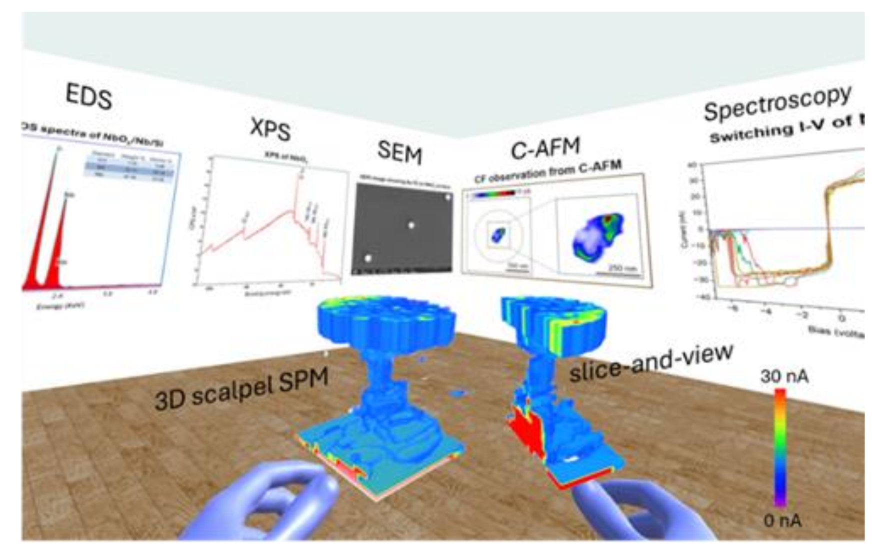
Headsets like the HoloLens 2, Meta Quest 2, and others are transforming fields like healthcare, engineering, and architecture through immersive visualization and efficient, hands-on training. Applying AR/VR to semiconductor metrology and failure analysis can similarly enhance efficiency, streamline workflows, and allow for precise 3D data interaction, supporting better defect detection and optimization in manufacturing.



Sample of Niobium Oxide Conductive Filament as viewed in AR



Different scaling ratios in AR



Sample of Niobium Oxide Conductive Filament as viewed in VR [3]

3) VR/AR Integration and Visualization: The 3D models are optimized and integrated into AR software, allowing for real-time, interactive viewing through AR headsets. Users can rotate, zoom, and annotate the models directly within the AR environment, enabling detailed spatial analysis that enhances understanding of complex microstructures in a way that traditional screens cannot replicate.
The Microsoft HoloLens 2 was then used to enhance visualization and interaction with the 3D tomograms generated from the C-AFM data. This augmented reality device enabled immersive, hands-free exploration of the semiconductor samples, allowing for a more intuitive understanding of spatial relationships and material properties within the samples. Additionally, the Meta Quest 2 was used for VR visualizations, facilitating dynamic viewing and real-time manipulation of the 3D models, which provided an innovative approach to semiconductor analysis.