Extended reality activities for nanofabrication education

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With the growing reshoring of U.S. semiconductor manufacturing, there is a growing shortage of qualified professionals. However, training future experts in the design, fabrication, and testing of nanoelectronics and semiconductor chips requires adequate cleanroom facilities. Since these facilities are expensive to operate and maintain, previous efforts have explored fully virtual reality (VR)–based training environments. Nevertheless, users of VR simulators can experience challenges such as nausea, motion sickness, discomfort, and reduced sense of physical presence. Hardware limitations that confine training to fully virtual environments exacerbate these issues even further and can be significant barriers to effective learning. To address this workforce development gap and enhance training opportunities, this work investigates the use of Extended Reality (XR) tools to supplement and integrate lab activities within an academic cleanroom facility.

In this work, two XR methods were developed in line with physical equipment in the cleanroom facility: a Virtual Reality (VR) Simulation and an Augmented Reality (AR) simulation based on microfabrication facilities in real cleanroom space (Figure 1). The Virtual Reality (VR) Simulation provides a fully virtual, headset-based VR cleanroom environment that replicates the sputtering process performed in the physical laboratory (Figure 1a-b). The simulator guides students through a structured, step-by-step representation of the sputtering process (Figure 2)

Across all participants, several recurrent themes emerged: the importance of instructor support, the need for task monitoring and error recovery mechanisms, and the trade-off between immersion and usability. Figure 3 shows the proportion of participants who report experiencing motion sickness in real life, the VR simulator and the AR simulator. Motion sickness and occasional control difficulties were identified as limiting factors as users reported in their feedback, e.g., “Very cool but got too dizzy!”, but overall, XR simulations offered practical hands-on learning opportunities that were not feasible with traditional computer-based simulations alone. 75% of participants indicated that they would be interested in future cleanroom/nanofabrication learning experiences in VR/AR.

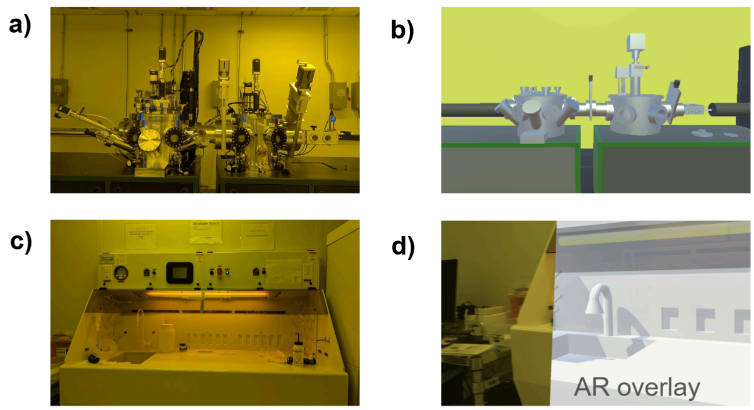

Figure 1: A comparison of the real vs. modeled facilities. A sputtering system in a) the physical laboratory space vs. b) in VR. A lab bench in c) the cleanroom vs. d) with overlayed AR capabilities.

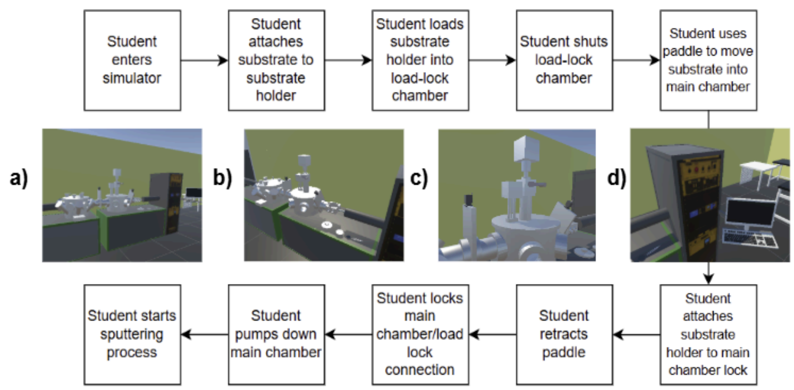

Figure 2: A general step-by-step of the simulator experience. a) Overview of on-axis portion of sputtering machine; b) Loading area of sputtering machine; c) Load-lock and main chamber connection; d) Computer and cabinet controls for sputtering machine

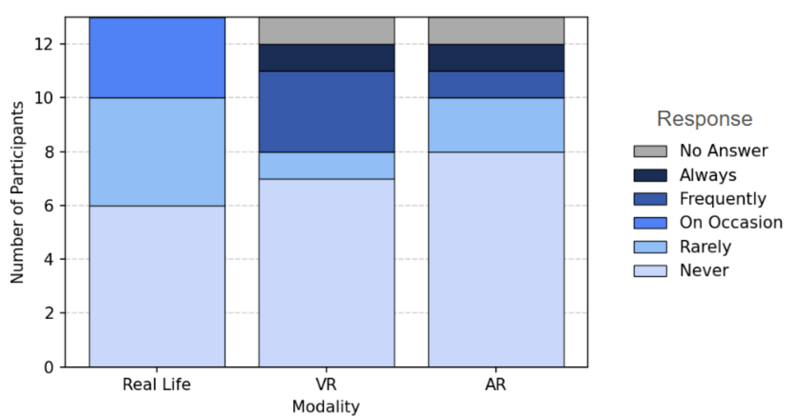

Figure 3: User self-reported degree of motion sickness in real life vs. proposed VR/AR experiences