SEMINAR

Department of
Mechanical Engineering

Interfacial Mechanics and Dynamics at the Nanoscale: Scanning Probe Microscopy Approaches across Functional Material Systems

SPEAKER

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ABSTRACT

Many challenges in modern mechanical engineering are governed by interfaces, where local structure, stress state, mechanical interactions, and electronic response evolve together under coupled operating conditions. In systems ranging from thin films and functional oxides to molecular assemblies and mechanically heterogeneous materials, overall behavior is often determined not only by bulk properties but by nanoscale interfacial processes such as charge trapping, defect-mediated transport, local stiffness variations, surface mass transfer, and thermally activated structural rearrangements. These processes are typically nonuniform in both space and time, making them difficult to capture with conventional characterization techniques based on spatial or temporal averaging. My research addresses this limitation by developing multidimensional scanning probe microscopy (SPM) techniques, particularly atomic force microscopy (AFM) methods, as quantitative experimental approaches for resolving interfacial mechanics and dynamic material response with high spatial and temporal resolution. This framework forms the basis of the research direction I envision, centered on advanced AFM/SPM methods for understanding how local mechanical interactions, transport processes, and time-dependent interfacial behavior govern material performance across a broad range of engineering systems.
In this seminar, I will show how multidimensional AFM can be used as a quantitative tool for mechanical and electromechanical characterization to resolve coupled interfacial processes that govern transport, surface evolution, and local material response. I will begin with my Ph.D. work on time-resolved and multidimensional AFM studies of metal oxides, where nanoscale charge-carrier dynamics were examined as interfacial processes shaped by local defects, fields, and junction behavior under coupled loading and external stimuli. I will then discuss direct measurement of lateral mass-transfer barriers across atomic-scale surface features on Au(111) surfaces (i.e., the Ehrlich-Schwoebel barrier), providing a direct nanoscale view of the energetic constraints that govern surface diffusion, thin-film growth, and morphological evolution. Finally, I will present current translations of the expertise and measurement framework to low-temperature three-dimensional (3D) AFM studies of molecular systems, where local interaction landscapes (e.g., force and potential) can be quantified with sub-molecular resolution, and to the nanoscale mechanical characterization of bulk metallic glasses (BMGs) through stiffness mapping and temperature-dependent measurements. Together, these studies illustrate how advanced AFM can provide a unified experimental framework for Mechanical Engineering problems in which local structure, interfacial mechanics, and time-dependent response jointly govern material behavior and performance.

ABOUT THE SPEAKER

Irmak Dr. Bugrahan Guner received his B.S. in Mechanical Engineering from Middle East Technical University (METU) in 2021 and completed his Ph.D. in Mechanical Engineering at École de technologie supérieure (ÉTS), University of Quebec, in 2025, under the supervision of Prof. Omur E. Dagdeviren. His doctoral research centered on advanced scanning probe microscopy (SPM) technologies, including the development of custom instrumentation and multidimensional atomic force microscopy (AFM) methods for probing time-resolved charge-carrier dynamics in metal oxide and functional material systems. He has authored multiple peer-reviewed publications, with five of them featured as editor's highlights and journal covers. His work has received both national and international recognition, including the top provincial ranking among Ph.D. students in Quebec in 2023 and the AVS Graduate Research Award in 2024. During this period, he also held a Visiting Assistant in Research position at Yale University, contributing to AFM customization and instrumentation development. He is currently a Postdoctoral Associate at Yale University's Mechanical Engineering Department, where he is extending his research toward the nanoscale mechanical characterization of bulk metallic glasses and the study of molecular catalyst systems through advanced multidimensional SPM techniques.

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