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RPPR Final Report
as of 23-Feb-2022

Agency Code: 21XD

Proposal Number: 75729MSRIP **Agreement Number: W911NF-20-1-0077**

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Begin Performance Period: 20-May-2020 **End Performance Period:** 21-Nov-2021
Report Term: 0-Other
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STEM Degrees: 3 **STEM Participants:** 11

Major Goals: The major goal is to acquire a versatile Atomic Force Microscope (AFM) system to enhance cross-campus multidisciplinary research activities and research-related education at California State University, Los Angeles (Cal State LA). The common theme of the enabled research projects seeks to fundamentally understand the physical and chemical interactions and properties at molecular surfaces or interfaces of novel bio-/nanomaterials and devices. The acquired AFM system will be a multi-user instrument across the campus and entail a multifaceted approach to student involvement with research. Students will be able to examine problems at the crossroads of materials science, physics, chemistry, engineering, and other related sciences. This acquisition will promote cross-campus collaboration and multidisciplinary research activities, and enhance student research training and education for our population of predominantly underrepresented minority undergraduate and graduate students in the Southern California region, in disciplines important to DoD ARO missions.

Accomplishments: The AFM instrument (Bruker Dimension Icon) was fully installed in mid-April 2021 in the

Materials Characterization Room (E&T C164a) of the Mechanical Engineering Department at Cal State LA. The installation and training took much longer time than expected to complete due to the pandemic and COVID lockdown, as well as the Cal State LA campus restrictions and safety procedures/measures to bring external visitors on campus during the original funding period (20 MAY 2020 - 21 MAY 2021). The Facilities Services at Cal State LA was also short-staffed for more than half a year. Modification of the room and installation of the compressed air line (needed for the AFM AVH-1000 air table, which provides increased acoustic isolation and vibration isolation) was delayed before the instrument can be installed. With all the uncertainty and impediment, we received great support from the College of Engineering, Computer Science & Technology, the College technician, and Office of Research, Scholarship, and Creative Activities, to overcome the challenges.

The following lists the AFM instrument installation timeline:
1. The purchase order is placed for the AFM system on 06/29/2020.
2. The AFM shipment was delivered in mid-September of 2020.
3. The actual AFM installation and 1st training were completed in mid-April of 2021
4. A second round of training by the Bruker field technician will be scheduled for Spring 2022. More research students from the PI and Co-PIs groups will get a chance to be trained to use the instrument for research.

Contribution of equipment/instrumentation (AFM) to scientific advancement:
Up to date the AFM system has been employed and will be employed in the following research projects at Cal State LA. No journal or proceeding publications have been generated yet since the new installation and recent training of the system.
1. Adhesion - Friction Coupling in Gecko Inspired Dry Adhesives (PI. Dr. Travis Shihao Hu in Mechanical Engineering Department)
2. Nano-Scale Wettability of Free-Standing Capped CNTs (PI. Dr. Travis Shihao Hu)
3. CVD Growth Mechanisms of High-Quality Large-Sized 2D Materials (PI. Dr. Travis Shihao Hu)
4. Cell Morphological and Mechanical Changes Under Exposure Toxic Molecules/Particles (Co-PI Dr. Yixian Wang in Chemistry and Biochemistry Department)
5. Protein Characterization Under Liquid Environment (Co-PI Dr. Yixian Wang)
6. Surface Modification Characterization Under Liquid Environment (Co-PI Dr. Yixian Wang)
7. Characterization of the Crystalline Nature of Dielectric Optical Coatings for Interferometric Gravitational Wave Astronomy Applications (New Participant Dr. Marina Mondin in Electrical Engineering Department)

Application of the AFM Instrument in Hu Group:
Current synthetic dry adhesives suffer from large required preloading and intolerance of dusty environments, which significantly limit their use for sticking to or manipulating fragile and non-dust-free objects. We proposed to study the engaging and disengaging mechanisms of anisotropic fibrillar adhesive units featuring a variety of contact shapes/geometries and structural/materials gradients across multiple lengths and temporal scales. The ultimate goal of this project is to fundamentally understand the 'contact shape dependency' of bio-inspired anisotropic fibrillar adhesives in non-dust-free environments and under different temperatures and relative humidity. The research outcomes help to significantly improve the multifunctional performances of bio-inspired dry adhesives in the three symbiotic attributes, namely, strong/robust adhesion, easy detachment, and self-cleaning.
In this project, we have fabricated bio-inspired wedge-shaped micropillar adhesives with different contact shape geometries using a bottom-up approach (i.e., nanoscale 3D printing). The AFM system is employed to study the nanomechanics and adhesion-friction coupling of the wedge-shaped micropillars as controllable dry adhesives (in terms of strong attachment, easy detachment, and self-cleaning). Careful selection of the AFM cantilever probe size and geometry, allow us to obtain the force curves (1) at the individual micropillar level and (2) at the micropillar array level for samples with varied contact shapes. The collected data were used to abstract the mechanical/interfacial properties and the adhesive and nanotribological performances of the samples. Further AFM testing will be implanted under different environmental conditions (e.g., with a combination of temperature and relative humidity) to study the robustness of the dry adhesives and how their microstructure can affect water bridging and condensations. Eventually discretized finite element cohesive zone models will be built and fitted with the AFM testing data, in order to elucidate the underlying mechanism, and for the purpose of parametrization and theory development.

Application of the AFM instrument in Wang Group:
The Wang group has utilized this AFM to characterize nanomaterials. Various nanomaterials have been studied and explored for catalysis and energy-related applications, because of their unique chemical and physical properties. The traditional ensemble methods provide only averaged properties of nanomaterials with different shapes and sizes in a typical sample. Characterizing nanomaterials at the single-entity level is thus essential to

determine the relationship between the catalytic activities and the structure of the nanomaterials. The Wang group aims at delineating the relationship between the electrocatalytic performance of nanocatalysts and their surface structures by using plasmonic electrochemical microscopy (PEM). They have carried out a preliminary test of characterizing individual Prussian blue nanoparticles. The next step will be correlating the surface structure obtained from AFM to their electrocatalytic activities from PEM at the individual nanoparticle level. The fundamental study will shed light on the major factors governing the catalyst activity of nanocatalysts and also help the design and development of other catalysts.
The Wang group will also look into the cell membrane mechanical studies after the second round of training including the liquid cell. Numerous studies have linked a wide range of diseases to harmful particulate matter (PM) emissions, particularly for those in urban areas such as Los Angeles, California, USA. Investigating the impact of PM at the cellular level will further our understanding of the mechanism. The Wang group will assess the effects of PM2.5, fine PM with diameters of 2.5 micrometers or less, from incense smoke emission exposure in real-time on A549 lung carcinoma epithelial cells and SH-SY5Y neuroblastoma cells. Nanoscale morphological and mechanical monitoring of the cell membranes utilizing AFM and scanning ion conductance microscopy (SICM) will provide information for understanding the mechanism of the cell toxicity from PM2.5.

Application of the AFM instrument in Mondin Group:
Interferometric gravitational wave astronomy requires test mass surfaces that are extremely mechanically and thermally stable. We wish to characterize the effect of the coatings' thickness and annealing temperature on the formation and the size of the crystallites. Characterization of the crystalline nature of these coatings is typically performed with X-ray diffraction, yet that method is only sensitive to relatively large regions of crystalline coherence. Atomic Force Microscopy has been observed to be sensitive enough to detect differences in surface roughness for different thicknesses of coating stacks, even just after deposition but before annealing when the crystallites have not yet grown into regions that are detectable by XRD. By using AFM to analyze the surfaces of the coatings after deposition, and perhaps after some annealing stages, we hope to find a correlation between roughness and the nature of the crystals that are embedded within.

Training Opportunities: Undergraduate or graduate students have been trained or allowed to use the equipment or instrumentation - Up to date, there are 7 graduate and 4 undergraduate students who have been trained to use the AFM instrumentation from the PI and Co-PIs labs (i.e., Hu, Wang, and Gomez Groups). Dr. Wang and I together trained these students multiple times after we have been trained by the Bruker field technician. We will have our second round of training from the Bruker field technician scheduled in Spring 2022, to learn how to perform the testing in fluids, varied methods to calibrate the cantilever probes, and AFM nDMA (nano-dynamic mechanical analysis) to measure viscoelastic properties right near an interface or in interphase.

Results Dissemination: Technology breakthrough that has resulted in additional teaming with other DoD scientists or engineers - All the aforementioned projects are still ongoing. No major technology breakthroughs have been facilitated yet. We will make effort to collaborate and make the AFM instrumentation available to other DoD scientists/engineers on campus and in close neighbors (e.g., Dr. Yangyang Liu in the Department of Chemistry and Biochemistry at Cal State LA, who was awarded the 2018-2021 DoD Army Education & Research Grant as the PI). No journal or proceeding publications have been generated yet since the new installation and recent training of the system.

Honors and Awards: Nothing to Report

Protocol Activity Status:

Technology Transfer: Nothing to Report

PARTICIPANTS:

Participant Type: PD/PI
Participant: Travis Shihao Hu
Person Months Worked: 1.00 **Funding Support:**
Project Contribution:
National Academy Member: N

Partners

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I certify that the information in the report is complete and accurate:
Signature: Travis Shihao Hu
Signature Date: 2/22/22 12:49AM

Final Report

Understanding the Interplays of Mechanical and Chemical Interactions at the Molecular Interfaces of Multifunctional Bio-/Nano- Materials

Army DURIP Proposal No. 75729-MS-RIP

PI: Travis Shihao Hu
Department of Mechanical Engineering, California State University, Los Angeles

Major Goals

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Accomplished under Goals

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Participants
No Cost - No funding is budgeted for participants (PI: Dr. Travis Shihao Hu; Co-PIs Drs. Frank A. Gomez, Yixian Wang and Ni Li; Senior Personnel Dr. Xin Wen)