Coatings for Biomedical and Healthcare Applications
Room Palm 3-4 - Session MD2-ThA

Medical Devices: Bio-Tribo-Corrosion, Diagnostics, 3D Printing

Moderator: Hamdy Ibrahim, University of Tennessee at Chattanooga, USA

1:40pm **MD2-ThA-2 Mass-Production of Ultra-Sensitive 2d Electronic Biosensors via Roll-to-Roll Sputtering and Laser Patterning**, *B. Robertson, M. Muratore,* University of Dayton, USA*; N. Glavin,* Air Force Research Laboratory, USA*; **Christopher Muratore (cmuratore1@udayton.edu)**,* University of Dayton, USA

Materials with high surface-to-volume ratios demonstrate exquisite sensitivity and detection limits in diverse molecular sensing applications.Integration of nanowires, nanotubes, and two-dimensional (2D) semiconductors into sensing devices, however, presents challenges inhibiting product development.For example, thousands of trials are required to obtain US government approval for point of care diagnostics, yet producing a suitable number of 2D devices via conventional synthesis and fabrication techniques to meet this testing requirement is not currently feasible. To realize commercial applications of 2D transducers in ubiquitous low-cost diagnostic devices, new synthesis and fabrication approaches were developed. Processes for high-rate (>10^6 per day) mass-production of low-cost two-dimensional electronic medical diagnostic devices with limits of detection rivalling PCR (<10 fg/mL) with response times of <2 minutes will be presented. Rapid and inexpensive sensor chip fabrication relies upon sputter deposition, laser pattering, and laser annealing processes in a roll-to-roll physical vapor deposition system.Moreover, naturally abundant and recyclable materials were selected for use in these scaled processes for reduced waste stream impact in anticipation of large numbers of devices are consumed daily.An automated high-speed Raman spectroscopy system was developed for quality control of mass-produced materials during fabrication.Fundamental studies employing this system to measure point defect densities in 2D semiconducting transducer materials will be shown to correlate synthesis and fabrication process parameters, 2D materials structure, and diagnostic device performance.

2:00pm **MD2-ThA-3 Corrosion Risk Analysis of CoCrMo alloy as a Function of Microstructure: Biomedical Applications**, ***Maansi Thapa (mthapa3@uic.edu)**,* University of Illinois at Chicago, USA*; Y. Sun, B. Keaty, M. Mathew, C. Takoudis, M. Daly, D. Ozevin,* University of Illinois - Chicago, USA

CoCrMo alloys are widely used in orthopedic implants and various biomedical applications, exhibit excellent corrosion resistance and mechanical properties. However, it has raised concerns about inferior corrosion behavior and subsequent side effects due to metal ion release. While the electrochemical nature of this alloy is well studied, the microstructure's effect needs further research. The objective of this study is to evaluate corrosion behavior of CoCrMo alloys in two microstructures: unbanded (transverse) and banded (longitudinal).

Six CoCrMo disks (11x7mm) were prepared and polished following metallographical protocol for a surface finish of <50 nm. The unbanded CoCrMo rod was cut perpendicular to the axis, while the banded CoCrMo rod was cut parallel to the axis. The electrolyte used was bovine calf serum (30 g/L proteins) with a pH of 7.6 to simulate the joint environment. The electrochemical test followed ASTM G61 standard using a three-electrode system: the sample as the working electrode, a saturated calomel electrode (SCE) as a reference electrode, and a graphite rod as the counter electrode. The typical protocol involved: open circuit potential (OCP), electrochemical impedance spectroscopy (EIS), and cyclic polarization curve. Using Tafel's estimation, the corrosion potential (E_{Corr}) and corrosion current (I_{Corr}) were determined. EIS data was utilized to generate Bode and Nyquist plots and construct an equivalent electric circuit to determine polarization resistance (R_p) and double layer capacitance (C_{dl}). The corroded surfaces were characterized by white light microscopy, SEM, and EBSD.

Our study showed that the CoCrMo specimens with unbanded microstructures exhibited increased corrosion resistance (E_{corr}: -0.678 V vs SCE, I_{corr}: 1.85E-06 A/cm^2) compared to banded microstructures (E_{corr}: -0.736 V vs SCE, I_{corr}: 5.05E-06 A/cm^2). The EIS data supported this observation, revealing higher R_p and lower capacitance. SEM observations revealed larger pitting in the banded microstructure compared to unbanded. Previously, Jacob et al.[1] reported superior fretting-corrosion behavior of unbanded microstructures and potential risk of banded microstructures under an infected environment.

The banded microstructure, with increased grain boundary exposure, heightens the risk of intergranular and galvanic corrosion. Further exploration is needed to understand microstructural mechanisms and develop strategies to inhibit increased corrosion risk. Our investigation emphasizes the vital role of material composition and configuration in microstructural and corrosion behavior.

(1)Manthe, J *Mech. Behavior of Biomed Materials*. **2022**.

2:20pm **MD2-ThA-4 Comparative Study of Composite Coatings on Magnesium for Biomedical Devices**, *V. Patil,* University of Tennessee at Chattanooga, USA*; B. Williams,* University of Arkansas, USA*; J. Rich,* University of Tennessee at Chattanooga, USA*; M. Elsaadany,* University of Arkansas, USA*; **Hamdy Ibrahim (hamdy-ibrahim@utc.edu)**,* University of Tennessee at Chattanooga, USA

Magnesium (Mg) and its alloys exhibit a biodegradable nature in aqueous environments, rendering them appealing for diverse biomedical applications where permanent existence in the body is not advisable. However, the utilization of Mg for bone fracture repair faces notable challenges, primarily stemming from its constrained mechanical strength and rapid corrosion rates. To address these issues, extensive research has been directed towards the development of biocompatible coatings that can offer Mg the necessary protection in vivo. In this study, we have formulated various composite coatings and conducted a comprehensive assessment of their properties, including corrosion rates, biocompatibility, adhesion strength, and surface morphology. The evaluated composite coatings were derived from three distinct processes: Plasma Electrolyte Oxidation (PEO), sol-gel coating, and polymer dip coating. Results indicated a substantial enhancement in corrosion resistance within the sol-gel coated composite group. Moreover, the polymer-coated groups demonstrated superior osseointegration and biocompatibility. This investigation underscores the feasibility of producing biocompatible magnesium-based implants with enhanced strength and controlled corrosion properties through the application of diverse composite coatings.

2:40pm **MD2-ThA-5 Laser-Induced Graphene Coatings on Polymers for Biomedical Devices**, ***Mostafa Bedewy (mbedewy@pitt.edu)**,* University of Pittsburgh, USA **INVITED**

Nanocarbons like graphene and related materials are promising for various biomedical applications; however, major manufacturing challenges still hinder our ability to scalably produce graphene with tailored morphology and surface chemistry, especially on flexible and polymeric substrates. While chemical vapor deposition (CVD) processes enable the synthesis of high-quality graphene, the typically high temperatures in such reactors limit the choice of substrates to silicon, quartz, metals or other temperature-resistant materials. On the other hand, emerging flexible devices, such as implantable surgical meshes and biosensors require the fabrication of such nanocarbon coatings and electrodes directly on polymers. Unlike different transfer techniques of CVD-grown nanocarbons, or printing methods from inks, this talk will focus on a bottom-up approach for directly growing different types of graphenic nanocarbons on aromatic polymers by laser irradiation.The speaker will present an approach that leverages this direct-write process, often referred to as laser-induced graphene (LIG), for creating spatially-varying morphologies and chemical compositions of LIG electrodes, by leveraging gradients of laser fluence. Three distinct morphologies are identified, and process control map is generated for maximizing the electrical conductivity of these porous graphene for biomedical devices. Moreover, this talk will introduce a method for controlling heteroatom doping of LIG based on controlling the molecular structure of the polymer being lased, i.e. by introducing sulfur- and fluorine- containing backbones.We demonstrate superhydrophobic and parahydrophobic surface properties for the fluorine-doped LIG patterns. We also show antibacterial properties of LIG coated surgical devices. Finally, a demonstration of these functional doped LIG electrodes as electrochemical biosensors will be presented for the detection of the neurotransmitter dopamine with nanomolar sensitivity.

3:20pm **MD2-ThA-7 Microfluidic Device for the Isolation, Detection, and Purification of Exosomes Based on Metallic Nanostructure Arrays***, **Alfreda Krisna Altama (alfredakrisna@gmail.com)**, Y. Hsiao, C. Chen,*
National Taiwan University of Science and Technology, Taiwan*; R. Haliq,* National Taiwan University of Science and Technology, Indonesia*; P. Yiu,* Ming Chi University of Technology, Taiwan*; P. Wu, J. Chu,* National Taiwan University of Science and Technology, Taiwan

Due to their low cost, rapid processing, and ability to analyze even minuscule samples, microfluidic devices are widely used in disease detection and specimen separation. In this study, metallic nanostructure arrays (MeNTAs) with tube-like features are embedded into microfluidic devices for immunoaffinity-based detection and efficient exosome isolation. MeNTA candidates were evaluated based on their ability to withstand mechanical stress during microfluidic operations, X-ray diffraction, zeta potential, and electrostatic interactions. The $Zr_{60}Cu_{25}Al_{10}Ni_5$ thin film metallic glass (Zr-TFMG) exhibited superior mechanical properties and a negative zeta potential compared to other materials. (e.g., Cu, Bronze, Ag, 7075Al, Ti64, 718Ni, SS316, Cu-TFMG, W-TFMG, and Al-TFMG). The resultant microfluidic device featured Zr-based MeNTAs with an interdigital electrode in a microchannel. In testing with derived exosomes (liquid biopsy of 500 µL), the device achieved a 95.3% exosome recovery rate within 1 hour while resisting nonspecific binding to HeLa-derived exosomes (recovery rate < 0.1%). The device facilitated the isolation of 1×10^8 exosome particles per mL for electrochemical impedance spectroscopy detection and allowed efficient release of captured exosomes via cyclic voltammetry operations. The proposed Zr-MeNTA microfluidic device holds significant potential for the isolation, detection, and purification of exosomes in liquid biopsy samples for cancer diagnosis, as mentioned by Hsiao et al. (2023).

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