MEMS and NEMS
Room 205 ABCD W - Session MN2-ThA

Bio and Flexible/Wearable Devices

Moderators: Matthew Jordan, Sandia National Laboratory, **Margo Staruch**, Naval Research Laboratory

3:15pm **MN2-ThA-5 Fabrication of Wearable Carbon Microelectrode Arrays for Bioimpedance***, **Robert Davis**, Nick Allen, Sharisse Poff, Shiuh-hua Wood Chiang, Brian Jensen, Richard Vanfleet,* Brigham Young University

Reusable, dry microelectrodes for bioimpedance measurements can enable wearable health monitoring devices. Here we demonstrate the fabrication of carbon composite microelectrode arrays designed specifically for wrist-based bioimpedance. Carbon electrodes are chemically inert and can form 3D structures for positive skin engagement. The electrodes were fabricated using carbon nanotube-templated microfabrication, in which patterned carbon nanotube forests were infiltrated with a nanocrystalline carbon matrix material to create a solid structure. The electrode material was tested for strength and wear resistance by three-point bending. The fabricated electrode arrays were mechanically and electrically adhered to pads on a flexible printed circuit (FPC) using an anisotropic conductive adhesive film, which was cured with pressure and heat. A controllable alignment and attachment technique was developed to simultaneously attach all electrodes in the array to the FPC. Human subject bioimpedance data verified that the electrodes were effective in measuring bioimpedance from 100 kHz to 200 MHz.

3:30pm **MN2-ThA-6 3D Ultrablack Microstructures for Wearable Optical Spectroscopy***, **Bridgett Kemper**, Woodson Parker,* Brigham Young University*; Tyler Westover,* Octavian Solutions*; Richard Vanfleet, Robert Davis,* Brigham Young University

Miniaturized spectrometers could enable the application of spectroscopy in wearable devices such as fitness/health monitors. Here we will present the fabrication of miniaturized spectrometers with integrated carbon nanotube parallel-hole collimators for use in diffuse light spectroscopy. The microscale collimators are precise optical elements balancing low reflectance with low transmission through the high aspect-ratio carbon nanotube hedges that isolate the holes. The collimators are grown on a transparent fused silica substrate allowing the fragile collimators to remain on the transparent substrate for integration into optical systems.

3:45pm **MN2-ThA-7 A Tetrapolar Bioimpedance Sensor with Electropolymerized PEDOT:PSS Electrodes for Improved Stability in the Gastrointestinal Tract***, **Mateo Lim**, Justin Stine, Reza Ghodssi,* University of Maryland College Park

Inflammatory bowel diseases, such as Ulcerative Colitis and Crohn's disease, cause degradation of the mucosal barrier throughout the gastrointestinal (GI) tract. This leads to afflicted regions of intestinal tissue having higher permeability, increasing the uptake of undesired bacteria and exacerbating inflammation. Bioimpedance is a direct monitoring method that has been identified to relate tissue conductivity with alterations in permeability. Through integration of a bioimpedance sensor on the surface of an ingestible capsule, we can wirelessly measure impedance throughout the GI tract (Fig. S1a). However, adapting these sensors to maintain performance in the GI environment is challenging. Here, we present the fabrication of a tetrapolar impedance sensor with poly 3,4-ethylenedioxthiophene (EDOT) and polystyrenesulfonate (PSS) dopant (PEDOT:PSS) electropolymerized onto gold (Au) electrodes for minimal fouling in simulated GI fluids (Fig. S1b). The PEDOT:PSS film decreases electrode interfacial impedance while enhancing the charge transfer capability (CTC).

The Au electrodes are patterned onto a polyimide substrate with photolithography, electron-beam evaporation, and liftoff. The sensor is coated with a biocompatible Parylene-C layer to insulate the electrical traces, and the electrodes and contact pads are subsequently exposed using reactive ion etching (Fig. S2a). The electrodes are coated with a PEDOT:PSS film via chronopotentiometry (CP) using a BioLogic VSP potentiostat (current density: 5μA/mm^2) for 180s in a solution of 10mM EDOT and 2M PSS (Fig. S2b). The CTC of bare Au and PEDOT:PSS electrodes were characterized using cyclic voltammetry (CV) in phosphate buffered saline (PBS), resulting in a 375-fold increase in current response for the PEDOT:PSS sensor (Fig. S3a). Sensor reliability and drift were verified using simulated gastric fluid (SGF, pH 1) and simulated intestinal fluid (SIF, pH 6.8) to represent the traversal through the GI tract. Electrochemical impedance spectroscopy (EIS) measurements from 100Hz to 100kHz were recorded at 5-minute intervals over 90 minutes with the EVAL-AD5940BIOZ development kit while the sensor was immersed in the GI fluids. Overall, the impedance measurement remained invariant with frequency; hence, 10kHz was selected for analysis. The average impedance over time was observed to increase at 7.6%/hr and 0.04%/hr for SGF (Fig. S3b) and SIF (Fig. S3c), respectively. These results demonstrate minimal sensor degradation over prolonged exposure to GI fluids, marking an important step towards realizing non-invasive bioimpedance sensing in the GI tract.

4:00pm **MN2-ThA-8 Development of Ingestible Capsule Technologies for Sensing Gut Serotonin Toward Understanding the Gut-Brain Axis***, **Sydney Overton**, Michael Straker, Reza Ghodssi,* University of Maryland, College Park

Serotonin (5-HT) is a biomarker of the gut-brain axis (GBA), regulating neurological and gastrointestinal (GI) functions such as mood and GI motility. Notably, 95% of 5–HT is produced in the GI tract and secreted below the epithelium. Furthermore, 5-HT is implicated in GI and neurological diseases, motivating interest in understanding 5-HT dynamics for diagnostics, treatments, and unveiling the underlying pathways of the GBA. However, research insights have been limited by the absence of appropriate tools for quantifying 5-HT in the gut. Here we present a system engineering approach to address this critical technology gap using ingestible capsules. We report the miniaturization of an electrochemical biosensor and integration with a meso-scale electromechanical actuator to create a module for real-time quantification of subepithelial-5-HT (Fig. S1).

Our novel biosensor for penetrating the GI epithelium and measuring underlying 5-HT features a surface-modified carbon fiber microelectrode (CFME) working electrode and a quasi-reference/counter electrode (QRCE). Fabricated using additive manufacturing and microfabrication, the QRCE incorporates four 3D-printed microneedles (MN) with 60μm sharpness and is functionalized via electron-beam deposition. Directly assembling the biosensor in a micromotor-driven cam and follower (CnF) mechanism simplifies assembly, resulting in a more compact module. Future integration with custom printed circuit board (PCB) electronics would enable precise control of actuation and electrochemical measurements, while biocompatible packaging ensures safe traversal through the GI tract.

We modeled the integrated biosensor-CnF using dynamic simulation to estimate actuation time and displacement of the follower, demonstrating a total displacement of 1.0mm at a cam angle of 45.8°. Next, we demonstrated the repeated actuation of the CnF, where the biosensor was displaced outside the capsule 823±28μm in 0.3s, dwells for 5s for an electrochemical measurement, then returns inside the capsule shell (Fig. S2e). Subsequently, we measured the CnF's actuation force to be 3.85±0.1mN, which is 10x greater than the 0.3mN insertion force of the biosensor previously characterized (Fig. S3a-b). To validate the biosensor, cyclic voltammetry (CV) was conducted in Agar GI tissue phantoms spiked with 10μM 5-HT. The resultant peak oxidation current of 0.1μA at 0.4V compared to a PBS control confirmed the electrochemical detection of 5-HT (Fig. S3c). By integrating MEMS biosensing and meso-scale actuators into a compact module, we have demonstrated the first step towards an ingestible capsule capable of detecting micromolar concentrations of 5-HT.

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