Multifunctional and Hybrid Microsystems
Room 321 - Session MC-MoA

Multifunctional and Hybrid Microsystems: Optomechanics and Quantum Transduction

Moderators: Dr. Matthew Jordan, Sandia National Laboratory, **Prof. Dr. Yanan Wang**, University of Nebraska-Lincoln

1:30pm **MC-MoA-1 All-Dielectric Cavity Electro-Optic Systems for Quantum Sensing and Transduction***, Mihir Khanna,* ***Thomas Purdy****,* University of Pittsburgh **INVITED**

Currently, the best methods to manipulate microwave signals at the quantum level require complex, millikelvin temperature, superconducting electronics.Many platforms are being explored to couple microwave and optical systems, leveraging the quantum coherence inherent in room-temperature optical fields to enable quantum-limited readout and control of microwave devices.We are investigating how it is be possible to turn an electro-optic modulator, a workhorse of modern classical telecommunications systems for encoding microwave signals on laser light, into a transducer capable of efficiently moving quantum information between the optical and microwave domains.We have recently demonstrated bulk resonant electro-optic devices with photon-number transduction efficiency approaching unity, surpassing classical telecom modulators by more than six orders of magnitude. We are currently exploring how laser light in this room-temperature system can be used to manipulate and measure microwave devices in analogy to laser cooling in atomic and optomechanical systems, and via electro-optic parametric amplification.

2:00pm **MC-MoA-3 A Quantum Microwave-Optical Interface via Silicon Nanomechanics***,* ***Han Zhao****,* University of Central Florida **INVITED**

Optically interconnected networks of heterogeneous quantum hardware are milestones of future quantum information infrastructure. Integrating superconducting qubits as the prominent quantum processors in such a network requires microwave-optical interfaces with high conversion rate and low input-referred added noise. Here, we meet these requirements in an integrated electro-optomechanical device that utilizes electrostatic coupling between high-impedance microwave resonators and crystalline silicon nanomechanical oscillators [1]. Leveraging the small acoustic loss and low optical absorption heating of silicon, we demonstrate continuous quantum-enabled microwave-to-optical conversion with an external efficiency of 2.20 ± 0.06%, bandwidth of 88.9 ± 2.1 kHz, and a sub-photon input-referred added noise at 0.94 ± 0.03 [2]. Our device provides a realistic path towards optically heralded high-rate entanglement of superconducting quantum processors over long distances.

[1] A. Bozkurt, H. Zhao, C. Joshi, H. LeDuc, P. Day, M. Mirhosseini. A quantum electromechanical interface for long-lived phonons. Nat. Phys. 19, 1326-1332 (2023)[2] H. Zhao, W. D. Chen, A. Kejriwal, M. Mirhosseini. Quantum-enabled microwave-to-optical transduction via silicon nanomechanics. Nat. Nanotech. 20, 602-608 (2025).

2:30pm **MC-MoA-5 High-Performance 4H-SiC Optomechanical Resonators in the Sideband-Resolved Regime***,* ***Xirui Gou****, Qing Li,* Carnegie Mellon University

4H-silicon carbide (4H-SiC) has emerged as an exceptional material for integrated optomechanics, combining outstanding nonlinear optical properties with low acoustic dissipation. This work presents recent advances in the design, fabrication, and characterization of ultracompact, undercut 4H-SiC microdisk resonators operating in the sideband-resolved regime. These microdisks, with radii ranging from 2.1 to 2.7 microns, are fabricated through a combination of electron-beam lithography and fluorine-based dry etching to define the photonic structures. This is followed by a precisely timed isotropic buffered oxide wet etch to selectively remove the underlying silicon dioxide layer and achieve the targeted undercut ratios.

Optically, these microdisk resonators support both TE and TM modes with measured loaded optical quality factors consistently exceeding one million in the telecom band. Mechanically, the dominant mode is the fundamental radial breathing mode (RBM) at frequencies ranging from 1.5 to 2 GHz. At room temperature, the acoustic frequency is approximately eight times the optical cavity linewidth (~0.2 GHz), placing our system deep into the sideband-resolved regime. This is a critical prerequisite for resolving mechanical sidebands, enabling coherent optomechanical interactions, and advancing toward ground-state cooling.

A key focus of our investigation has been understanding and mitigating mechanical anchor loss. Using finite-element method (FEM) simulations alongside experimental validation, we analyzed the impact of the pedestal undercut ratio on the mechanical quality factor. Our simulations revealed a distinct local resonance where the anchor-loss-limited Q-factor exhibits a sharp maximum at specific pedestal widths. By tracking the mechanical Q-factor across consecutive undercutting rounds, we experimentally confirmed an optimal undercut ratio regime between 55% and 65%. This regime offers a critical balance between minimizing anchor loss and maintaining high fabrication yield. Engineering this balance allowed us to demonstrate mechanical Q-factors exceeding 15,000 at 1.58 GHz in ambient conditions. Leveraging these high-Q resonators, we observed strong nonlinear dynamics, including phonon lasing and the generation of a coherent harmonic frequency comb extending up to 70 GHz with only 1 mW of dropped optical power. These results highlight the vast potential of 4H-SiC microdisks as an integrated platform for low-noise microwave photonics and quantum interfaces.

2:45pm **MC-MoA-6 Parametrically Coupled Nanomechanical and Macroscopic Mechanical Resonators***,* ***Chris Ligato****, Thomas Purdy, Youssef Tawfik,* University of Pittsburgh

We develop a novel hybrid mechanical system that leverages an acoustic intermediary for high-precision optomechanical sensing. The motion of a macroscopic silicon tuning fork resonator is measured and manipulated by coupling to a nanomechanical high-stress silicon nitride (SiN) string. We fabricate these devices from a high-stress, SiN-coated silicon wafer by using double-sided photolithography and reactive-ion etching to pattern the SiN, followed by through-wafer KOH wet etching to define the tuning fork and release the string. This process yields centimeter-scale, milligram-mass tuning forks with kHz-frequency modes, bridged by an MHz-frequency, nanogram-mass string stretched across the tines. Vibrations of the tuning fork stretch the string, modulating its mode frequencies. This interaction is similar to cavity optomechanics, where mechanical motion modulates the modes of an electromagnetic resonator. Following this analogy, we demonstrate cooling of the tuning fork, sensitive detection of its motion, and phonon swapping between the tuning fork and string. We drive the system with a piezoelectric shaker. When the drive is red-detuned from the string frequency by the tuning-fork frequency, phonons transfer from the tuning fork into the string and dissipate into the environment, cooling the tuning fork. By reading out the string using an optical interferometer, we can detect the motion of the tuning fork imprinted on the string with high sensitivity. Driving the string harder allows us to enter the strong-coupling regime, where the string and tuning-fork modes hybridize. We aim to explore this system's potential for high-precision accelerometry and measurements at quantum limits.

3:00pm **MC-MoA-7 Magnetic Nanostructures for Coupling and Control of Defect Spin Qubits***,* ***Jesse Berezovsky****,* Case Western Reserve University **INVITED**

Defect spin qubits, such as the nitrogen-vacancy (NV) defect in diamond, perform splendidly as single qubits. With a coherence time that can exceed 1 s at room temperature, defect spins provide an excellent basis for single qubit devices, such as nanoscale magnetometers. But to go beyond single qubits, we require an efficient scalable platform for controlling defect spin qubit registers, and controllably coupling qubits to engineer entanglement. In this talk, I will describe recent advances in our understanding of how magnetic materials and structures couple to defect spin qubits, and how this opens an avenue towards engineering the magnetic environment of the spins for control and coupling. Magnetic nanostructures such as nanoisland arrays and nanoscale magnetization textures such as magnetic vortices provide strong, local magnetic field gradients that can be controlled dynamically for addressable control of qubits [1]. Coupling between qubits may be enabled by a magnon-mediated process. On the other hand, spin-magnon interactions can lead to enhanced spin relaxation or decoherence (e.g. [2]). I will review recent work exploring the interactions of defect spins with magnons in adjacent magnetic structures and discuss the implications for proposed technologies incorporating coherent spins with proximal magnetic elements.We acknowledge support from NSF awards No. 2326528 and 2403743[1] Wolf, M. S., Badea, R., and Berezovsky, J. “Fast, Nanoscale Addressability of Nitrogen-Vacancy Spins via Coupling to a Dynamic Ferromagnetic Vortex” Nature Communications 7, (2016): 5.[2] Trimble, J., Gould, B., Heremans, F. J., Zhang, S. S.-L., Awschalom, D. D., amd Berezovsky, J. “Relaxation of a single defect spin by the low-frequency gyrotropic mode of a magnetic vortex” J. Appl. Phys. 130, (2021).

3:30pm **MC-MoA-9 Robust Topological Phonon Transport in Suspended Hexagonal Boron Nitride Waveguides***, **Sanchaya Pandit**,* University of Nebraska - Lincoln*; Jaesung Lee,* University of Central Florida*; Yanan (Laura) Wang,* University of Nebraska-Lincoln

Topological concepts, originally developed in electronic condensed-matter systems, have recently been extended to bosonic platforms such as photons and phonons, enabling new approaches for robust wave transport in engineered media. These concepts have opened pathways toward designing waveguides that suppress backscattering and maintain stable propagation even in the presence of structural disorder, which is essential for scalable integrated phononic circuits. In this work, we demonstrate a quasi-one-dimensional Su-Schrieffer-Heeger (SSH) topological phononic waveguide based on suspended hexagonal boron nitride (h-BN), a mechanically robust two-dimensional material suitable for high-frequency phonon propagation. By engineering the unit-cell geometry, we construct two distinct phononic lattices representing trivial and nontrivial topological phases with matched band structures. At the interface between these two phases, a confined phononic state emerges within the bandgap, analogous to topologically protected edge states in electronic systems. Furthermore, geometric optimization of the unit cells—including variations in hole shape (circular and oval) and feature size (diameter)—is used to tune the phononic bandgap and control the spectral position of the interfacial mode. The robustness of this mode is systematically evaluated under variations in strain and membrane thickness, and it remains stable, confirming its topological origin rather than defect-induced localization. Overall, the proposed h-BN-based platform provides a promising route toward robust and low-loss phononic transport and may enable future hybrid optomechanical systems through integration with defect-based quantum emitters.

Multifunctional and Hybrid Microsystems
Room 318 - Session MC-TuM

Multifunctional and Hybrid Microsystems: MEMS and Bio Applications

Moderators: Prof. Dr. Jesse Berezovsky, Case Western Reserve University, **Prof. Dr. Jaesung Lee**, University of Central Florida

8:00am **MC-TuM-1 Ultralow-Dissipation Diamagnetically Levitated Graphite Rotors for Gyroscopic Inertial Sensing**, ***Samira Yasmin**, Pooja Roy,* University of Central Florida*; Yunong Wang, Philip Feng,* University of Florida*; Jaesung Lee,* University of Central Florida

Rotational degrees of freedom are nearly unconstrained, making levitated rotors compelling candidates for next-generation inertial sensors. By eliminating mechanical anchors entirely, this approach suppresses the dominant loss pathways—support loss and friction—that limit the performance of conventional gyroscopes. Here we report on a diamagnetically levitated pyrolytic graphite rotor platform operating under high vacuum, characterized through ringdown measurements, and analyzed toward practical gyroscopic readout.

The rotor is laser-machined from highly oriented pyrolytic graphite, which exhibits strong negative magnetic susceptibilities ($\chi_x = \chi_y = -85\times10^{-6}$, $\chi_z = -450\times10^{-6}$) enabling passive, stable levitation above a concentric permanent-magnet assembly integrated beneath a custom PCB. The annular rotor geometry (inner radius 2.175 mm, outer radius 4.175 mm, mass ~95 mg) concentrates rotational inertia at large radius.

Rotational actuation and sensing are implemented via a closed-loop system combining a 633 nm laser interferometer, FPGA-based digital timing, and a high-voltage (200 V) electrostatic pulse drive. The optical contrast between the graphite rotor arms and the PCB surface generates a periodic photodetector signal, from which the FPGA extracts instantaneous rotation speed and generates phase-synchronized drive pulses. Under vacuum conditions of 80−100 µTorr, where gas damping is substantially reduced, the rotor is driven to 410 RPM, after which free ringdown is recorded. The rotational speed decay follows $\Omega(t) = \Omega_0 e^{-\gamma t}$, yielding an extracted damping constant of $\gamma = 1.9\times10^{-4}$/s.

The measured γ and I_Z directly set the thermomechanical noise floor, expressed as an angular random walk (ARW). At 410 RPM and room temperature, the thermal-noise-limited ARW is estimated at 2.28×10^{-4} °/√h, with a projected improvement to 9.1×10^{-5} °/√h at 1100 RPM. To connect this platform to practical gyroscopic operation, we derive an analytical scale factor linking optically measured out-of-plane rim displacement to input angular rate through the coupled tilt dynamics of the spinning rotor. Under the nearly symmetric rotor approximation in the weak-damping limit, the estimated scale factor is $S = 3.02\times10^{-5}$ m/(rad/s), implying that a 1 nm displacement resolution at the rotor rim translates to an angular-rate resolution of ~40 µrad/s upon full gyroscope readout implementation.

These results establish a quantitative performance framework for diamagnetically levitated graphite rotors, highlighting vacuum environment, spin-axis inertia, and tilt stiffness as the primary design levers for advancing sensitivity in compact, anchor-free rotational inertial sensors.

8:15am **MC-TuM-2 Influence of Fluid Dynamics on a Halide-Suppressor Electrolyte for Copper Electrodeposition in High Aspect Ratio Through Silicon Vias**, ***Jessica McDow**, Matthew Jordan,* Sandia National Laboratories

Through silicon vias (TSVs) are essential for three-dimensional microelectronic integration, enabling enhanced electrical and thermal connectivity. Copper electrochemical deposition (ECD) with halide-suppressor chemistries has achieved void-free, bottom-up filling of high aspect ratio TSVs[1]. However, the interplay between hydrodynamics, ion transport, and suppressor adsorption kinetics within these recessed features remains incompletely understood.

This work combines experimental electrochemical depositions and computational fluid dynamics (CFD) modeling to understand the critical role of fluid flow in governing copper deposition profiles within TSVs of a 70 µm diameter and 625 µm depth. Cyclic voltammetry (CV) on rotating disk electrodes reveals that increased rotation rates enhance suppressor replenishment, shifting the re-inhibition potential and diminishing hysteresis associated with the s-shaped negative differential resistance (S-NDR) behavior. Electrochemical deposition experiments demonstrate that rotation rate modulates deposition uniformity: low rotation rates lead to void formation due to insufficient suppressor transport, while excessively high rotation rates cause premature plating termination near the via opening due to enhanced suppressor adsorption.

CFD simulations confirm that convective flow penetrates only the upper ~100 µm of the via, establishing a hydrodynamic boundary layer where suppressor concentration approaches bulk levels, sustaining suppression and limiting deposition at the via mouth. Below this region, transport is diffusion-dominated, enabling concentration gradients that promote bottom-up filling. By strategically modulating rotation rates—starting at 400 rpm, increasing to 1000 rpm, then returning to 400 rpm—void-free filling is achieved with a 33% reduction in plating time from 18 to 12 hours.

These findings highlight the complex balance between convective and diffusive transport in controlling suppressor dynamics and copper deposition within TSVs. Understanding and harnessing fluid dynamic effects are crucial for optimizing scalable, high-throughput TSV filling processes in advanced 3D integration technologies.

[1] Schmitt, R. P.; Menk, L. A.; Baca, E.; Bower, J. E.; Romero, J. A.; Jordan, M. B.; Jackson, N.; Hollowell, A. E. Void-Free Copper Electrodeposition in High Aspect Ratio, Full Wafer Thickness Through-Silicon Vias with Endpoint Detection. *J. Electrochem. Soc.* **2021**, *167* (16), 162517. https://doi.org/10.1149/1945-7111/abd56e.

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8:30am **MC-TuM-3 Redefining Dynamic Limits of MEMS Resonators via Nonlinear Dynamics**, ***Hanna Cho**,* The Ohio State University **INVITED**

As resonant MEMS approach fundamental material and performance limits, new design paradigms are required to enable the next generation of sensing and timing technologies. Nonlinear dynamics are increasingly recognized as a pathway to overcome the constraints of conventional linear operation. Among these, internal resonance (InRes), in which two or more vibrational modes are nonlinearly coupled through integer frequency ratios, provides opportunities for dynamic range extension, frequency stabilization, and controlled intermodal energy transfer. Unlike traditional MEMS devices operating within narrow linear regimes, InRes enables energy exchange between coupled modes, allowing stable resonance to be maintained under large excitation levels and environmental perturbations. In this talk, I will present recent advances in understanding and engineering InRes in MEMS resonators through combined theoretical modeling and experimental validation. In particular, I will demonstrate how InRes can passively suppress frequency drift by anchoring the primary mode response to an InRes condition, effectively mitigating amplitude-to-frequency conversion induced by nonlinear effects. These insights have direct implications for the development of timing references with long-term frequency stability, as well as for the design of high-performance inertial sensors with larger scale factors. The results illustrate the emerging potential of nonlinear resonance as a transformative design paradigm for next-generation MEMS technologies.

9:00am **MC-TuM-5 Multifunctional AlN-Based MEMS Resonator Platforms for Advanced RF Filtering and Sensing Applications**, ***Mingyo Park**,* Pennsylvania State University **INVITED**

Next-generation wireless systems (5G and emerging 6G) are driving demand for RF nano/micro-electromechanical (N/MEMS) acoustic resonators that operate across the 3–30 GHz band. Future RF front-ends require compact, high-performance devices that deliver low insertion loss, wide bandwidth, multi-band compatibility, and robust high-power operation — requirements captured by the resonator figure of merit, FoM = $Q \times kt^2$. Pushing acoustic resonators toward higher frequencies, however, demands aggressive reduction of piezoelectric film and electrode thicknesses, introducing compounding mechanical and electrical losses that ultimately limit performance.

This talk will discuss recent progress in thin-film piezoelectric MEMS resonators built on ultra-thin epitaxial AlN and AlScN. AlScN has emerged as a particularly attractive piezoelectric due to its enhanced electromechanical coupling relative to conventional AlN. By pairing high-quality epitaxial films with optimized resonator geometries, film bulk acoustic resonators (FBARs) operating near 19 GHz [1] have demonstrated strong potential for compact filtering solutions in next-generation RF front-ends, while surfacing the central challenges of mm-wave acoustic design: electrode loss and material quality at extreme thinness.

Beyond passive filtering, piezoelectric MEMS resonators can also be engineered to support nonlinear electromechanical functionality through mechanical frequency comb generation [2]. When driven beyond a critical threshold, single or coupled resonators exhibit strong nonlinear modal interactions that produce equally spaced spectral lines in the mechanical domain. These phononic frequency combs can evolve from a few discrete sidebands into broad, tunable spectral clusters as device geometry, modal coupling, and drive conditions are varied. The resulting nonlinear dynamics offer a route to on-chip multi-frequency signal generation without the complexity of external circuitry.

Taken together, high-frequency acoustic filtering and nonlinear comb generation point toward a broader class of reconfigurable RF microsystems built on the AlN/AlScN piezoelectric material family. Such devices could enable compact filters, low-power frequency sources, spectral processors, and multi-frequency sensing architectures for future wireless and sensing networks. The talk will close by reflecting on how materials engineering, resonator design, and nonlinear dynamics can be combined to expand the functionality of piezoelectric MEMS well beyond conventional RF filtering.

[1] M. Park, et al., EDL.,2024 [2] M. Park, et al., JMEMS.,2019.

9:30am **MC-TuM-7 Electrochemical Sensing of Hormonal Serotonin Levels in Crayfish***, **Sydney Overton**, Kanishka Balamurugan, Jens Herberholz, Reza Ghodssi,* University of Maryland College Park

The neurotransmitter serotonin (5-hydroxytryptamine, 5-HT) has been implicated as a key biomarker that regulates a range of neurobehavioral functions, including playing a prominent role in modulating social behavior across species. Here, we refined a surface-modification method to enable detection of endogenous (i.e., naturally occurring), nanomolar concentrations of 5-HTfrom crayfish hemolymph (i.e., blood) collected from communally housed (COMs) animals and those isolated for one (1-day ISOs) or seven days (7-day ISOs). The three-electrode sensor for measuring 5-HT is comprised of a carbon-fiber microelectrode (CFME) working electrode, Pt counter electrode, and Ag/AgCl reference electrode. Previous *in vivo* measurements utilized a CFME electrochemically etched (EC) then dip-coated into a carbon nanotube (CNT)-Nafion dispersion (EC/CNT-Nafion). However, to match the electrochemical sensor's detection sensitivity, crayfish were injected with 5-HT. Here, we optimized the surface modification to improve signal-to-noise and sensitivity for *in vitro* 5-HT detection by dip-coating then electrochemically etching (CNT-Nafion/EC). Doing so improved the signal-to-noise ratio 2.8x and maintained the limit of detection from previous fabrication (60nM), enabling successful measurements of endogenous 5-HT *in vitro.*

To investigate how social isolation affects serotonergic mechanisms, we measured hormonal 5-HT in hemolymph from isolated and communally housed crayfish utilizing our CNT-Nafion/EC CFME.Voltammetry results show a clear oxidation peak at 0.29 V, demonstrating detection of un-spiked, hormonal 5-HT. Our findings indicate that 5-HT levels change in response to social isolation, and these changes are species-dependent. 7-day ISOs *Procambarus* (*P. clarkii)* crayfish exhibited a major increase in 5-HT compared to COMs, whereas *Faxonius* (*F. Spp*) crayfish hormonal concentrations of 5-HT peaked in 1-day ISOs. 7-day ISOs *P. clarkii* crayfish contained an average of 581.2nM 5-HT in their hemolymph, a 307.6% increase from COMs, and1-day ISOs did not have significantly higher concentrations compared to COMs. By comparison, *F. spp* 5-HT concentrations in 1-day ISOs were 867.5nM, a 540.1% increase in hormonal 5-HT concentrations compared to COMs, and 7-day ISOs 5-HT concentrations matched COMs.

The *in vitro* results demonstrate the sensor's utility for studying 5-HT dynamics and exhibit results strongly suggesting an underlying effect of social isolation on hormonal 5-HT. Moreover, our findings provide an exciting avenue for future studies, including those providing higher temporal fidelity on 5-HT changes that modulate neural activities and corresponding behaviors.

9:45am **MC-TuM-8 Development of Dissolvable Cantilevers for Localized Oral Drug Delivery***, **Yung Priscilla Lai**, Joshua Levy, Reza Ghodssi,* University of Maryland

Therapeutics to treat inflammatory bowel disease can cause severe systemic side effects. Localized drug delivery in the gastrointestinal (GI) tract can lower these side effects and increase drug efficacy. Our team has developed an ingestible device that can deliver drugs on-demand in the intestines with multiple cantilever actuators (Fig. S1a). The strained cantilever beams act as springs that can drive the penetration of drug-loaded microneedles into inflamed areas. The current polymer cantilevers made of polyether ether ketone (PEEK) films remain rigid but are not dissolvable, leading to risks of retention and unforeseen consequences as they remain in the body after drug delivery. Dissolvable and biocompatible cantilevers provide a safer alternative for targeted drug delivery in the GI tract.

The difficulty in using dissolvable polymer films as cantilevers arises from their low mechanical strength and stress relaxation under strain, undermining their ability to deploy drugs into the GI mucosa. We can improve these properties by changing the film's degree of crosslinking while maintaining film dissolution. Several crosslinked films were investigated: 1) polyvinyl alcohol (PVA), 2) PVA with citric acid (PVA-Citric) baked at 120°C for 4 hours, 3) freeze-thaw crosslinked PVA with 1M NaCl (PVA-NaCl), and 4) PEEK as a control. Polymer films were cut to size with a CO_2 laser cutter as the cantilever's length dictates its delivery range, ensuring the drug can reach inflamed areas further above the device surface (Fig. S2a). The films were then characterized for their blocking force (Fig. S1b and Fig. S2a), dissolution (Fig. S1c), and stress relaxation (Fig. S1d).

We measured the blocking force at the cantilever tip to evaluate whether polymer films could deliver drug-loaded microneedles without tissue damage. Crosslinking parameters that can provide higher blocking force at large cantilever displacements were identified. (Fig. S2a, PVA-NaCl and PVA-Citric vs. PEEK). Moreover, higher citric acid content appeared to increase film swelling for cantilever dissolution (Fig. S2b, PVA-Citric 80:20). Further materials optimization will enable lower PVA stress relaxation (Fig. S1d and Fig. S2c) while maintaining high blocking force and film dissolution.

Multifunctional and Hybrid Microsystems
Room Ballroom A - Session MC-ThP

Multifunctional and Hybrid Microsystems Poster Session

MC-ThP-1 Integrated Magnetic Bio-MEMS for High-Speed, Trajectory-Based Microparticle Classification in Laminate Microfluidic Channels*, Muhammad Tahir,* ***Umer Hassan,*** Rutgers, The State University of New Jersey

Microfluidic diagnostics increasingly depend on microsystems that combine sample handling, physical actuation, optical readout, and data analysis within one workflow. We present a magnetically actuated bio-MEMS platform that uses particle motion, rather than fluorescence or impedance, as the primary signal for distinguishing magnetically responsive microparticles in flow. The approach integrates a laminate polymer microchannel, an external permanent magnet, high-speed brightfield imaging, and automated video analysis, making it relevant to multifunctional microsystems where sensing, actuation, and signal processing are co-designed.

The device was constructed from three laser-cut polymer layers to form a transparent channel with a 35 mm length, 150 µm width, and 87 µm height. Nonmagnetic polystyrene beads and magnetic beads, both approximately 5–5.9 µm in diameter, were used as model negative and positive particle populations. Samples were introduced at 5 µL/min, producing an estimated particle velocity of 6.4 mm/s. Motion was recorded at 3,030 frames/s with 324 µs exposure over a field of view of approximately 600 µm × 162 µm. A computer-vision pipeline converted the image sequence into particle centroids, reconstructed paths, and extracted trajectory slope as a compact metric of magnetically induced lateral displacement. COMSOL Multiphysics modeling guided the microsystem geometry before testing. Simulations examined magnet-channel spacing from 0–10 mm, magnet width from 3.175–9 mm, and channel widths from 250–750 µm. The model showed that smaller magnet-channel separation, larger magnet width, and narrower channels improved deflection within the imaging window; for example, mean simulated slope decreased from 0.151 to 0.005 when the magnet was moved from the channel edge to 10 mm away.

Later, experimental data confirmed that trajectory-derived signatures can separate the two particle groups. Using a slope threshold of 0.03, 240 of 393 magnetic particles were classified as deflected, compared with 53 of 347 control particles. This corresponded to 61% deflection for the magnetic population and 15.2% apparent deflection for controls. Mean trajectory slope shifted from -0.01 ± 0.059 for control beads to 0.039 ± 0.062 for magnetic beads, demonstrating measurable motion contrast between populations. This work demonstrates an integrated fluidic-actuation-imaging-analysis platform for magnetic microparticle classification. With improved tracking and antibody-labeled cell validation, the system could support compact bio-MEMS workflows for cell phenotyping, surface-marker-linked magnetic response, and low-cost diagnostic microsystems.

MC-ThP-2 Internal Friction, Creep, and Mechanical Behavior of Zr-Based Metallic Glass Thin Films for MEMS/NEMS Applications*, KAI-AN YANG, Yan-Wei Chang,* National Chung Hsing University, Taiwan*; Hsiang-Yu Hsieh, Chen-Jia Wang,* National Chung Hsing University, Taiwan*; Tra Anh Khoa Nguyen,* ***Ming-Tzer Lin,*** National Chung Hsing University, Taiwan

Zr-based metallic glass alloys exhibit high hardness, wear and corrosion resistance, ductility, high strain toughness, and low Young's modulus, making them attractive candidates for MEMS and NEMS devices. Yet, research on the internal friction characteristics, creep behavior, and fracture mechanisms of metallic glass thin films remains limited, and the fundamental processes of internal friction and shear band slip within their amorphous structure are not fully understood. In this study, Zr-Cu-Ti metallic glass thin films are employed to investigate anelastic mechanical behavior, creep resistance, and fracture response across a broad temperature range from room temperature to elevated conditions. Internal friction measurements and bulge tests are conducted to quantify energy dissipation, structural relaxation, and crack propagation resistance. In addition, Zr-Cu-Ti metallic glass thin films are also examined before and after annealing to investigate the effects of phase transformation from amorphous to crystalline states. Preliminary results indicate that annealing-induced crystallization alters internal friction and mechanical performance, establishing correlations between atomic-scale structural evolution and macroscopic reliability. These findings provide new insights into the reliability of metallic glass thin films, enabling their integration into MEMS/NEMS devices where durability, adaptability, and long-term stability are critical. This work directly supports the MEMS and NEMS area of interest by advancing knowledge of thin-film mechanical behavior under structural transformation.

MC-ThP-3 Influence of the Structural Regions of a Si_3N_4 Membrane Window on the CMOS Image Sensor Signal*,* ***Kamil Baranowski****, Michał Krysztof, Michał Zychla,* Wroclaw University of Science and Technology, Poland*; Rupert Schreiner, Matthias Hausladen,* Ostbayerische Technische Hochschule (OTH) Regensburg, Germany*; Mathias Bartl,* Ostbayerische Technische Hochschule (OTH) Regensbur, Germany*; Alexandr Knápek,* Institute of Scientific Instruments of the Czech Academy of Sciences, Czechia

1. Introduction

A CMOS sensor coated with a copper layer can be used to detect an electron beam [1]. Incoming electrons are decelerated within the layer, generating Bremsstrahlung X-rays, which the sensor records and converts into a beam's image. The target application is the detection of an electron beam in a gaseous environment [2]. A silicon nitride (Si_3N_4) membrane separates the vacuum environment of the electron-optical column from the gaseous environment of the sensor, maintaining the pressure difference while allowing electron transmission. Here we examine how the membrane and supporting silicon chip influences the CMOS signal, aiming to isolate its contribution from effects caused by other factors, such as gas composition.

2. Experiment

To assess this, the CMOS signal intensity was mapped along a line scanning the membrane (Fig. 1). The CMOS matrix was mounted inside a JEOL JSM-100 SEM, which served as both the electron source and the vacuum chamber. The sample stage was moved along a predefined scanning path, directing the 10 keV electron beam at successive regions of the membrane window. Three regions are distinguished
(Fig. 1): A - full silicon substrate, ~350 µm thick; B - sloped pyramid wall formed during KOH etching; C - Si_3N_4 membrane, 100 nm thick. Signal intensities are reported relative to region C, taken as 100%. The recorded signal reflects the combined effect of electron scattering, energy loss, and Bremsstrahlung yield in the copper layer, rather than a simple beam transmission ratio.

3. Conclusion

The experiment quantified how the Si_3N_4 membrane and surrounding substrate geometry contribute to the CMOS signal. In region A no signal above the noise floor was detected (0%), confirming that the 350 µm silicon substrate fully absorbs the beam and X-rays that can be generated in it. In region B the signal increases as the silicon thickness decreases, indicating that the KOH-etched pyramid walls also contribute to the detected signal. In region C the signal reaches its maximum (100%). These results show that the etched window geometry significantly influences the signal and must be accounted for when separating membrane-related contributions from gas-related effects in future measurements at elevated pressure.

ACKNOWLEDGMENT

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[2] K. Baranowski et al., Proc. IVNC 2025, doi:10.1109/IVNC65669.2025.11120851

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