MEMS and NEMS
Room 205 ABCD W - Session MN1-ThA
RF and Magnetic MEMS

Moderators: Robert Davis, Brigham Young University, **Sushma Kotru**, University of Alabama

2:15pm **MN1-ThA-1 Control of Magnetoelastic Properties for Magnetoelectric Magnetic Field Sensors***, **Margo Staruch**,* US Naval Research Laboratory **INVITED**

The increasing demand for low SWaP-c magnetic field sensors has led to heightened interest in magnetoelectric MEMS and NEMS resonators. The direct coupling of the piezoelectric and magnetic phases allows for highly sensitive readoff of AC magnetic fields via an induced voltage. Dynamic sensing modalities, achieved by driving the piezoelectric phase at a resonance, have also been demonstrated to significantly decrease the noise floor and improve sensitivity. Much of the recent focus has been on maximizing the sensitivity of the resonant frequency to a field either through magnetoelastic effects or the ΔE effect. At NRL, efforts have been focused on fabricating clamped-clamped beam resonators with heterostructured AlN and magnetostrictive layers that operate at the fundamental bending mode. In this presentation, methods to improve the figures of merit including the piezomagnetic coefficient and the change in frequency with magnetic field (df/dH) through selection and control of the deposition of the magnetic phase will be explored. The impacts of boundary conditions and film stresses on the resonance behavior and the selection of the resonance modes will be established. Considerations of the development of shape anisotropy due to the high aspect ratio of the beams and resultant angular dependence of the sensitivity will emphasize the use of these resonating beams as vector magnetometers. Lastly, recent results on the limit of detection and noise floor of the sensors will be presented. Based on these results, design parameters for future packaged MEMS field sensors will be discussed.

2:45pm **MN1-ThA-3 Low-Loss Wideband Nonreciprocal Magnetoacoustic RF Isolators Enabled by Non-Collinear Dipolar-Coupled Ferromagnetic Stack***, **Bin Luo,*** Department of Electrical and Computer Engineering, Northeastern University*; Andreas Winkler, Hagen Schmidt,* SAWLab Saxony, Leibniz IFW Dresden, Germany*; Vipul Sharma, Mingzhong Wu,* Department of Physics, Northeastern University*; Benyamin Davaji, Nian-Xiang Sun,* Department of Electrical and Computer Engineering, Northeastern University

Nonreciprocal RF isolators and circulators have enabled full duplex radio systems and protection of power amplifiers from back-reflections in high power microwave transmitters, greatly boosting the spectral efficiency and coordination in mesh or relay networks for modern wireless communication systems like 5G, IoT, and future 6G [2]. However, conventional RF isolators and circulators are bulky, expensive with high power consumption owing to CMOS-incompatible ferrites with high growth temperature in oxidizing environment and the need of permanent magnet/electromagnets for operation via Faraday rotation [2]. Recently, non-reciprocal magnetoacoustic RF devices exhibit substantial nonreciprocity with remarkable power efficiency and CMOS compatibility [1] [3-7]. They consist of a magnetic stack within the SAW path between two interdigital transducers (IDTs) on a piezoelectric substrate. By applying RF voltage on IDTs, the induced SAW propagates and interacts with spin waves in a magnetic stack. The magnon-phonon interactions lead to hybrid magnetoacoustic waves that exhibit a much higher backward loss rate than the forward one or vice versa [2]. Despite progress using various magnetic heterostructures, such as FeGaB/Al_2O_3/FeGaB [3, 4] and synthetic antiferromagnetic CoFeB/Ru/CoFeB stacks [6, 7], prior demonstrations often suffer from high insertion loss (>40 dB) due to the inefficiency of higher-order SAW harmonics. Additionally, devices with giant nonreciprocity often exhibit narrow bandwidths, and vice versa. Here we demonstrate a low-loss wideband non-reciprocal magnetoacoustic RF isolator based on a non-collinear dipolar-coupled ferromagnetic FeGaB/SiO_2/FeGaB stack driven by SAW fundamental mode at 2.87 GHz on 128° Y-X cut $LiNbO_3$ substrate (**Figure 1**). By intentionally misaligning uniaxial anisotropies in the two ferromagnetic layers (10° and 70° to k_{SAW}) using in-situ angled magnetic field depositions, multiple wideband non-reciprocity has been first realized from 2.48 to 3.15 GHz with reduced insertion loss (**Figure 2**). The maximum nonreciprocity reaches ~40 dB (200 dB/mm) near modulated SAW peaks, where standing waves enhance acoustic resonance. The device demonstrates a low insertion loss of ~13 dB off-resonance and ~25 dB on-resonance at 2.87 GHz, with ~10 dB nonreciprocity (33.3 dB/mm) (**Figure 3**). The ultra-compact, low-loss, wide-band non-reciprocal, integrated magnetoacoustic isolator shows great potential for low power compact full-duplex radio/radar commmunication systems [2], efficient and coherent excitation of ground state NV^- centers [8] and nonreciprocal quantum information transfer in future magnon–phonon transducers [9].

3:00pm **MN1-ThA-4 High-Q Diamagnetically Levitated Mechanical Resonators for Magnetic Field Sensing***, **Pooja Roy**, Samira Yasmin,* University of Central Florida*; Yunong Wang, Philip Feng,* University of Florida*; Jaesung Lee,* University of Central Florida

Diamagnetically levitated and trapped systems hold great promise in the development of high-performance, anchor-less resonant devices with excellent stability. This scheme generates sufficient levitation force via diamagnetism, enabling three-dimensional (3D) trapping at room temperature without external power input (Supplementary Fig. 1).

In this work, we combine theoretical analysis with experimental investigation to explore the complete levitation behavior and rigid body resonances of diamagnetically levitated graphite/dielectric composite plates, ranging in size from millimeters to centimeters and in mass up to 680mg. These systems exhibit stable, clamping-free levitation with low energy dissipation and high quality (*Q*) factors, making them promising candidates for high-precision sensing applications.

The fabricated composite plates, in which graphite particles are embedded in a dielectric material (nonconducting epoxy), are diamagnetically levitated over permanent magnets (Supplementary Fig. 2). Their resonant performance is measured by using a laser interferometry system (Supplementary Fig. 3), where resonance motions of the plates are excited by simultaneously applying both AC and DC signals to the permanent magnets. A representative device with a mass of 34mg (Device 1) exhibits multiple resonant modes, including a primary resonance at *f*=19.7Hz with *Q*=7 in air. Operating the devices in vacuum, significantly improves the *Q* factor to *Q*=1400 at 10mTorr and *Q*=33,000 at 0.6mTorr (Supplementary Fig. 4). A larger 680mg device (Device 2) shows a resonance at *f*=20.35Hz with *Q*=17,000 at 24μTorr.

To evaluate frequency stability and resonant sensing performance, we implement Device 2 into a phase-locked loop (PLL), achieving an Allan deviation of σ_A=~$2.5*10^{-8}$ at averaging time of *t*=10ms (Supplementary Fig. 5). Upon applying a ~2mT magnetic field, we find clear resonance frequency shift; the device shows magnetic field sensing responsivity of 0.45Hz/T, with a sensitivity of 0.15mT/$Hz^{1/2}$.

This extensive experimental characterization manifests high-*Q* resonant levitated microsystems with significant mass and enhanced sensitivity, laying the foundation for advanced levitation technologies and the development of next-generation resonant sensors.

Author Index

Bold page numbers indicate presenter