MEMS and NEMS
Room 125 - Session MN1-TuM
RF and Magnetic MEMS

Moderators: Robert Davis, Brigham Young University, **Vikrant Gokhale**, Naval Research Laboratory

8:30am **MN1-TuM-3 Acoustoelectric Devices on Thin-Film Piezoelectric on Substrate Platform: Harnessing the Potential of Phonon-Electron Coupling***, **Reza Abdolvand,*** University of Central Florida **INVITED**

MEMS devices based on the thin-film piezoelectric on substrate (TPoS) platform, such as resonators, have demonstrated exceptional characteristics including low loss, high power handling, and low noise, enabling the creation of high-performance filters, clocks, and sensors. The TPoS platform also facilitates strong energy coupling between acoustic phonons and electrons, which can be harnessed for key radio frequency (RF) components in the micro-acoustic domain. This talk will review the advancements in utilizing the TPoS platform to achieve amplification, non-reciprocal transmission, and phonon mixing in a compact and energy-efficient manner. These innovations can simplify and miniaturize RF frontend modules, transitioning from passive RF filters to active amplifiers, isolators, and mixers, potentially reducing or eliminating the need for their electronic and magnetic counterparts. Despite the phonon-electron coupling, known as the “acoustoelectric effect,” being understood for over sixty years, only recent advancements in thin-film processing technology have enabled the development of scalable and manufacturable platforms with strong phonon-electron coupling. Heterostructures like thin-film lithium niobate on silicon, tailored to support specific acoustic waves with high electromechanical coupling and optimized electronic properties, offer a promising platform for scalable fabrication of miniaturized and energy-efficient “acoustoelectric” devices.

9:00am **MN1-TuM-5 Enhanced Performance of Thin-Film Lithium Niobate RF Acoustic Devices through Novel Material Process***, T. Busani, **Arjun Aryal,*** University of New Mexico*; S. Tiwari, D. Branch, A. Siddiqui,* Sandia National Laboratories, USA

Advancements in RF acoustic devices for telecommunications are significantly enhanced by the novel application of thin-film lithium niobate (LiNbO3), favored for its high electromechanical coupling. A persistent challenge in utilizing this material has been its compatibility with Si process manufacturing which results in poor quality device manufacturing. Moreover, the various spurious resonances present in those devices degrades the resonator efficient in storing energy, thus degrading quality factor *Q* and the electromechanical coupling coefficient k_t^2. This can be overcome typically by device design or by material processing, such as controlling the side walls roughness and their verticality. In this work we demonstrate how, comparing different edge treatments, i.e. different etching processes, we can both suppress spurious modes and increase the coupling coefficient at the main mode.

Unlike conventional methods, our innovative approach involves adjusting the surface roughness of the resonator's edges. In this study, resonators with specifically engineered roughened edges exhibited significant reduction and elimination of spurious resonances below 500 MHz frequency. This effect is more pronounced for a surface roughness of approximately 110 nm. Further explorations in this work demonstrate that varying the degree of roughness allows for controlled suppression behavior not only in the lower frequency range, but also potentially across broader frequency spectra. This method opens new opportunities for optimizing the performance of lithium niobate RF devices. Future investigations will focus on quantifying the effects of both higher and lower roughness levels to develop a comprehensive understanding of their impact on device performance across all operating frequencies.

Figure 1. (b) compares the resonant behavior between two resonators of same architecture with two different edged roughness. Several spurious modes, respectively at 50 MHz, 150 MHz, and 365 MHz are completely removed by the edge treatment process, while the peaks at 175 MHz and 250 MHz are greatly suppressed. The observed phenomenon is attributed to the ability of the roughened edges to scatter short-wavelength spurious modes, preventing the establishment of strong resonances.

9:15am **MN1-TuM-6 Garnet Based Integrated GHz Thin Film Inductors With High Quality Factor and High Inductance Density***, **Rafael Puig**, D. Hedlund, P. Kulik,* University of Central Florida

Demand for lighter and smaller devices is increasing, and thus the interest in thin film inductors (TFI) is rising. Inductors are key components in electronics and are used for e.g. power delivery and filters. Especially TFIs that can be heterogeneously integrated with e.g. existing silicon processing steps for integrated circuits. Furthermore, the inductor should be easy to fabricate. TFI need magnetic layer(s) and to magnetically bias the devices to be effective.

The magnetic material in a TFI should have a large permeability (μ) in the operating frequency (f_0). This can be achieved through the relationship $\mu \approx 4\pi M_s/H_a$, where M_s is the saturation magnetization and H_a is the magnetic anisotropy field. Kittel’s formula [1] of ferromagnetic resonance (FMR)

$$f_{FMR}=\gamma(4\pi M_s H_a)^{1/2}$$

where γ is the gyromagnetic gives rise to Snoek’s limit [2], where to achieve high μ, M_s/H_a should be large, whereas to achieve high FMR frequency $M_s H_a$ should be large. Frequencies near and above f_{FMR} yields that μ is mainly imaginary, i.e. a high magnetic loss tangent tan(δ), in this regime the inductor starts working resistively. In addition, the material should have low FMR linewidths, as this is related to dissipation processes, such as eddy currents in the material, which are mostly reduced with electrical insulation. This can be mitigated by using magnetic materials that are electrically insulated, such as ferrites in inductors.

The first published magnetic TFI dates back more than 50 years [3] and demonstrated a quality factor (Q) of 18 at an $f_0$of 10 MHz. Major advancements in thin-film inductors were made 10 years later when Soohoo [4] presented a thorough analysis on the requirements of the magnetic material and how high-performing TFI could be produced. It is rare to find thin film inductors operating in the GHz range with high Q, even though major advancements has been made in recent years [5–11].

In this work, we used Ansys Maxwell to model and design a $Y_3Fe_5O_{12}$ (YIG)-integrated TFI that has a f_0 in the GHz range, Q of 8, and an inductance density of 4300 nH/mm^2 when approaching magnetic saturation. We applied the magnetic field both in-plane and out-of-plane. The thin film stack used composed of 500 μm thick gadolinium gallium garnet substrate coated with a 10 μm thick YIG layer with M_s of 140 kA/m (1750 G), to which we placed a spiral inductor composed of 1 μm thick Cu wires with 270 μm spacing. This design was a compromise for rapid prototyping. We used YIG because it shows highμ [12] in the GHz range, with very few losses associated with dissipative processes. Future work will involve fabricating several designs to improve performance and incorporating with MEMS.

9:30am **MN1-TuM-7 Fabrication of Strip Line Micro Inductors Using Nickel-Iron Oxide Nanocomposite for Power-Supply on Chip Applications***, **Sai Pranesh Amirisetti**, D. P. Arnold,* University of Florida, Gainesville

The demand for miniaturized, more power efficient electronics has spurred the need for power supply solutions using novel magnetic materials that offer high permeability, operate at high frequencies, and minimize losses [1]. This study introduces a microfabrication technique for strip line inductors using nickel-iron oxide nanocomposite cores with an area of 0.07 mm^2, offering a significant advancement over traditional air-core or other magnetic-core microinductors.

Electro-infiltration, a process where a magnetic composite is formed by electroplating a metal through a deposited nanoparticle layer, yields a nickel-iron oxide nanocomposite with high relative permeability (~20) up to 300 MHz and low loss tangent [2,3]. The fabrication process, as shown in figure 1, involves deposition of the magnetic nanocomposite over patterned molds on a silicon substrate, followed by planarization, insulation layer deposition, seed layer deposition for copper electroplating, and finally a second deposition of the magnetic nanocomposite layer.

While there are relatively large device-to-device variations in this early-stage fabrication process, the experimental findings demonstrate that these nickel-iron oxide nanocomposite microinductors exhibit inductance between 0.5-1 nH and with a max quality factor between 4-6 at 100 MHz Furthermore, the compatibility of the fabrication process with semiconductor manufacturing techniques enables seamless integration for power system on chip (PwrSoC) applications.

This research contributes to the advancement of micro inductor technology for PwrSoC applications, shedding light on the potential of nickel-iron oxide magnetic nanocomposites as promising materials for high-performance on-chip power supply solutions.

References:

[1] Mathúna, Cian Ó., et al. "Review of integrated magnetics for power supply on chip (PwrSoC)." IEEE Transactions on Power Electronics 27.11 (2012): 4799-4816.

[2] Smith, Connor S., et al. "Electro-infiltrated nickel/iron-oxide and permalloy/iron-oxide nanocomposites for integrated power inductors." *Journal of Magnetism and Magnetic Materials* 493 (2020): 165718.

[3] Mills, Sara C., et al. "Method for the fabrication of thick multilayered nickel/iron oxide nanoparticle magnetic nanocomposites." *Journal of Magnetism and Magnetic Materials* 542 (2022): 168578.

9:45am **MN1-TuM-8 Rapid Fabrication of Tunable Resonators on Garnet based Magnetic Thin-Films***, **Nicholas Gagnon**, M. Franz, M. Gamez, D. Hedlund, R. Abdolvand, P. Kulik,* University of Central Florida

Current MEMS-based resonators are limited in frequency tunability by providing a narrow operational frequency range or requiring complex architectures. These challenges impose practical limitations for tunable devices operating over desired large frequency ranges (>5%). For the first time, an Al/YIG/GGG (aluminum, yttrium iron garnet, and gadolinium gallium garnet) tunable resonator was fabricated using rapid laser lithography. This tunable resonator requires zero static power and leverages a permanent magnet to provide a magnetic field bias (H_{ex}). YIG is a promising material for tunability due to high permeability (μ), low losses and low Gilbert damping [1–6]. The ferromagnetic resonance frequency, the shift in frequency due to a H_{ex}, can be calculated using Kittel's equation (eq. 1) [7],

$$f_{FMR}=\gamma(4\pi M_s H_a)^{1/2},\text{(eq. 1)}$$

where M_s,H_a,γ is the saturation magnetization, magnetic anisotropy field and gyromagnetic ratio respectively. The H_{ex} applied by the permanent magnet shifts the operational frequency of the device, hence providing tunability. Using finite element method (FEM) simulations, we have designed a device that can operate between 0.5 and 2 GHz with a quality factor (Q) of 200. Q is calculated using eq. 2,

$$Q=f_{res}/(\Delta f_{3db}),\ \text{(eq. 2)}$$

where f_{res} is the resonance frequency and Δf_{3db} is the 3-dB bandwidth. The results of the FEM simulations can be seen in Figure 1(A) together with the model in Figure 1(C). Compared to conventional lithography our method can prototype devices in *seconds* on any garnet material stack. The resonator presented here was manufactured in <10s and shows tunability of 33%. Figure 1(C) shows the tunability, and the resonator can be seen in Figure 1(D). The Q factor of the fabricated resonator operating near 1 GHz is 130. For a rapid prototyping method, that eliminates conventional lithography, a Q factor that is more than 50 % of expected from simulations is promising.

Future efforts will delve into investigating means to improve our fabrication method, i.e. smaller feature sizes as it is applicable to a wide range of devices. Additionally, we are focusing on concentrating H_{ex} using flux-based techniques providing additional tunability. The thin-film resonator presented here shows great potential to compete with commercially available sphere based YIG-resonators, with much smaller size and ease of manufacturing.

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