Overview of Acoustics, Sensors and Signal Processing

People

- **James H. Miller**, *Professor, Ocean Engineering*, URI (Lead)
- **Otto Gregory**, *Distinguished Engineering Professor*, Chemical Engineering, URI
- **Yaakov Bar-Shalom**, *Board of Trustees Distinguished Professor & Marianne E. Klewin Endowed Professor in Engineering*, Department of Electrical and Computer Engineering, UConn
- **Faquir Jain**, *Professor*, Department of Electrical and Computer Engineering, UConn
- **Gopu Potty**, *Associate Research Professor*, Ocean Engineering, URI
- **Lora Van Uffelen**, *Assistant Professor*, Ocean Engineering, URI
- **Harold (Bud) Vincent**, *Associate Research Professor*, Ocean Engineering, URI
- **Steven Crocker**, *Adjunct Professor*, Ocean Engineering, URI
- **Georges Dossot**, *Adjunct Professor*, Ocean Engineering, URI
- **Peter Willett**, *Professor*, Department of Electrical and Computer Engineering, UConn
- **Shengli Zhou**, *Professor*, Department of Electrical and Computer Engineering, UConn
- **George Rossetti Jr.**, *Associate Professor*, Materials Science and Engineering, UConn
- **Brian Willis**, *Associate Professor*, Chemical & Biomolecular Engineering, UConn
- **Bahram Javidi**, *Board of Trustees Distinguished Professor*, Electrical & Computer Eng. Dept., UConn

Acoustics, Sensors and Signal Processing

Active Research Projects

- “Representing Targets as Systems: Feature-Aided Tracking for Asymmetric Threats,” funded by DOD/Navy/NAVSUP, PI: Peter Willett.
- “Integration of Biomolecular Recognition Elements with Solid-State NanoDevices for Chemical Sensors with Specificity,” funded by DOD/Navy/ONR, PI: Brian Willis.
- “Target Detection using GPS Signals of Opportunity,” funded by DOD/Navy/ONR, PI: Peter Willett.
- “Stable Tunable Intermediate Frequency (STIF) Laser and Gain Chip,” funded by DOD/Navy/NUWC, PI: Faquir Jain.
- “MEMs Xylophone Antenna Development,” funded by DOD/Navy/NUWC, PI: Faquir Jain.
- "Low Frequency Acoustic Propagation: The Effects of Sediment Properties". funded by DOD/Navy/ONR, PIs: James Miller and Gopu Potty.
- "Glider-based Measurements of Acoustic Tomography Signals: Modeling and Experiments in Canada Basin and Philippine Sea", funded by DOD/Navy/ONR, PI: Lora Van Uffelen
- "Scaled Acoustic Source Model Development for High-Speed Projectile Impacting on Water Surface", funded by DOD/Navy/NUWC, PI: Sau-lon Hu
- "Sub-terahertz-range-interrogated fiber-optic devices for high-speed distributed sensing applications", funded by DOD/Navy/ONR, PI: Tao Wei
- "Glider-based measurements of acoustic tomography signals." PI: Lora Van Uffelen
- “Multi-static sensor array testbed,” funded by MITRE Corp, PI: Harold Vincent

Acoustics, Sensors and Signal Processing

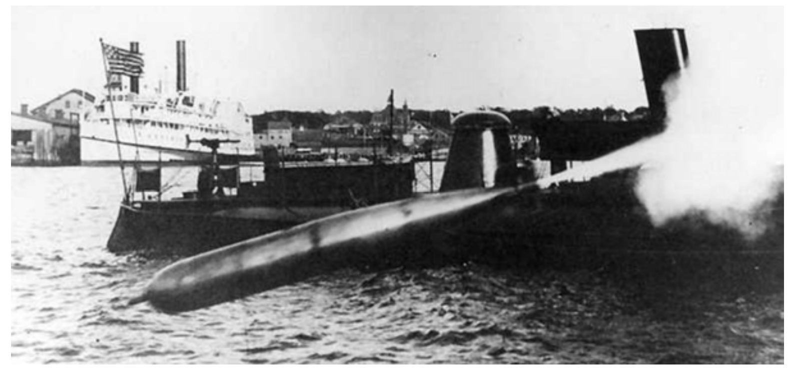
Capabilities

- Underwater acoustics
- Acoustic signal processing
- Acoustic navigation underwater and under-ice, acoustic sensing on underwater vehicles
- Low frequency acoustic propagation, shallow water acoustics, deep water acoustics, seabed acoustics.
- Underwater acoustic transducer design and calibration, array signal processing, structural acoustics, and vibration.
- Services include transducer calibration and design, at sea testing of underwater acoustic instrumentation, training, and workshops.
- MEMS sensors for ultra-high sensitivity magnetic detection.
- Development of chirped laser with very low lower, weight, & volume.
- Fiber optics for distributed sensing

Acoustics, Sensors and Signal Processing

Undersea Vehicle Technology Applications

- Active and passive detection, classification, and tracking
- Navigation and communications
- Countermeasures
- System performance prediction
- Training



Mk3 Whitehead torpedo fired from East Dock, Goat Island, Newport Torpedo Station, Rhode Island, 1894 (Wikipedia)

URI Sea Glider AUV (Kongsberg)

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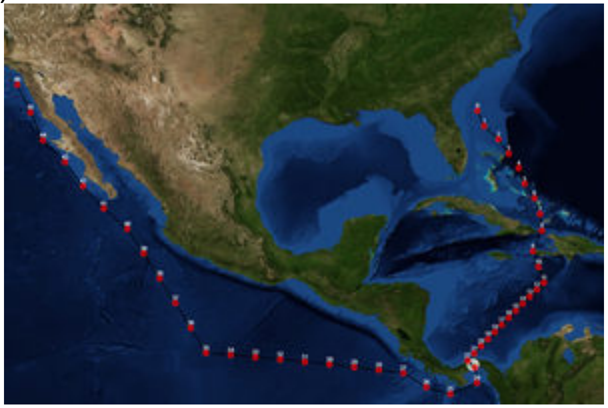
Systems, technology and algorithms being deployed and tested at sea

- URI "Cryobox" system for monitoring seismic signals in ice, designed for ICEX 2018 this spring.
- UCONN has developed TMPLAR (Tool for Multi-objective Planning and Asset Routing) for the Navy to vastly improve the ability of ships to reroute through unpredictable weather.

The Seawolf-class fast-attack submarine USS Connecticut (SSN 22) and the Los Angeles-class fast-attack submarine USS Hartford (SSN 768) break through the ice March 10, 2018, in support of Ice Exercise (ICEX) 2018. (US Navy photo)



On Oct. 1, 2015, the cargo ship El Faro sank with its 33-member crew in Hurricane Joaquin. This is the route of that ship. (UCONN graphic)

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Available Facilities

- URI has unique facilities for testing and calibration of underwater acoustic transducers as well as underwater vehicles.

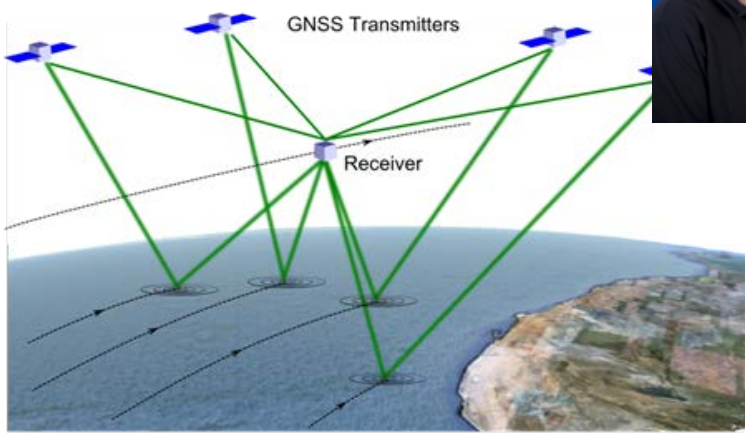
- UCONN has the Estimation and Signal Processing Lab for signal and information processing for estimation and data fusion with applications in target tracking and remote sensing.

The Ocean Engineering Acoustic Test Tank on the URI Bay Campus.

A Raytheon THAAD radar, which uses Yaakov Bar_Shalom's JPDAF algorithm. (from Peter Willett)

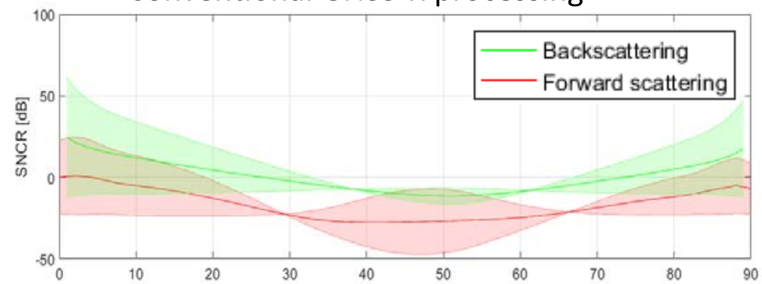
Acoustics, Sensors and Signal Processing

Peter Willett
UCONN EE Department

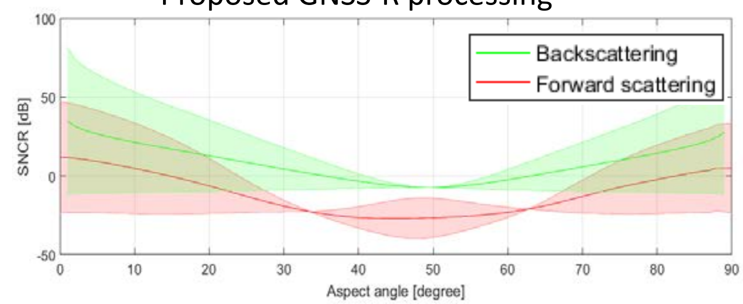


- Goal: maritime surveillance "passive radar" via GNSS in back-scattering mode.
- Much present research has focused on forward-scattering mode for sea-state.
- The decreased sea clutter in backscatter mode may expose low-observable targets.
- Project uses real data and high-fidelity target models for proof of concept.
- The project is joint with NATO CMRE.

Conventional GNSS-R processing



Proposed GNSS-R processing



Configuration	Backscattering		Forward scattering	
Processing	Conventional	Proposed	Conventional	Proposed
SNCR [dB]	24.3	33.4	-1.4	11.7
SNR [dB]	25.1	34.6	13.3	23.5
	Tomorrow		Today	

- The results (blend of real data and models) indicate that reduction of necessary target RCS of more that 30dB relative to forward scattering is possible.

ONR Young Investigator Program: Sub-THz-Range-Interrogated Fiber Optic Systems for Distributed Sensing

Tao Wei, EE Dept., University of Rhode Island

Objective

– conduct fundamental research that will lead to the development of a new sensing platform—a sub-terahertz-range-interrogated fiber optic sensor array (sub-THz array) for intermediate-scale (several hundred meters or less) , high spatial resolution distributed sensing applications.

Deliverables

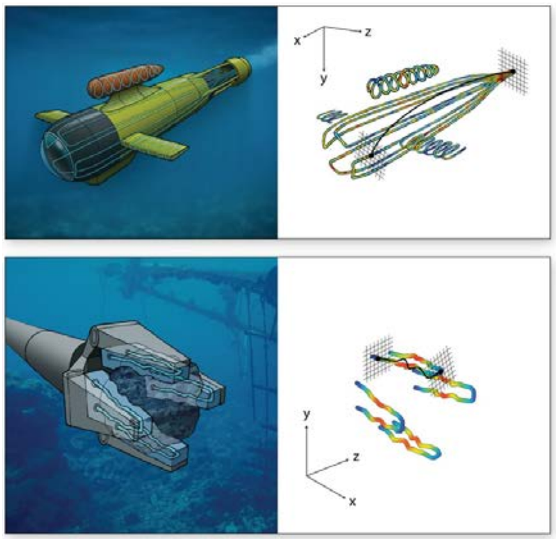
A working prototype that can demonstrate the distinct advantages of the proposed sensing platform over current state-of-the-art.

Milestones

- UV fabrication methodology
- A fully functional auto-fab system
- A theoretical framework of chirp control
- A fast chirping prototype; design methodology
- A digital implemented chip; methodology
- A theoretic framework on signal demodulation
- A parallel processing unit; design methodology
- Complete characteristics of the sub-THz array prototype

Accomplishments to Date (started on 06/01/2017)

- Working on the fast chirping prototype and its design methodology
- Working on the theoretic framework on signal demodulation
- Working on the parallel processing unit and its design methodology



Payoff to the Navy

- Distributed real-time temperature/strain profiles are key sensing parameters in the development of tactical and strategic awareness in the maritime battle space.
- Low SWaP-C distributed sensing platforms are attractive for implementation as on-board equipment for Navy surface ships, submarines, aircraft and unmanned vehicles. They may also be deployed from these platforms as mobile drifting or fixed ocean surveillance systems operating under autonomous or remote control.

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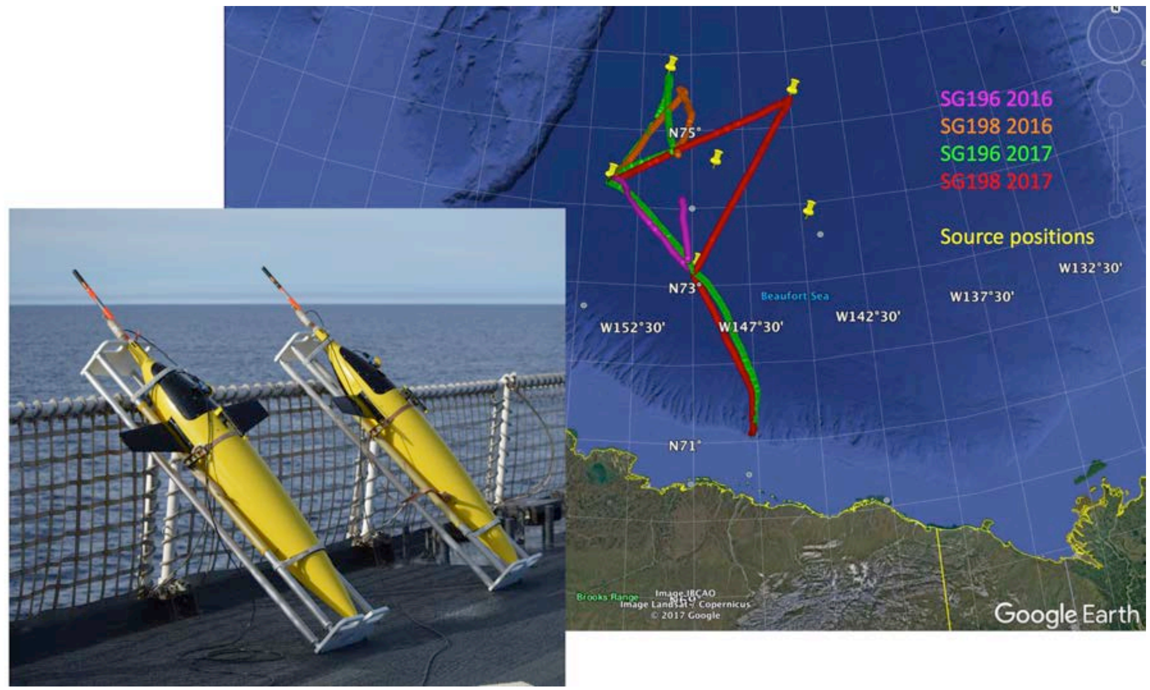
Long Range Underwater Vehicle Navigation
Prof. Lora Van Uffelen, URI



- Canada Basin Acoustic Glider Experiment: Arctic Seaglider deployments in 2016 and 2017
- Localized gliders in semi-real time using acoustic receptions from moored 250 Hz sources
- Transmissions received at ranges up to 480 km due to Arctic duct
- Demonstrated 80 m rms error in navigation accuracy

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Seafloor Effects on Low Frequency Acoustic Propagation

James H. Miller and Gopu R. Potty
URI Ocean Engineering

ASIAEX East China Sea

Objectives

Investigate the role of sediment properties on acoustic propagation in shallow waters leading to advanced capabilities in Anti-Submarine Warfare (detection and tracking), Mine Counter Measures (detection, classification, plus burial), and understanding the effects of noise on the marine environment.

Technical Approach

The work focuses on understanding the frequency and depth dependence of compressional wave attenuation and developing new inversion schemes for shear wave properties.

Products

This project supports the Office of Naval Research goals to understand propagation and scattering of acoustic energy in shallow-water ocean environments in support of Navy missions.

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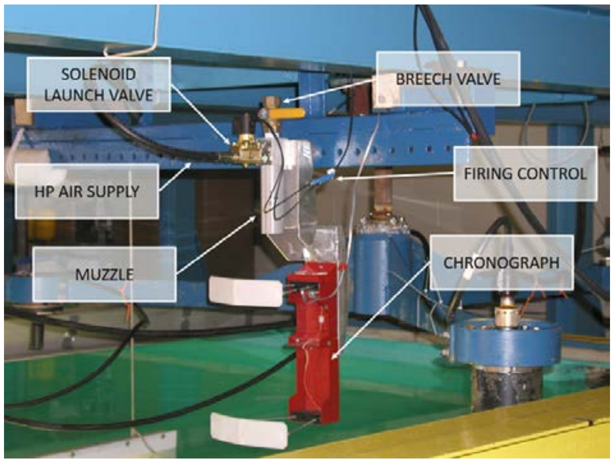
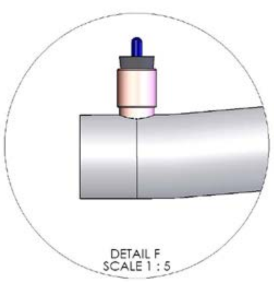
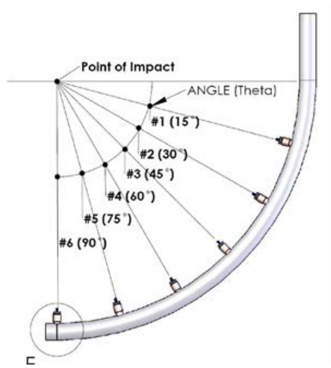
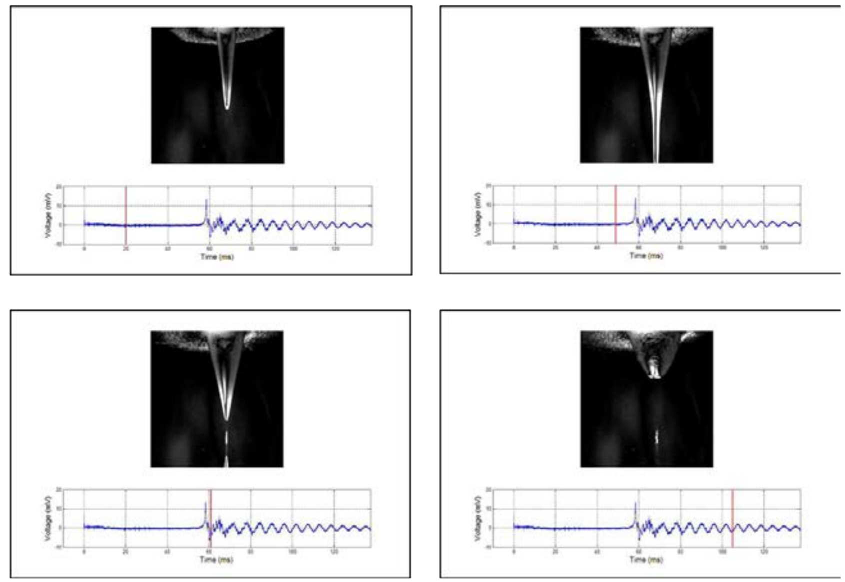
Hydro Acoustic Detection and Localization of Projectiles Impacting Ocean Surface

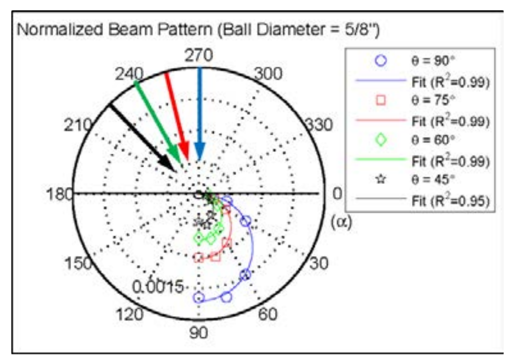
Dr. Harold "Bud" Vincent, CDR USN (Ret.)











Acoustics, Sensors and Signal Processing

The Realization of an Artificial Magnetoelectric Heterostructure (FeCo/AlN) Micro-Beam Resonator for Ultra-High Sensitivity Magnetic Sensing Applications

Steven P. Bennett[1], Margo Staruch[1], Jeffrey W. Baldwin[2], Bernard Matis[2], Olaf Van't Erve[1], Konrad Bussmann[1], Bill Zappone[3], Ron Lacomb[3], Peter Finkel[1]

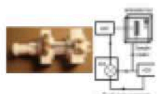
[1]Materials Science and Technology Division, U.S. Naval Research Laboratory, Washington DC
[2]Acoustics Division, U.S. Naval Research Laboratory, Washington DC
[3]Naval Undersea Warfare Center, Newport RI

ONR, Arlington VA
ASEE, Washington DC

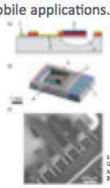
MOTIVATION:

- It's becoming more and more crucial to develop high sensitivity cryogen-fee, chip based magnetic sensors. This new generation of sensors must perform at very low power consumption, ruling out most of our current-hungry technologies (i.e. search-coil, Hall effect, flux gate, fiber optic, superconducting quantum interference device (SQUID) etc…).
- The realization of such a device which, not only operates at low power, but also potentially harnesses the capability of environmental energy harvesting opens the door to a plethora of previously unattainable mobile applications.

T. Nan, Y. Hui, M. Rinaldi, N. X. Sun, Sci. Rep. 2013, 3, 1985.

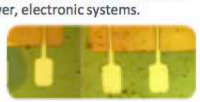


J. Kiser, P. Finkel, J. Gao, C. Dolabdjian, J. Li, D. Viehland, Appl. Phys. Lett. 2013, 102, 42909

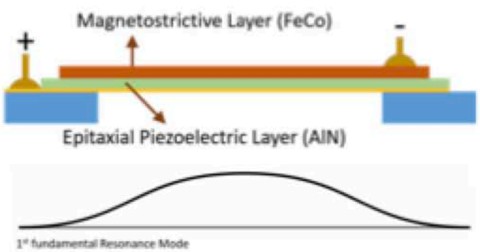


S. Marauska, R. Jahns, H. Greve, E. Quandt, R. Knöchel, B. Wagner, J. Micromechanics Microengineering 2012, 22, 65024

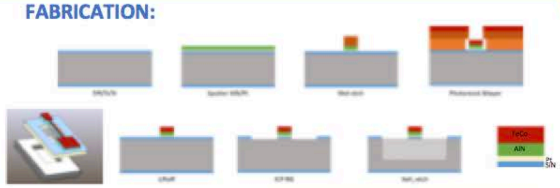
- The current state of the art of magnetoelectric resonator are limit to very large sized (<1cm). They are also limited by their needs for Op-amp detection, battery power and a high equivalent noise floor of ~10^{-10} Tesla at 1Hz.
- Miniturization of the sensors to the chip based micro-scale domain can decreased the equivalent magnetic noise to <10^{-1}pT.Hz$^{0.5}$.
- Additionally this allows for easy integration into silicon based, low power, electronic systems.



Here we demonstrate a new way to sense a changing magnetic field by using the resonance shift of a free-standing magnetoelectric, doubly symmetric, micro-beam resonator.

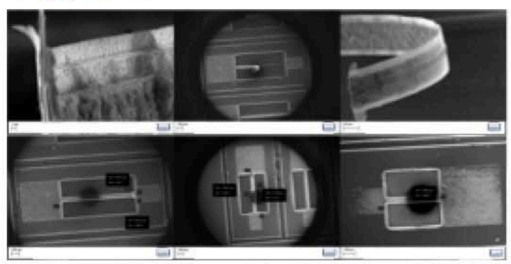


FABRICATION:



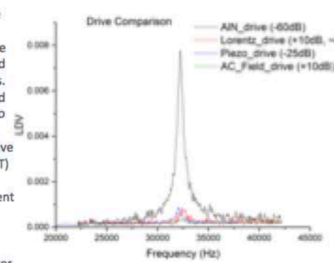
- Multistep fabrication procedure developed to create suspended micro-beams
- Sputter growth of AlN for good piezoelectric characteristics
- Sputter growth of FeCo to target good magnetostrictive characteristics (~$Fe_{70}Co_{30}$ composition)

Thin film heterostructures exhibit very high degrees of internal **stress**. When substrate is released there is a massive internal stress released causing breakage and curling (see SEM image).
**** Growth conditions and fabrication process must be tuned to create optimal final structure for both desired resonance fundamental freq. and stress breakage avoidance.

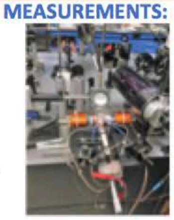


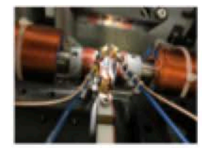
There are multiple ways to drive the beams to resonate:

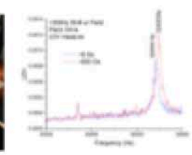
- AC magnetic Field drive – place sample in copper windings and supply AC current through coils. The AC magnetic field generated interacts with the magnetic FeCo layer and drives the beam
- Piezoelectric Crystal "shaker" drive – affix sample to a piezo (PMN-PT) crystal
- Lorentz force drive –supply current through FeCo conductor in a magnetic field
- Piezoelectric Layer (AlN) drive – directly supply voltage to AlN layer



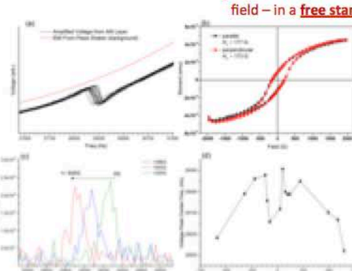
MEASUREMENTS:



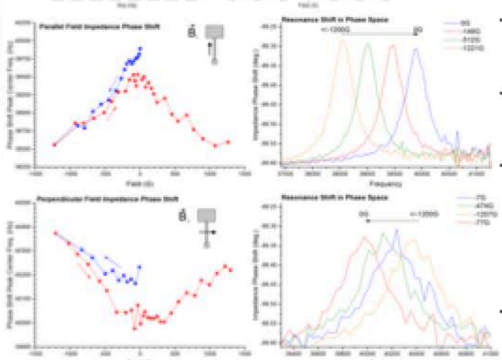




We've measured for the first time a magnetic field induced magnetostrictive resonance converted directly to an electric field – in a free standing thin film heterostructure.



- Shows the voltage signal generated by the AlN layer when driven to resonance with a piezoelectric shaker
- The raw signal (a) shows an EMI induced background voltage signal which increases with drive frequency. It is the radiated EMI from the contacts on the PMN-PT shaker used to resonate the device (not present with other drive methods
- (b) & (c) show the shift in the resonance with applied DC field up to 645G



- Shows impedance phase (in degrees) of the beams when the AlN layer is driven directly with an impedance analyzer.
- **Measurement of impedance phase shift seems to be the best measurement method for these heterostructures.**
- These microscale magnetoelectric seem to be highly sensitive to the inherent internal resonances of piezoelectric crystal. We have found that using the AlN layer results in the lowest signal to noise for fundamental resonance detection.
- Additionally the impedance phase angle detection provides the best route for tracking the field induced phase shift in these devices