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Research Area: Advanced materials and fabrication methods for micro- and nanoelectromechanical and electrofluidic systems.

Current Projects:

1) Bulk Micromachined Titanium (Ti) MEMS – Recently, we have developed a micromachining process that allows, for the first time, fabrication of high aspect ratio structures in titanium. Titanium is already well proven for use in harsh environment applications on the macro-scale (e.g. aircraft structures, marine drilling heads, hip implants, etc), hence the natural inclination to develop technology to apply it on the micro-scale as well. Using the Metal Anisotropic Reactive Ion etching with Oxidation (MARIO) Process, we are now able to define arbitrarily complex, high aspect ratio structures with vertical sidewalls and micron-scale features in bulk titanium. Work is currently ongoing to further develop this fundamental process technology and apply it to the fabrication of novel device applications, including:

- Harsh environment, robust, micromechanical RF relays
- Ti-MEMS-based micromirror arrays
- Ti-based multifrequency traveling wave dielectrophoresis device
- Ti microfluidic networks for biomaterial studies

2) Nanomechanical Characterization – Understanding the behavior of materials on the micrometer and nanometer length scale is an important aspect of MEMS characterization and design. For example, the mechanical properties of titanium have been thoroughly studied for macro-scale applications, however, very little is known about the effects of scaling in polycrystalline Ti. In this case we are currently investigating the fatigue and yield characteristics of micron and submicron Ti samples. To broaden the properties attainable in Ti-based MEMS devices, ion implantation is being investigated as a means to alter the properties of the Ti surface layer; the goal being to create TiN, TiB$_2$, and TiC as wear resistant MEMS coatings. Additionally, two projects are currently underway focusing on the mechanical properties of single-crystal Si. The first involves understanding the effects of oxidation-induced strain in Si nanostructures. In addition, work is currently underway to develop a Si-based composite for fracture resistant MEMS devices. The composite material is a two-dimensional laminate of Si/SiO$_2$. The SiO$_2$ layers have a residual compressive stress after processing that enables them to act as crack traps. The process allows for the fabrication of composite MEMS devices with standard processing equipment. Experimental studies have demonstrated improved damage tolerance of this composite as compared to single-crystal silicon.

- Effects of scaling on the mechanical properties of microscale Ti devices
- Ion implantation of Ti MEMS for mechanically robust devices and packaging
- Investigation of oxidation-induced strain in single-crystal silicon (SCS) nanostructures
- Si/SiO$_2$ nanocomposite architectures for improvement of MEMS reliability

4) Piezoelectric MEMS – Thin film bulk acoustic resonators (FBARs) are being explored for use in RF devices such as cellular phone filters due to their potential for high quality factors in the 1-5 GHz regime. We are sputtering a piezoelectric wide bandgap semiconductor, aluminum nitride (AlN), on <100> silicon wafers and using Si-based micro fabrication techniques to build through-thickness actuated FBARs from the AlN/Si wafers. Scattering parameters of the resonators are measured with a network analyzer to access the resonator and film quality. In addition, sputtered AlN films are being investigated for use as an active material for piezoelectrically actuated MEMS devices in both single-crystal Si, and polycrystalline bulk Ti structures.

- AlN RF Resonators (FBARs)
- Novel piezoelectric actuators using AlN on Si and Ti

3) BioMEMS – Current bioMEMS research spans topics in microfluidics, cellular interactions, and biomolecular analysis. Devices are fabricated in both Si and Ti and use a multitude of surface treatments, including oxidation techniques and self-assembled monolayers. Current microfluidic devices include a ring electroosmotically-driven chaotic mixer fabricated in Si and a Ti-based multi-frequency traveling wave dielectrophoresis device. Development of novel devices that incorporate channels etched into both Si and Ti have allowed for in-situ X-ray scattering of aligned bio-macromolecules. Using these devices, F-actin protein bundles have been aligned in channels of widths approaching the persistence length. In addition, a simple technique to fabricate and integrate crack-free nanostructured titania (TiO_2) features into microsystems has been developed and is being investigated for applications ranging from cell adhesion layers to gas and biomolecular sensing. BioMEMS research is an interdisciplinary effort and necessitates close collaboration with other research groups in the Chemistry, Materials, Mechanical and Environmental Engineering, and Physics Departments.

- Micromixer fabricated from single-crystal Si
- MEMS/NEMS-based bio-instruments
- Titania nanofiber based gas sensors
- Ti-based multifrequency traveling wave dielectrophoresis device
- Ti microfluidic networks for biomaterial studies

5) Optical MEMS – A variety of materials and processes are used to create micromechanical devices for both active and passive optical components, including hybrid Ti/Si micromirror arrays, dielectric-based scanned bimorph IR focal plane arrays, and III-V MEMS-based widely tunable vertical-cavity semiconductor optical amplifiers. The micromirror array combines bulk micromachined Ti torsional mirrors with a novel Si sloping electrode structure to produce a heterogeneously integrated device for use in optical cross connects, or advanced display technologies. The scanned bimorph IR array utilizes surface micromachined metal/dielectric films to create an on-chip array of free-standing MEMS bimorph structures for use in IR imaging systems. Finally, we have developed the first MEMS-based widely tunable vertical-cavity semiconductor optical amplifiers (MT-VCSOAs). These devices are advantageous as they can be fabricated as on-chip 2-dimensional arrays, and are promising as a low-cost alternative to erbium-doped fiber amplifiers (EDFAs) for use in optical networks such as metropolitan, access, and local area networks. The use of a Fabry-Perot resonant cavity results in a narrow gain bandwidth, allowing the VCSOA to operate as an amplifying filter. In order to achieve wavelength tuning of the peak amplifier gain, an integrated electrostatic actuator is used. In fabricating these devices we utilize a combination of AlGaAs-based micromachining with GaAs-InP direct wafer bonding.

- Ti-MEMS-based micromirror arrays
- Scanned bimorph MEMS for high sensitivity, high density, IR focal plane arrays
- MEMS tunable vertical-cavity semiconductor optical amplifiers (MT-VCSOAs)