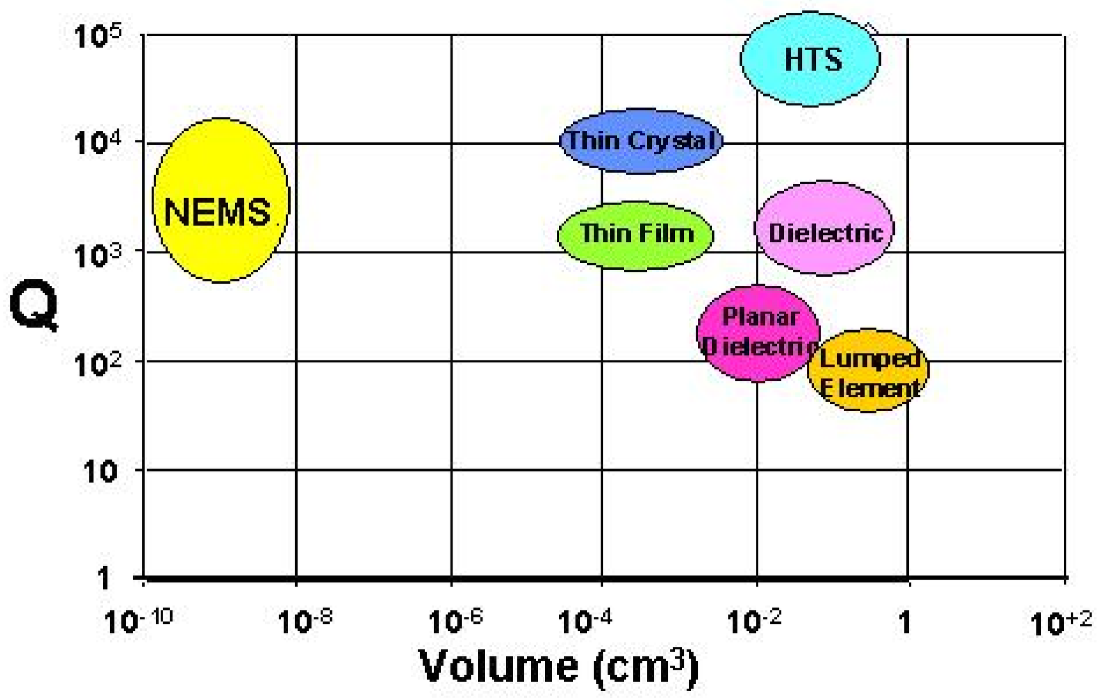
High-Q Piezoelectric Nanomechanical Filter Arrays

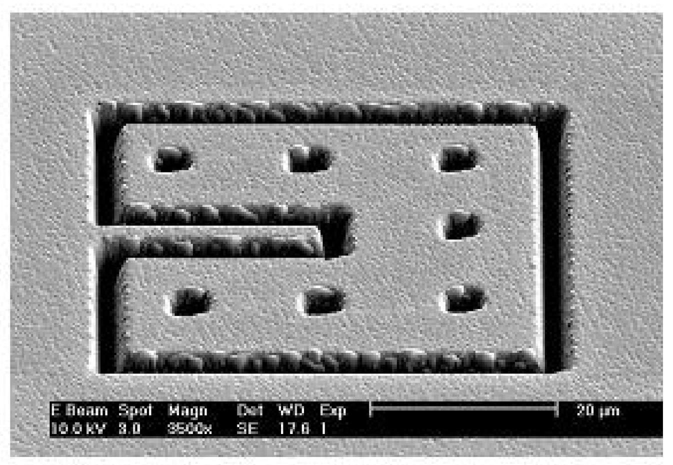
P. Kumar, M. Edelen, L. Li, J. Melngailis, P. Boudreaux, D.L. DeVoe

Project Goals

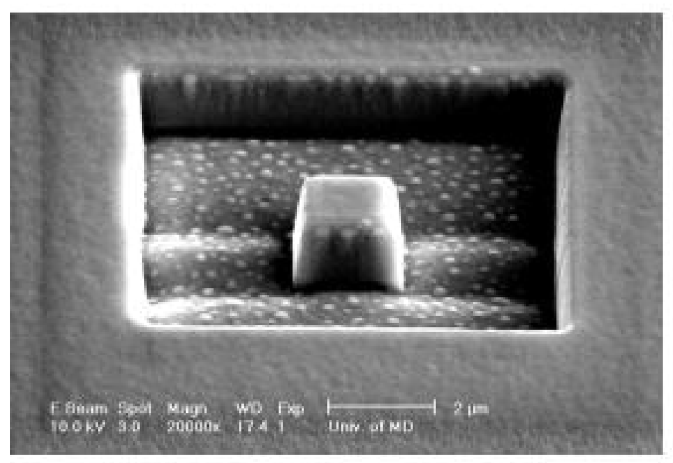
- **Functional filter banks based on nano-scale piezoelectric structures:**
  - orders-of-magnitude size reduction compared to SAW devices
  - direct integration with VLSI (ZnO) and high-speed electronics (AlAs)
  - low power operation



AlAs Piezo Characterization

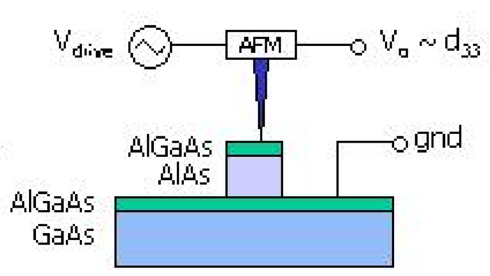


FIB-machined AlGaAs/AlAs/AlGaAs/GaAs heterostructure for d_{31} characterization

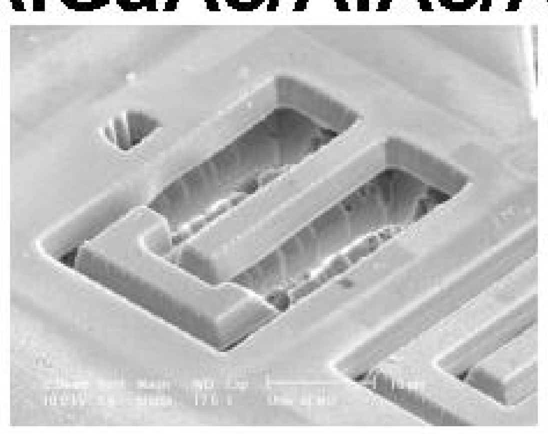


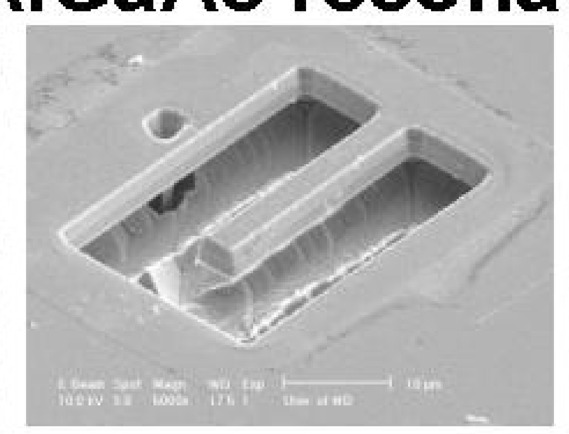
FIB-machined AlGaAs/AlAs/AlGaAs/GaAs heterostructure for d_{33} characterization

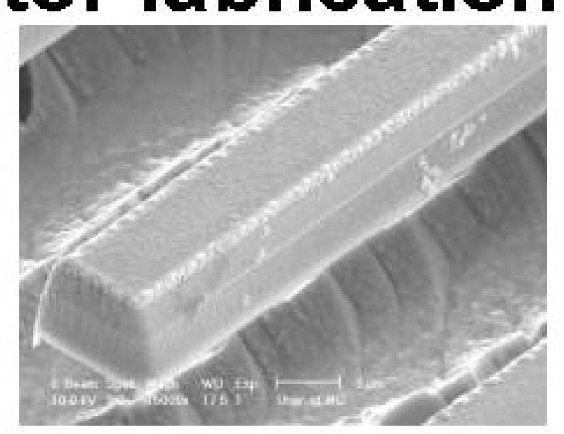
- AFM d_{33} characterization (in collaboration with R. Ramesh, UMd)



AlGaAs/AlAs/AlGaAs resonator fabrication

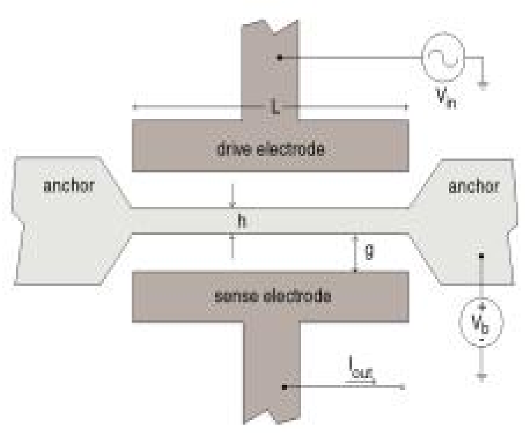


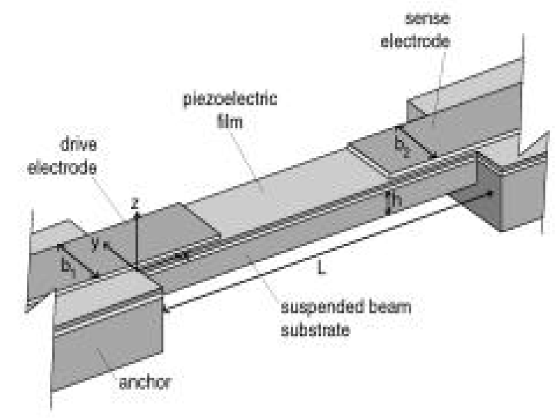


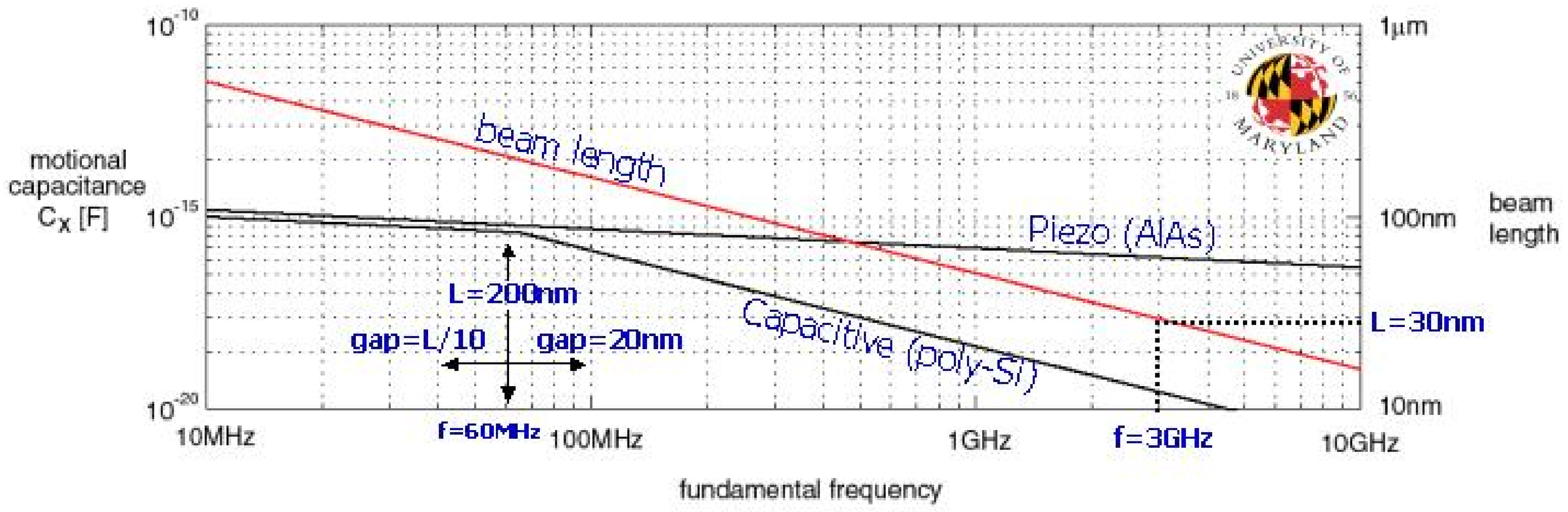


Why piezoelectric filters?

- Piezoelectric coupling scales into the nano regime much more favorably than capacitive coupling for lower insertion loss, higher SNR
- High-Q single crystal piezoelectric materials, e.g. AlAs, will enable direct integration with high speed electronics, optoelectronics
- Comparison of displacement-based capacitive and strain-based piezoelectric doubly-clamped beam resonators up to 10GHz:

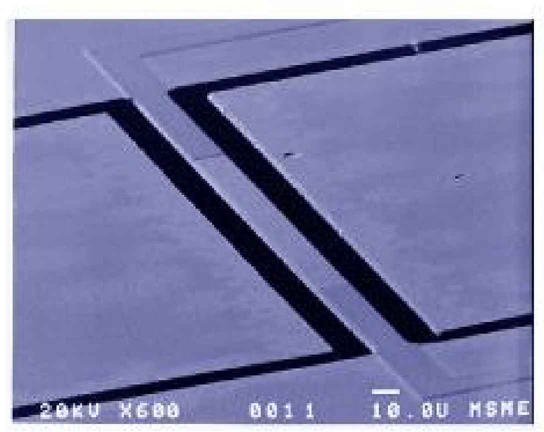


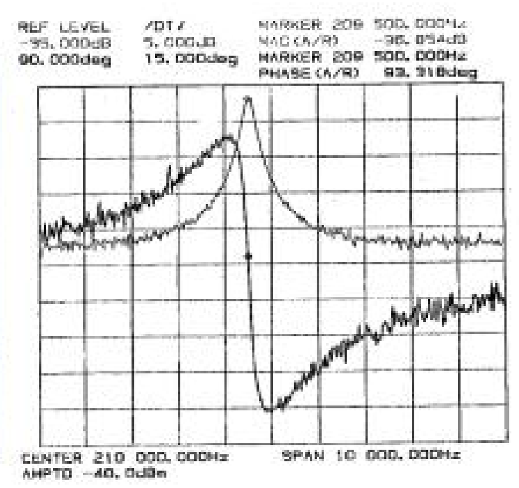




- Major challenges remain to be addressed for nanoresonators in filter applications:
  - impedance matching
  - adsorption effects / mass sensitivity
  - thermal stability
  - SNR limits
- Piezoelectric transduction can reduce the impact of these issues by enabling larger-scale high frequency resonators into the S-band range

- Typical PZT-based microscale filter and spectrum output:





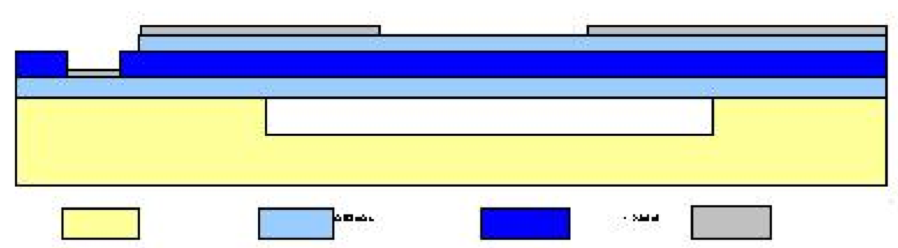
- Related designs in progress:
  - bending mode resonators (use d_{31}, with higher modes, new anchor designs)
  - shear mode block resonators (use high d_{14})
  - thickness mode disk resonators (use d_{31}, but higher Q expected)

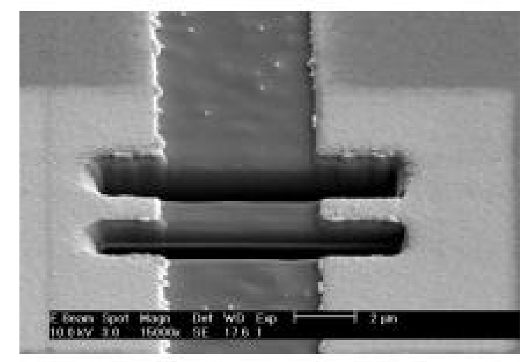
AlAs Piezoelectric Filters

	Si	GaAs	AlAs	
ρ [kg/m^3]	2330	5360	3760	moderate density
E [GPa]	166	118	120	moderate stiffness
$f_n \sim (E/\rho)^{1/2}$	f_{Si}	$0.55f_{Si}$	$0.67f_{Si}$	higher f_n than GaAs
$-d_{31}$ [pC/m]	----	1.34	1.91	strong relative piezo
ε_r	----	10.9	8.2	lower capacitance
k^2	----	----	0.08	Coupling > ZnO, AlN

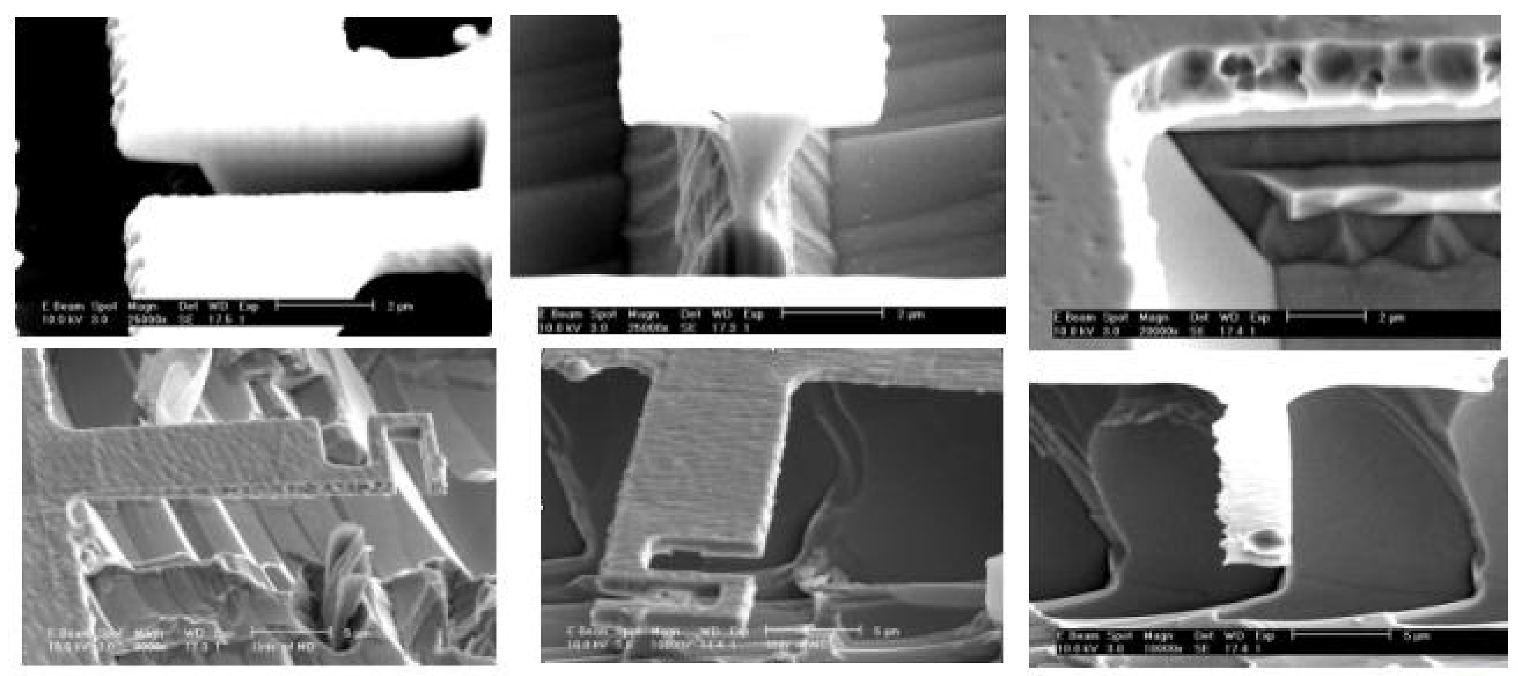
- AlAs is an excellent material for nanoscale resonators
- Higher piezoelectric coupling than ZnO, AlN, GaAs
- Good fracture toughness, ultimate yield strength
- moderate density and stiffness for higher frequencies than GaAs
- Single xtal epitaxial growth, lattice match to GaAs for high Q

- GaAs micromachining used for device release
- Typical anisotropic etch profiles shown at right
- 3-layer heterostructures fabricated via MBE, FIB, and wet etching
- plasma etching processes under development for selective AlGaAs/AlAs etching
- initial microscale structures designed for d_{31}, d_{33}, Q, f_n measurements
- epitaxial regrowth for future devices
- Typical clamped-clamped beam AlAs heterostructure structure patterned by FIB:





AlAs/GaAs bulk micromachining:



DARPA
MTO MEMS