POST-CMOS COMPATIBLE AlN RESONANT ACCELEROMETERS

LABORATORY DIRECTED RESEARCH & DEVELOPMENT

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Goal: To develop small, low power accelerometers that can be placed directly on-top of foundry CMOS circuitry.

– Resolution < 10 mG/℘Hz

– Bandwidth 10 Hz – 1 kHz

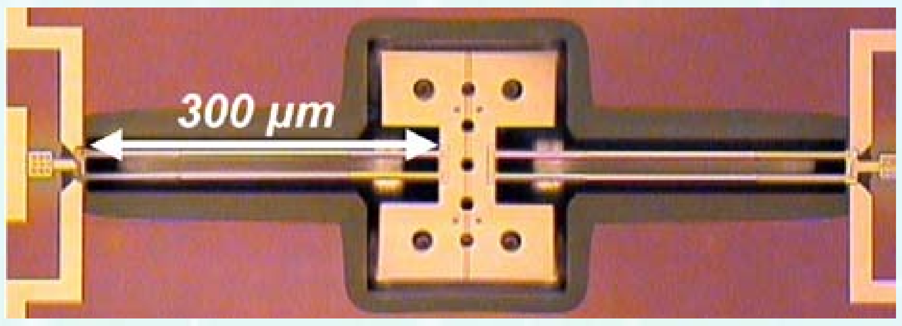
– CMOS compatible materials, max. processing temp = 400ºC

Approach:

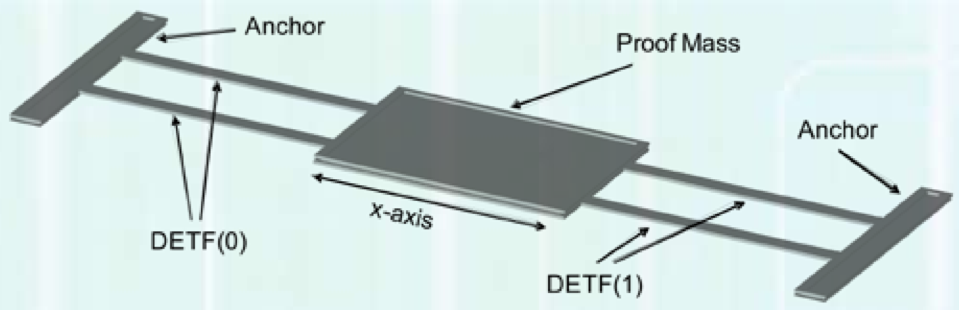
– Develop post-CMOS compatible, piezoelectric thin film MEMS process

– Design and fabricate accelerometers

– Design readout circuitry and measure acceleration resolution



Resonant Accelerometer Operation and Properties



- Double-ended tuning forks (DETF) placed in oscillation loop
- Positive x acceleration increases frequency of DETF(0), decreases frequency of DETF(1)
- Differential design improves cross-axis rejection, reduces temperature sensitivity, high dynamic range
- Low power digital output
- Measures strain not displacement, high stiffness, lower masses, more reliable and easier to fabricate

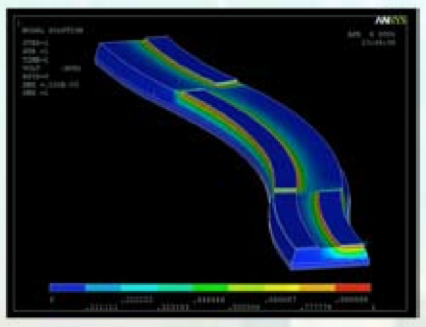
DETF Sensing Beams

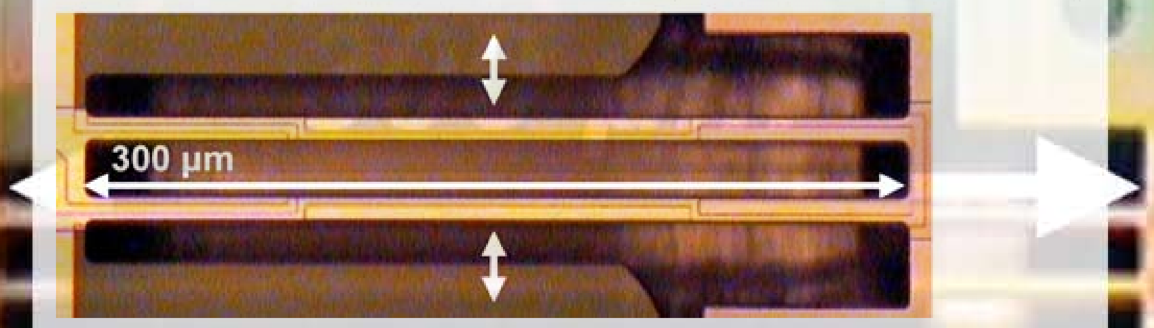
Double-Ended Tuning Fork (DETF)

– Electric field across AlN film causes lateral displacement due to d31 piezoelectric coefficient

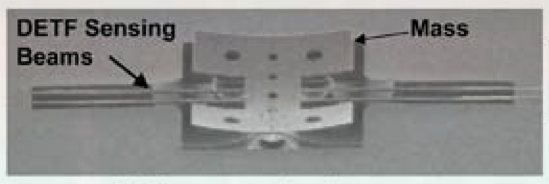
– DETF mode driven through electrode layout

– DETF mode reduces anchor losses

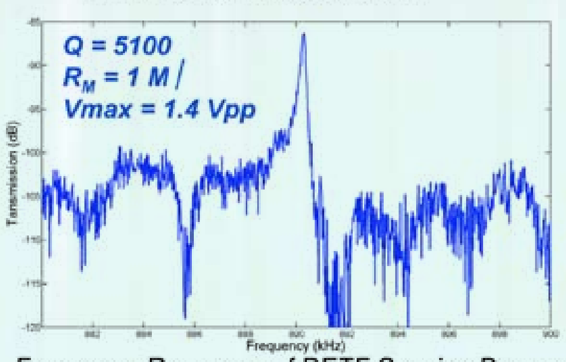




Aluminum Nitride Piezoelectric Transduction



AlN Resonant Accelerometer



Frequency Response of DETF Sensing Beams

Piezoelectric Transduction

– Low Impedance

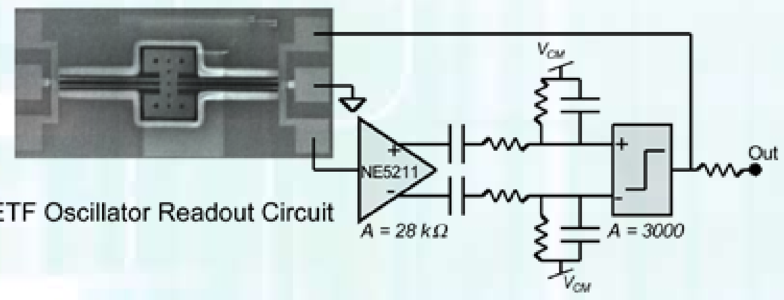
– Linear with Drive Voltage (10x Higher Power Handling)

– 1.4x Lower Q than Electrostatic Si Beam Sensors (Offset by Improved Power Handling)

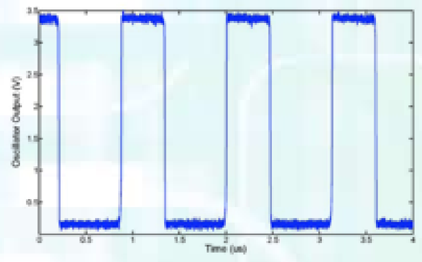
– Post CMOS Compatible Materials

High-Q enables very accurate frequency and thus acceleration measurement

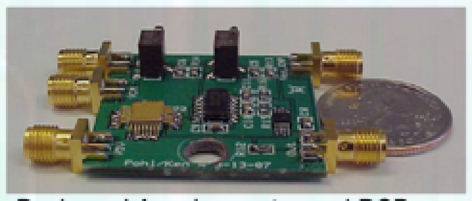
DETF Oscillator Readout Circuit



DETF Oscillator Readout Circuit



Output of the DETF Oscillator



Packaged Accelerometer and PCB Readout Electronics

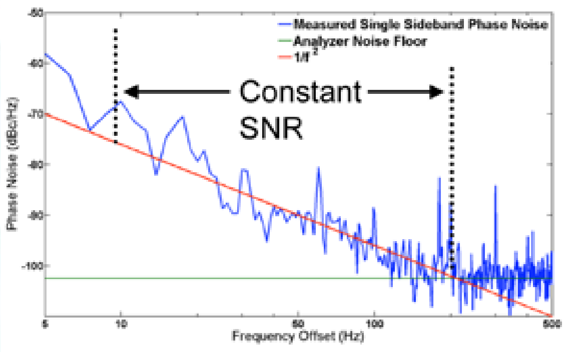
Accelerometer Performance Analysis

Readout Oscillator Circuit Phase Noise

$$L_{osc}(\Delta f) = 10\log\left[\frac{2KT}{P_{sig}}\left(\frac{f_0}{2Q\Delta f}\right)^2\right]$$

Vibration Induced Signal

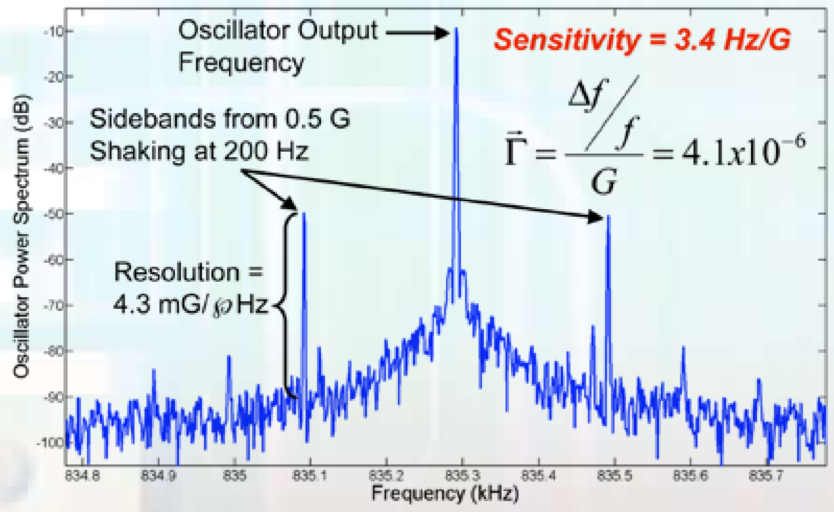
$$L_v(\Delta f_v) = \left(\frac{\left|\vec{\Gamma}\right| f_0 \vec{a}(f_v))}{2 f_v}\right)^2$$



Accelerometer Resolution

$$\frac{a_{min}(f_v)}{\sqrt{Hz}} = \frac{2 f_v \sqrt{L_{osc}(\Delta f_v)}}{\vec{\Gamma} f_0}$$

Acceleration Measurement

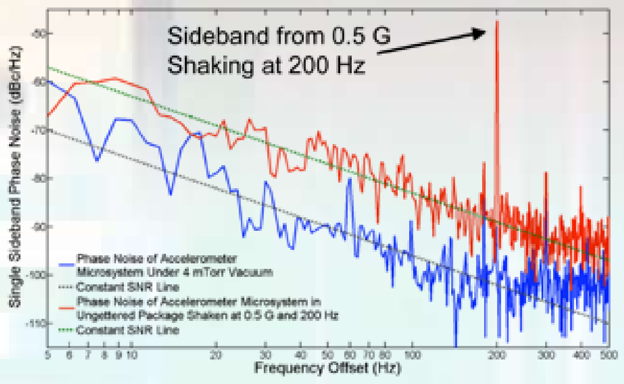


$$\vec{\Gamma} = \frac{\Delta f / f}{G} = 4.1x10^{-6}$$

Shaker Testing on an AlN Resonant Accelerometer in a Chip Scale Vacuum Package Without Getters

Acceleration Measurement

Vacuum	Mass Width	Mass Length	Thickness	Mass	Resolution
Ungettered	200 µm	150 µm	1.35 µm	120 ng	4 mG/℘Hz
4 mTorr	200 µm	150 µm	1.35 µm	120 ng	0.9 mG/℘Hz
4 mTorr	2 mm	2 mm	1.35 µm	15.6 µg	7 µG/℘Hz



Significance

- Very high resolution for a given proof mass (30x > than capacitive sensing)
- Inertial sensors integrated over custom CMOS signal processing and RF communications circuitry

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