Microelectromechanical Systems in 3D SOI-CMOS: Sensing Electronics Embedded in Mechanical Structures

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3D SOI CMOS MEMS

• 0.18 micron SOI
• 1 poly and 3 metal layers
• MIM capacitors
• 3 CMOS tiers fabricated, stacked and electrically connected
• Thickness of CMOS layers ~18 microns
Advantages for MEMS

• Embed cap sense electronics inside of MEMS proof mass
  – Less wasted area
  – Less parasitic capacitance
• Increased proof mass weight per area
• Increased sidewall capacitance
  – For 100 micron wide plate
    • Parallel plate approximation gives ~16fF
    • Ansys simulation gives ~19fF
  – Eliminates need for interdigitated comb fingers
Release Steps

- First surface micromachining step always RIE plasma etch
- Second final release step can vary
  A. Etch from top all the way
  B. Thin entire bottom then etch from top
  C. Thin selected bottom then etch from top
  D. XeF2 vapor etch
Etching Results

- Metal etch mask gone
- Etched for 240 min
- Removed ~17um of oxide
Etching Results (cont)

Etch Hole | Folded Spring Contacts | Z-Axis support

1μm gap for capacitor | Optical view shows electronics
XY Accelerometer

- Layout showing embedded circuits
- 3D view showing final device
- ANSYS modal simulation
  - Resonant Freq ~43 kHz (Beam Spring) and ~27.5 kHz (Folded Spring)
Capacitive Sense Electronics

- **Op-Amp Specs**
  - Two Stage
  - PMOS inputs
  - Input FET’s sized to match MEMS capacitance of ~16fF
  - H gate geometry
  - Open loop gain ~30db
  - Bandwidth ~2Mhz
  - Input referred noise ~100uV rms

- **4 different setups**
  - Open loop with reset switch
  - Feedback capacitor with regular reset switch
  - Feedback capacitor with annular reset switch
  - Feedback resistor
Cap Sense Preliminary Results

- Output Swing: 1.46V
- Open Loop Gain: ~14dB
- -3 dB @ 34kHz
- Results poor due to
  - Quick and dirty test setup
  - Large capacitance on output
  - Input to amplifier not readily available, used probe to scrape away oxide to expose input node
- Follower mode operation showed bandwidth > 200 kHz

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Z Axis Accelerometer for Optical Detection
Structures needed for Optical Detection

- Cross Section of Z-Axis MEMS device
- Simplified layout of PIN diode structure
Theory of Standing Wave Detection

\[ E_1 = E_0 e^{i(\omega x - kn_2 x)} \]
\[ E_2 = E_0 e^{i(\omega (x - 2kn_1l - 2kn_2t_a + kn_2 x + \pi)} \]
\[ I \propto \int_0^{t_a} |E_1 + E_2|^2 \, dx \]
\[ = 2E_0^2 \left\{ t_a - \frac{\sin(kn_2 t_a) \cos(2kn_1 l + kn_2 t_a)}{kn_2} \right\} \]

where \( t_a \) is the thickness of the detector,
\( l \) is the distance between the detector and reflective surface,
\( k = 2\pi / \lambda \), where \( \lambda \) is the wavelength of the light,
\( n_1 \) is the refractive index of air,
\( n_2 \) is the refractive index of silicon
Testing of Standing Wave Detection

- Testing performed by vibrating laser at 1kHz
- Laser mounted on piezo actuator
- Laser moving ~12nm in the z direction
- Position detector used to make sure there is no motion in the x-y directions