Fabrication Approaches for Microelectromechanical Resonators

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Microelectronic Fabrication

Fall 2002

Motivation for MEMS Resonator

1987

1996

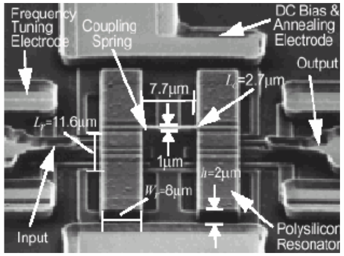
2001

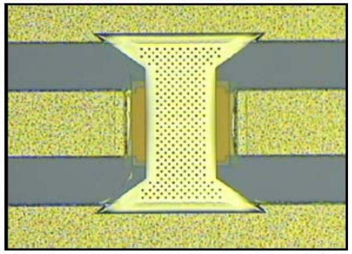
2002

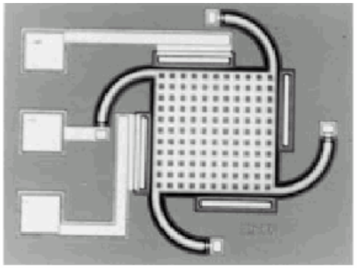
2010

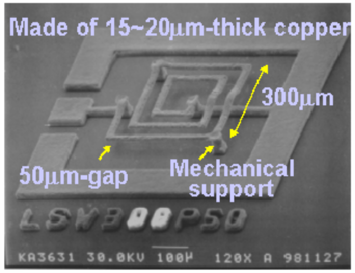
MEMS Contribution In Miniaturization

- ✓ **Smaller Passive Component**
- ✓ **Low Cost (Batch Fabrication)**
- ✓ **Low Power Consumption**
- ✓ **Higher Performance**









Outline

- What is a micromechanical resonator ?
- Why do we need high Q resonator ?
- Surface micromachining Process;
  - Vertically Driven Resonators
  - Laterally Driven Resonators
- Bulk Si micromachining Process;
  - Silicon electrode
  - Polysilicon electrode

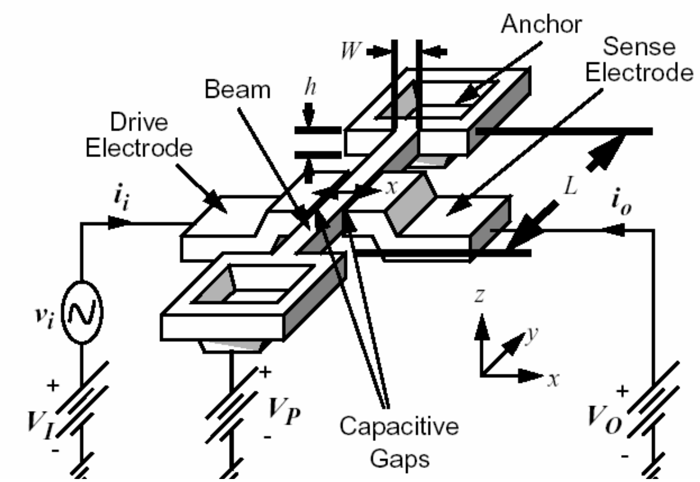
Micromechanical Resonator

Advantages :

- ✓ **High Q**
- ✓ **Low Power**
- ✓ **On-Chip Fabricated**

Fabrication Demands :

- ✓ **Small Dimensions**
- ✓ **Very Small Gaps**
- ✓ **Low Loss**
- ✓ **Tight Control On Dimension**



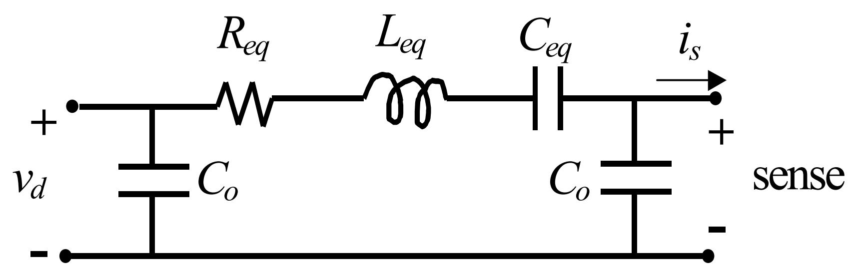
Definition: Quality factor (Q factor)

Ratio of stored energy and lost energy: $Q = 2\pi \frac{E}{|\Delta E|} = 2\pi \frac{\tau}{T} = \omega_0 \tau$

Mechanical system: $Q = \omega_0 \frac{m}{b} = \frac{\sqrt{Km}}{b}$

Similar for electric systems: (a) $Q = \omega_0 \frac{L}{R} = \frac{1}{R}\sqrt{\frac{L}{C}}$

(b) $Q = \omega_0 RC = R\sqrt{\frac{C}{L}}$

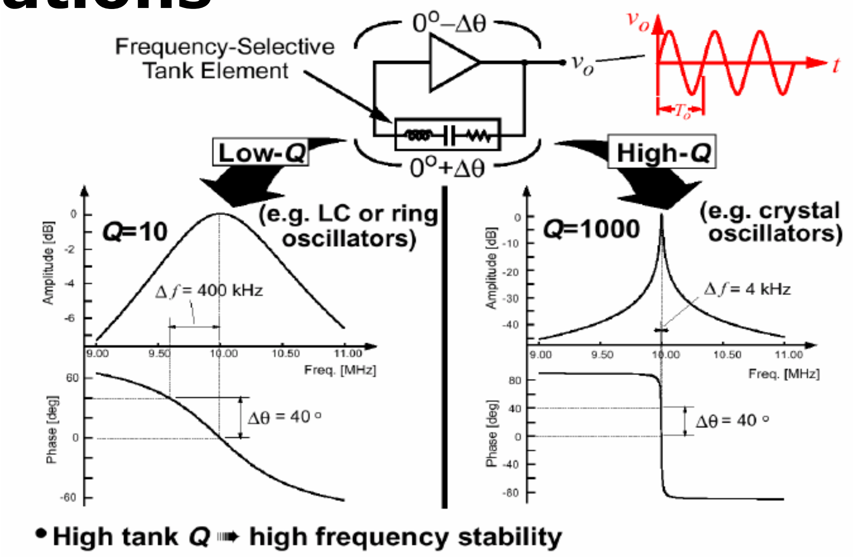


Electrical Equivalent

$$R_{eq} = \frac{kg^4}{\varepsilon_o{}^2 A^2 \omega_1 Q V_p{}^2}$$

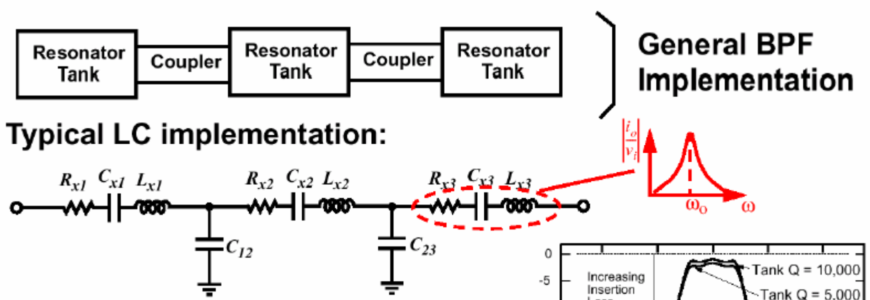
Advantages of High Q in Different Applications

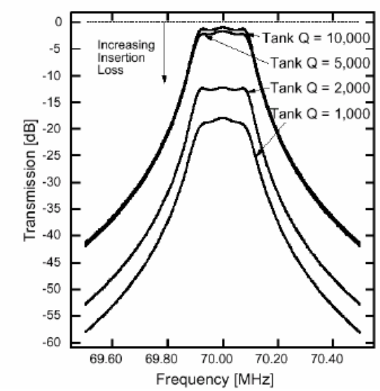
Oscillator :



High Q ➡ ✓**High Stability**
✓**Low Phase Noise**

Bandpass Filter :





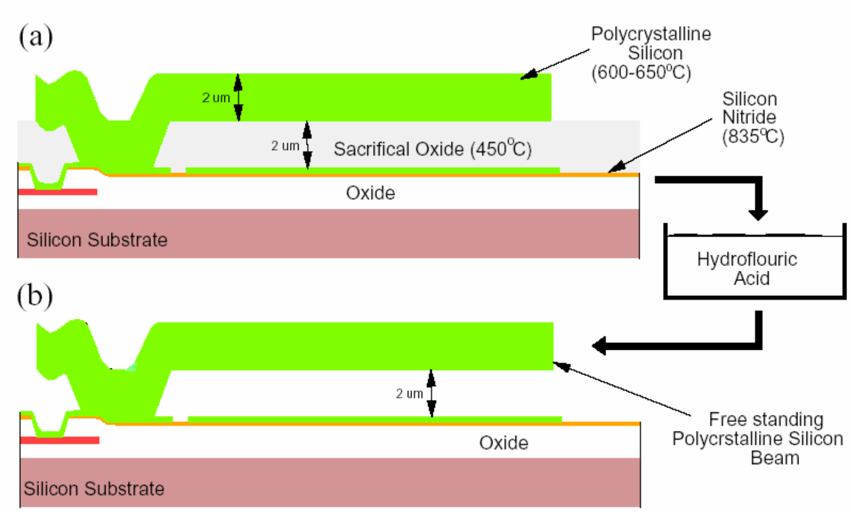
High Q ➡ ✓**Low Insertion Loss**
✓**Higher Selectivity**

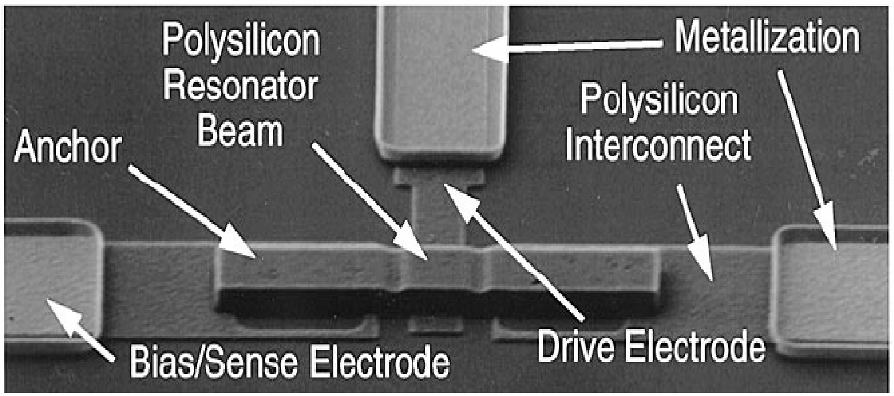
Surface Micromachining Process

- **Polysilicon Surface Micromachining**

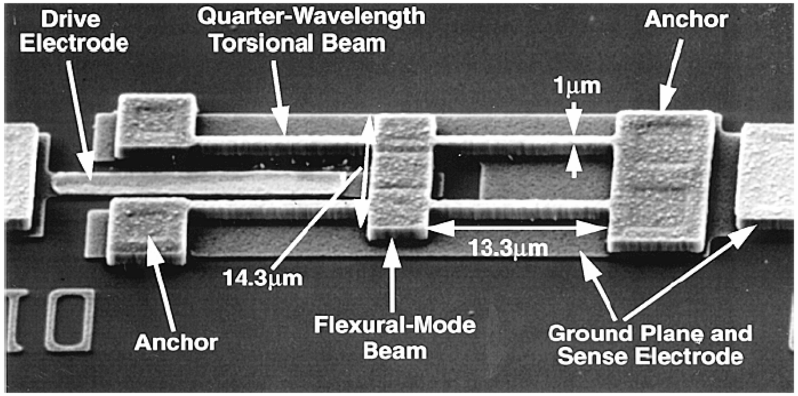
Advantages:
- ✓ **Design flexibility**
- ✓ **High material Q**
- ✓ **Small gaps easily achievable**

Challenges:
- ✓ **Q of resulting resonator is Heavily dependent on process variations**
- ✓ **Sacrificial layer uniformity**
- ✓ **Large electrode series resistance**





Clamp-Clamp Beam Resonator, C. Nguyen et al



Free-Free Beam Resonator, C. Nguyen et al

- **Multiple-Metal-Electrode Lateral Resonator**

a) - Thermally Grown Oxide
- LPCVD Nitride
- LPCVD Poly and Patterning
- LPCVD HTO and Patterning Vias
- LPCVD Structural Poly and Doping
- Hard Mask HTO and Annealing
- Oxide Patterning and Poly Etching
- HTO Gap deposition

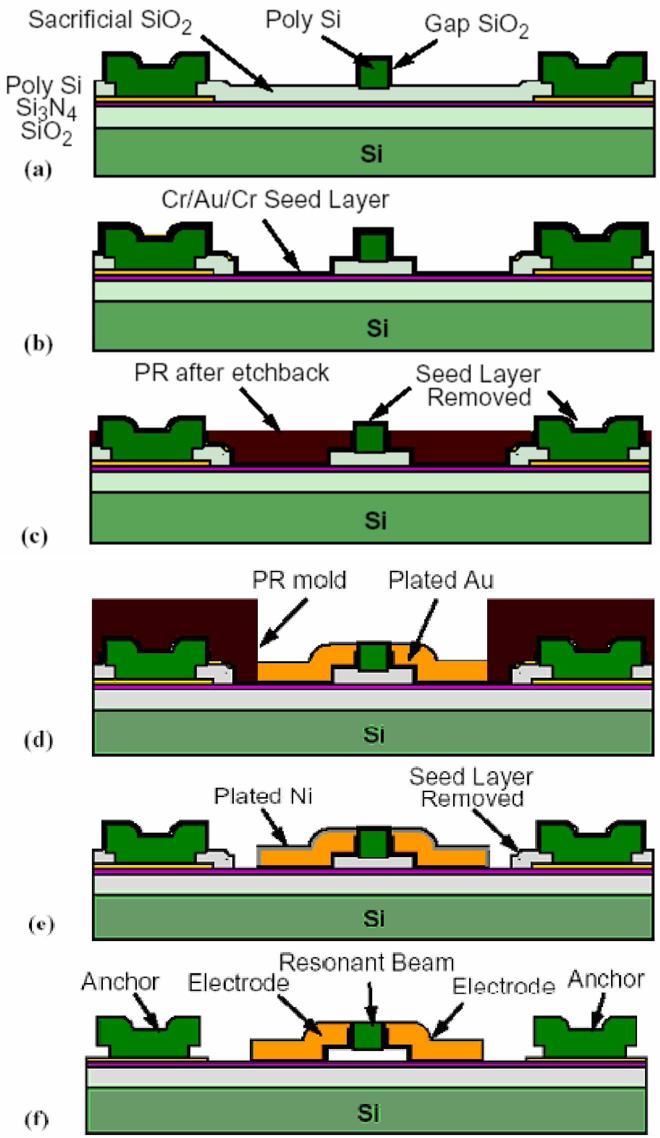
b) - Bottom Oxide Etch
- Thin film Cr/Au/Cr Evaporation

c) - PR Spinning and Etch back
- Seed Layer over Top of Poly Structure Removal

d) - PR Spinning and Etch back
- Seed Layer over Top of Poly Structure Removal

e) - PR Mold Patterning
- Au Electroplating to Form Electrodes

f) - HF Release

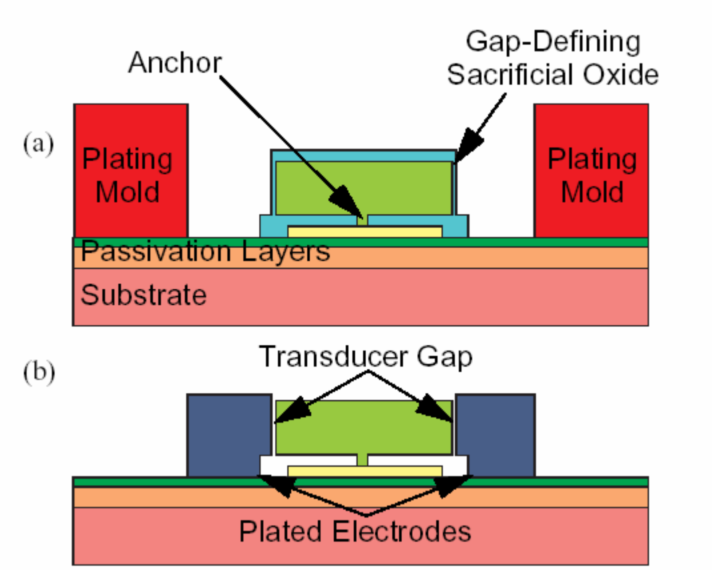


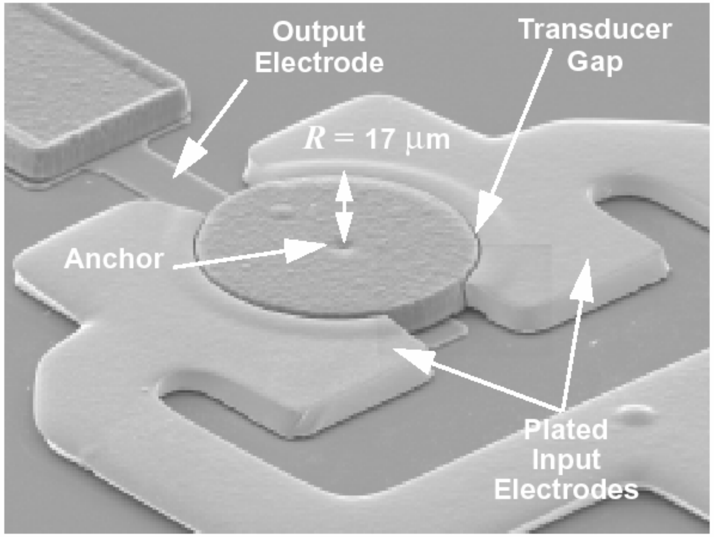
•Micromechanical Disk Resonator

✓ **Highest reported frequency for capacitive driven resonator ;**
f > 150 MHz

✓ **Highest reported Q at this frequency ; Q = 9400**

× **Achieving fully balanced structure which is supported at the center is not guaranteed.**



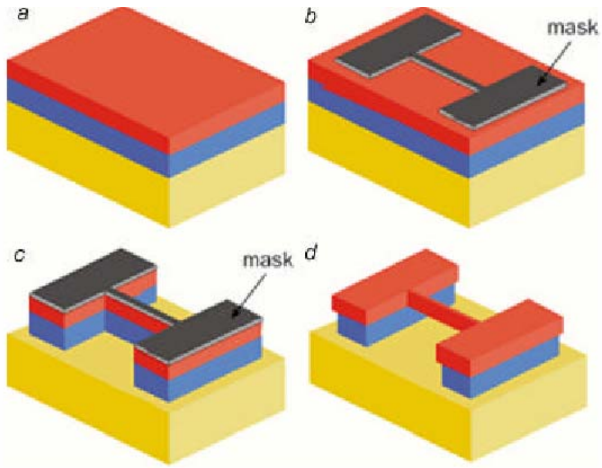


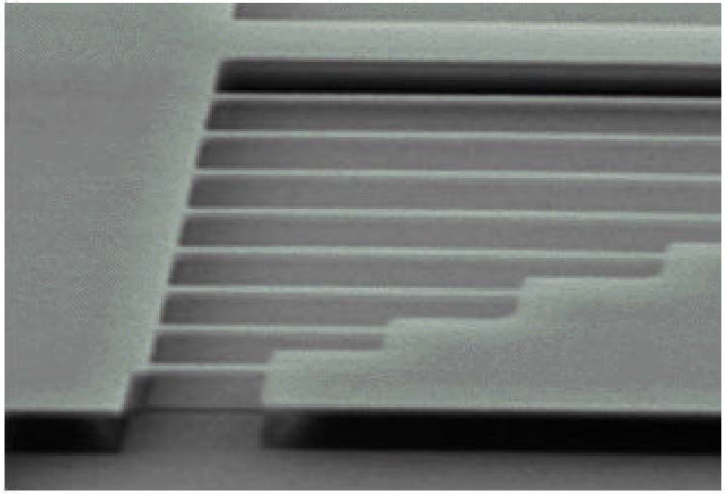
Disk Resonator, C. Nguyen et al

Single Crystal Silicon Resonators

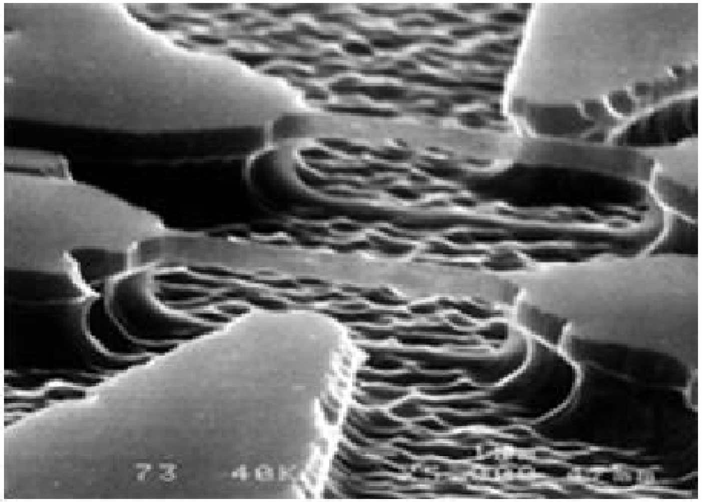
Advantages:
- ✓ **Higher material Q**
- ✓ **Less dependence on process variations**

Challenges:
- ✓ **Less design flexibility**





Doubly clamped Si beams, H.Craighead et al



Doubly clamped Si beams, M.Roukes et al

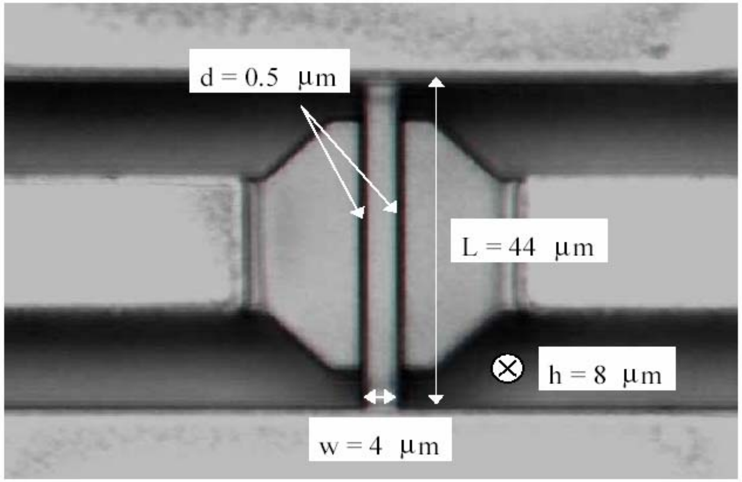
• SCS Resonator with Si Electrode (SOI Substrate)

Advantages:

✓ **Single mask easy process**

Challenges:

✓ **Very narrow trenches need to be etched for capacitive gap**



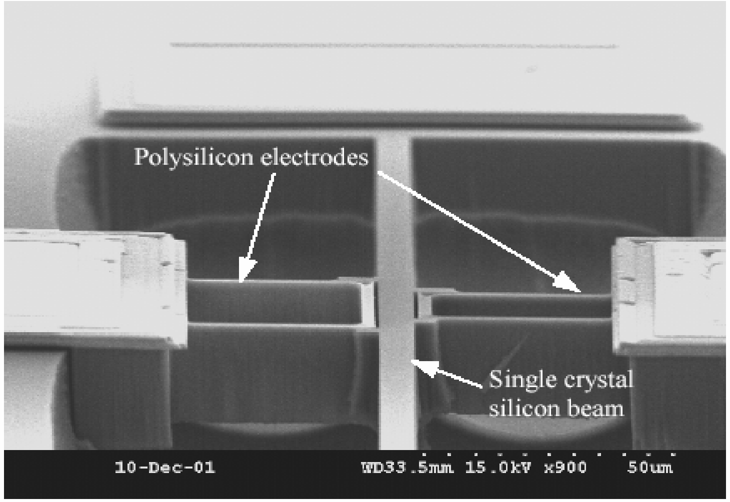
Doubly clamped Si resonator, I. Tittonen et al

• SCS Resonator with Polysilicon Electrodes

Advantages:

✓ **Combining the advantages of polysilicon micromachining with single crystal resonator**

To be explained in details by next presenter !



Doubly clamped Si resonator, F. Ayazi et al