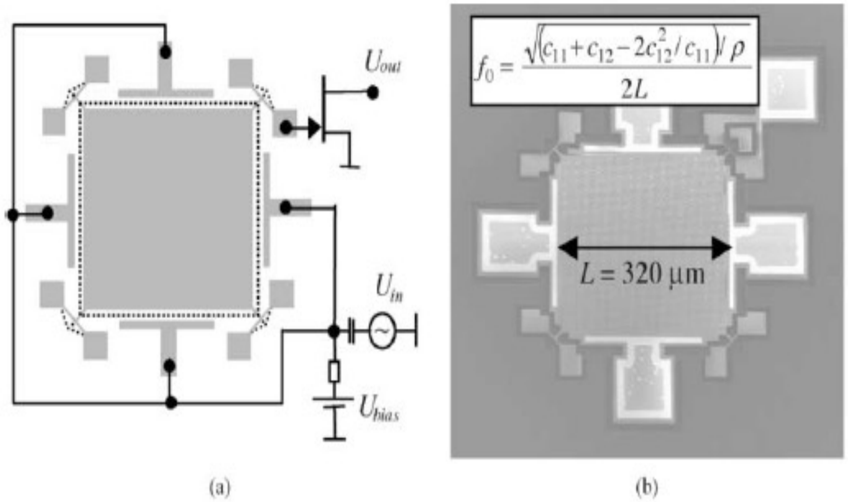
In-plane bulk-mode resonators (Lamé, breathing…)

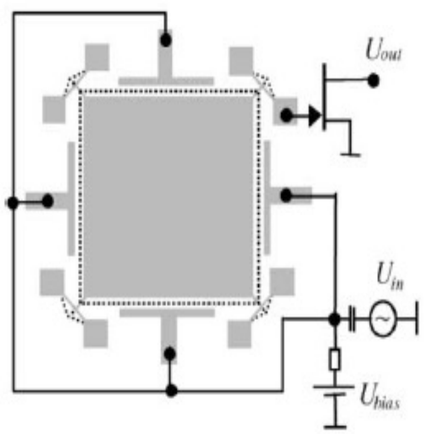


Here *h*=10 µm thick

Fig. 1. Square-extensional microresonator (f_0 = 13.1 MHz and Q = 130 000). (a) Schematic of the resonator showing the vibration mode in the expanded shape and biasing and driving setup. (b) SEM image of the resonator.

V. Kaajakari et al., « Square-Extensional Mode Single-Crystal Silicon Micromechanical Resonator for Low-Phase-Noise Oscillator Applications », IEEE ELECTRON DEVICE LETTERS, VOL. 25, NO. 4, 2004

Bulk mode: large mass, high Q, can make as thick as technology allows



320 x 320 x 10 µm^3

For this mode, the spring constant is:

$$k = \pi^2 Y_{2D} h$$

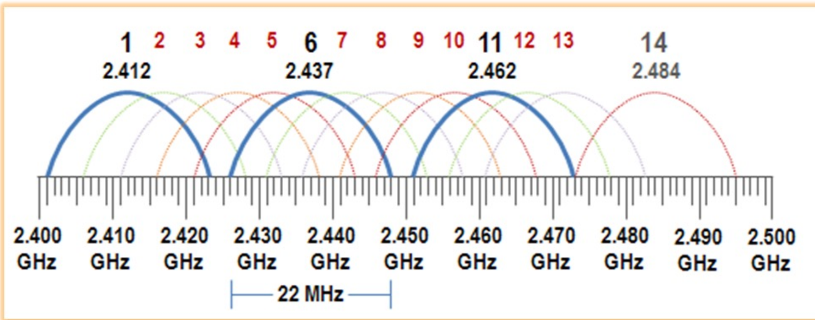
With Y_{2D}= 181 GPa

1. Compute f_{res} for given dimensions
2. How does f_{res} depend on h ?

$Y_{2D} = C_{11} + C_{12} - 2C_{12}^2/C_{11} = 181$ GPa

Frequency

- If we allow max 0.1% change in frequency, how much change in L can be tolerated?
- Is this feasible? (= how well can we control L?)



Motion due to ES force

- Compute k. how does this compare to spring constants you usually see in MEMS? Stiffer? Softer?

- compute the electrostatic force from the bias voltage only
  - Gap is 0.75 µm,
  - electrode length is 290 µm,
  - Bias voltage = 100 V.

- compute the electrostatic force from the AC voltage
  - Q=6200
  - V_{ac} = 1 V

- Compute the static displacement due to the bias voltage . Comments?

Thermal vs. mechanical energy

- At resonance, we have x_{vib} = 1.5 nm
- Compare thermal energy and mechanical energy. Your comments?
- E_{mech} : how does it scale with *h* ? With V?
- How low would the bias voltage have to be to have: $E_{mech} = 100 \times E_{thermal}$?