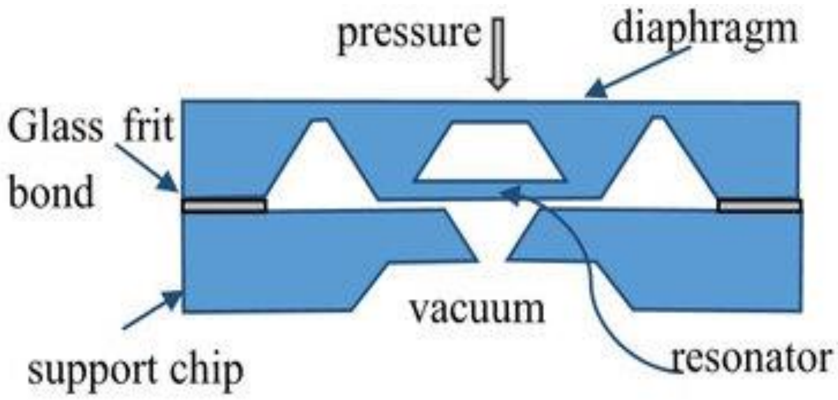
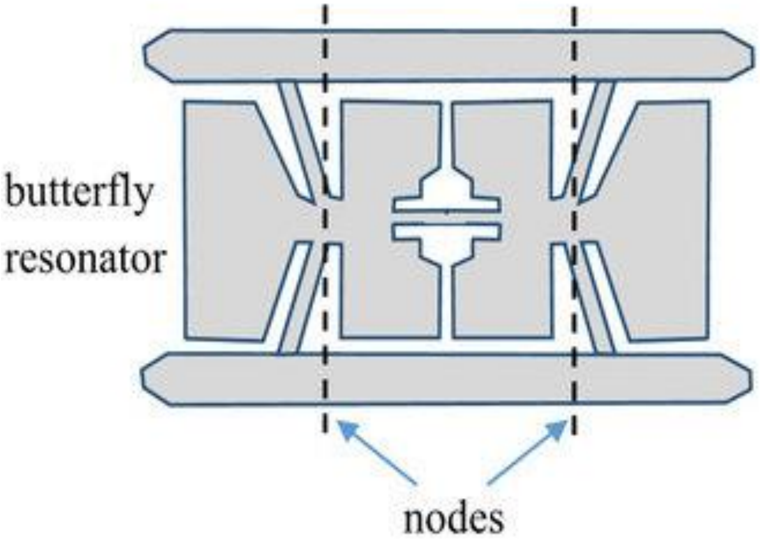
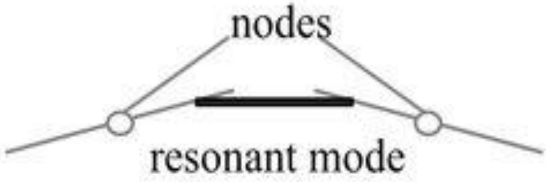
RESONANT SENSOR



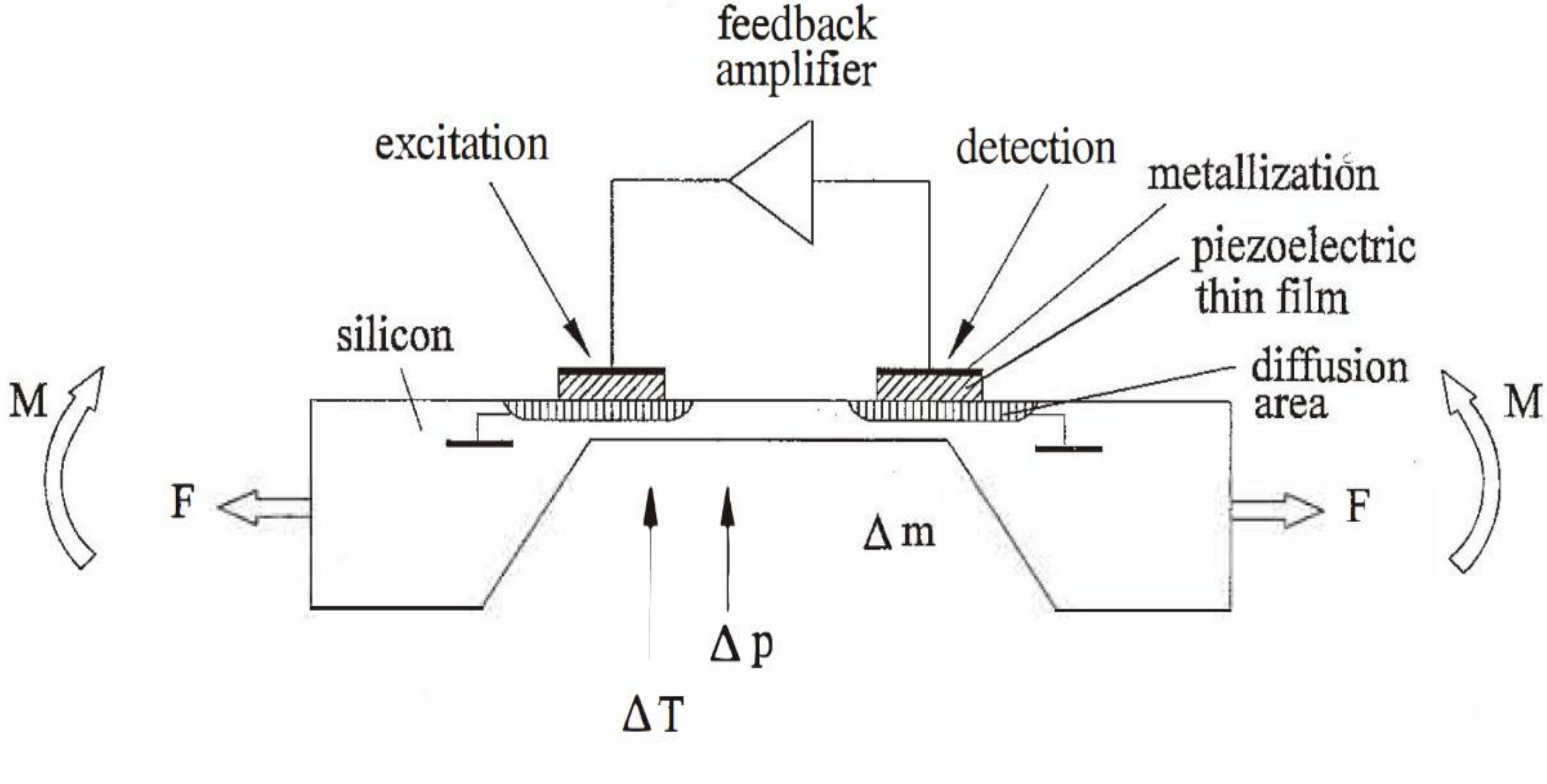




- Resonant sensors, which change their output frequency as a function of the quantity to be measured, are **attractive because of their high sensitivity, high resolution, and semi-digital output**.
- They are based on the fact that the frequency of acoustic waves in solids is a **highly sensitive probe for parameters** that alter the geometry or the boundary conditions of the resonating structure.
- They are **fabricated from single-crystal silicon** using **micromachining technologies like anisotropic** wet etching and thin film deposition.

- For ideal boundary conditions the dynamic behaviour of simple resonator structures, for example double-clamped prismatic beams or all-around clamped flat diaphragms, may be modelled analytically with sufficient accuracy.
- In the case of arbitrary boundary conditions or of more complex resonator structures like non-prismatic beams, ‘butterfly’-resonators it is very difficult or even impossible to perform the analysis on the basis of analytical models.
- Instead numerical methods like the **finite element method (FEM)** may be used to study the **behaviour of such resonators and to enable an efficient sensor design.**

Principle of resonant silicon micro sensors



finite element method ([FEM])

- The general scheme of a resonant pressure or force microsensor, which is **driven to resonant vibrations by piezoelectrical thin films,** is shown in Fig. 1.
- The **resonant element consists of a silicon diaphragm or beam wet etched** from the backside of the wafer. Piezoelectric thin films,
- for example **zinc oxide** (ZnO) layers are **used to excite and to detect the vibrations of the resonator** which is **connected to the feedback loop of an oscillator circuit.**

fabrication process

- patterning and doping of the ground electrode areas. In order to achieve a high electromechanical coupling efficiency, ZnO has to be grown with its c-axis perpendicular to the film plane and the silicon substrate.
- Well-oriented ZnO films may be deposited by **r. f. sputtering** from a Zn or ZnO target in an Ar/O2 plasma.
- The ZnO is wet etched in a stirred solution of HAc, H3PO4, and H2O in order to form the piezoelectrically active regions.

- A sputtered and patterned Al metallization layer is used as the top electrode contact for the ZnO film.
- After completing the planar front-side process, **anisotropic wet etching from the rear is applied to produce the desired beam or diaphragm thickness.** In the case of beamlike resonators, in the final step deep trenching is performed by **plasma etching the diaphragm from the front side.**

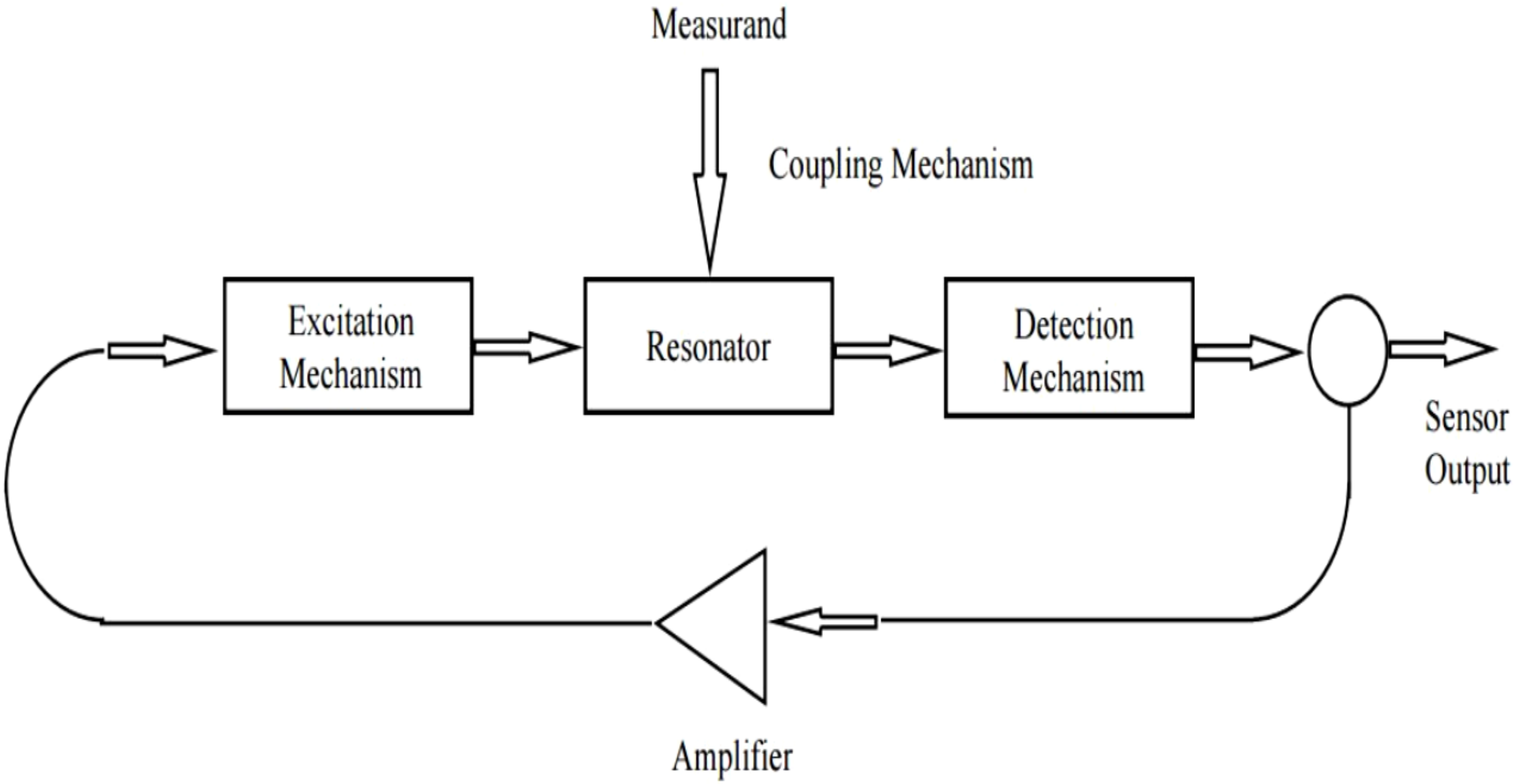
FUNCTION:

Mechanical loading of the resonator due to a pressure difference Δp at the diaphragm or due to external forces F and moments M exerted on the beam results in a tensile stress in the resonator element.

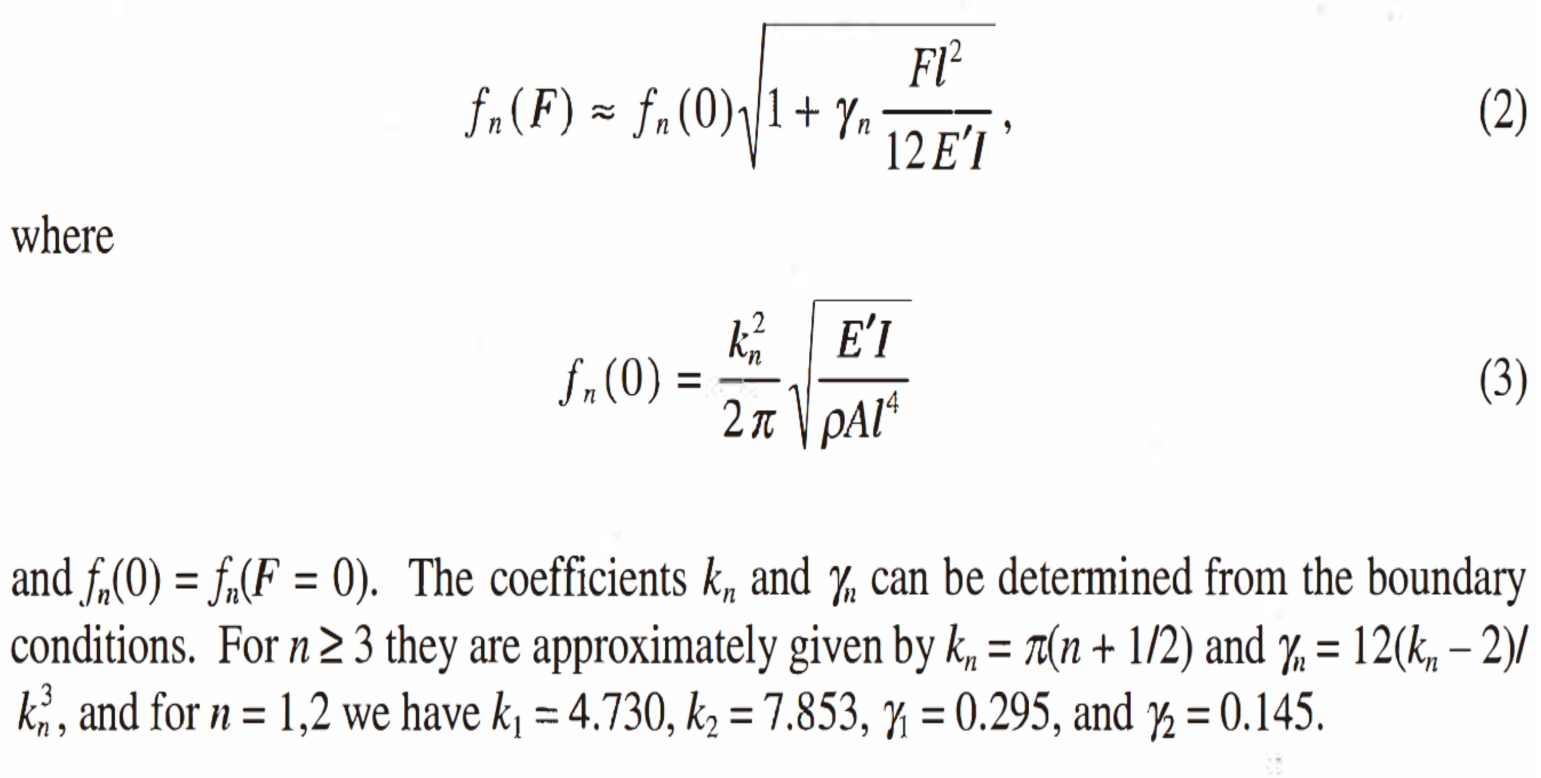
Stress **stiffening effects will occur, which increase the stiffness of the resonator,** thus changing its resonance frequency.

Furthermore, a **mass loading Δm or a temperature rise ΔT may lead to a frequency decrease**.

The output of the electronic oscillator circuit is fed to a frequency counter recording the load-dependent signal. The resonant microsensors are based on this principle; they consist of the **passive resonator element (i.e. beam, membrane, etc.) and active elements for excitation and detection (electronics) of vibrations.**


Measurand
Coupling Mechanism
Excitation Mechanism
Resonator
Detection Mechanism
Sensor Output
Amplifier

- Assuming homogeneous and isotropic material properties, the resonance frequencies, mode shapes, and load dependent frequency changes can be calculated with sufficient accuracy.



$$f_n(F) \approx f_n(0)\sqrt{1+\gamma_n \frac{Fl^2}{12E'I}}, \tag{2}$$

where

$$f_n(0) = \frac{k_n^2}{2\pi}\sqrt{\frac{E'I}{\rho A l^4}} \tag{3}$$

and $f_n(0) = f_n(F = 0)$. The coefficients k_n and γ_n can be determined from the boundary conditions. For $n \geq 3$ they are approximately given by $k_n = \pi(n + 1/2)$ and $\gamma_n = 12(k_n - 2)/k_n^3$, and for $n = 1,2$ we have $k_1 = 4.730$, $k_2 = 7.853$, $\gamma_1 = 0.295$, and $\gamma_2 = 0.145$.


Thank you