Novel simulation of DC voltage Electro thermo mechanical MEMS self-oscillator

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MEMS oscillators

Principle electro thermo mechanical oscillator

Modeling

Use of COMSOL

Future work
MEMS OSCILLATOR

An oscillator consists of a frequency selective element, which is the mechanical resonator, and a gaining element which is the feedback amplifier.

The feedback or sustaining amplifier is required to sustain a resonance in the frequency selective element.

Resonator and amplification separated; integrated with the CMOS die in the same package.
ELECTRO-THERMO-MECHANICAL OSCILLATOR

- NXP semiconductor (2009) and Rahafrooz (Denver 2010).
- The closed loop (self amplification) is obtained by crossing interaction between three physical domains: Joule heating (thermal domain), thermal expansion (mechanical domain) and piezoresistivity effect (electrical domain).

The resistive heating power in the nanobeam, results in an increasing temperature, after a thermal delay. The temperature increase causes a thermal expansion force, which acts as a feedback force on the mass.

The displacement of the resonator mass is amplified, because it modulates the resistive heating power in the nanobeam via the piezoresistive effect, which results in a power variation.

- Single crystal silicon resonator structure spontaneously starts to oscillate.

Feedback with piezoresistivity modulation
Resistive heating power increase = $\Delta T$

Thermal expansion

$\frac{\Delta X}{X_0} = \alpha \Delta T$

Compression

$\Delta X \rightarrow \frac{\Delta R}{R} < 0$

$\frac{\Delta R}{R} = \pi_t \sigma_t = \pi_t E \frac{\Delta X}{X_0}$

Dilatation

$\Delta X > 0$

$\frac{\Delta R}{R} > 0$

$\frac{\Delta R}{R} = \pi_t \sigma_t = \pi_t E \frac{\Delta X}{X_0}$
**ANALYTICAL MODEL**

**Barkhausen criteria**

\[ |A(\omega)\beta(\omega)| = 1 \quad \text{and the phase } [A(\omega)\beta(\omega)] = 2\pi n, \quad n \in 0, 1, 2, \ldots \]

**Novelty**

- DC voltage driven oscillator (more simple) and positive coefficient of piezoresistivity (most common)

**Bloc diagram model**

**Conditions of oscillation**

**DC voltage**

\[
\omega_{0osc}^2 = \omega_0^2 (1 + 1/C_{th}R_{th}\omega_0 Q_{int})
\]

\[
V_{dc}^2 = \frac{R_{dc}}{Q_{int}} \frac{1 + \omega_0^2 C_{th}^2 R_{th}^2}{C_{th}R_{th}^2 \omega_0 \alpha K_{pr}}
\]
COMSOL SIMULATION (OSCILLATOR)

- **Piezoresistivity effect**: Electrical conductivity expression of the material as a function of the stress due to the piezoresistivity property of silicon.

- **Simulation time optimization**: Stationary study as initial values for the complete Time dependent study.

- **Simulation “stabilization”: Hyperelastic material** to accentuate the nonlinearity effect of the material.

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Run implanting the piezoresistivity effect and presenting the growth oscillation aspect. *(Time dependent simulation)*
Parametric sweep simulation to check the threshold limit voltage condition
**FUTURE WORK**

**Fabrication**

1. Spin on photoresist
2. Pattern and develop photoresist (mask)
3. Spin on photoresist
4. Remove photoresist
5. HF release (removed part of the mask)

**Silicon On Insulator Wafers (SOI)**

**Measurements (just started)**

**Applications**

- Timing devices
- Sensors (gaz sensor)
- Heat engine, pumps..
- Sustained self system
- Energy harvesting..
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