Comparative Analysis of Three types of Micromechanical Resonator: An Overview

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ABSTRACT

A micromechanical resonator is a mechanical structure equipped with some transform mechanism that is capable of exciting the resonator to vibrate at its resonant frequency. The resonator is usually excited at its fundamental resonance mode. However, excitations at its higher-order modes are also possible. This paper is based on the comparative analysis of different types of micromechanical resonators. We have described C-C beam, F-F beam and lateral beam resonators. The main emphasis of this paper is on to review the advantages, disadvantages and tremendous characteristics of various micromechanical resonator sensors over the other traditional resonator sensors. It also covers various different parameters which are required to achieve the good quality of the resonator structures are also described in the work. The resonators are analyzed on the basis of various parameters like length of the beam, width of the beam, resonant frequency of the beam and the quality factor. Finally the paper is concluded by discussing some suggestion which can help in improving the quality factor in comparison to previous micromechanical resonator structure.

Keywords: Resonator, C-C beam-F beam, quality factor (Q-Factor), resonator frequency.

1. INTRODUCTION

The micromechanical resonator is usually excited at its fundamental resonance mode. However, excitations at its higher-order modes are also possible. The resonant frequency is dependent on the type of structural material used for vibrating parts and on the geometric dimensions of the resonator. Piezoelectric materials such as quartz or Lead Zirconate Titanate (PZT) could be used as an excitation source through piezoelectric actuation and sensing techniques. Although piezoelectric resonators have their advantages, their major drawback is the process limitation for integration with CMOS electronics, with the exception of AlN-based resonators. Furthermore, the drive and sense electrodes of piezoelectric resonators are in direct physical contact with the resonating body, resulting in higher energy loss and degradation in quality factor. Resonant sensor as the name suggest follows the key principle stated as[1,2].There are so many application based on the micromechanical resonator which uses the physical phenomenon such as shift or change in the resonance frequency of the main beam of the resonator because of the change in the applied force or voltage or external stimuli, some of the applications are, Vibratory gyroscope, Mass sensors, Biological & Chemical sensors and Temperature sensors. In communication resonator are implemented in devices for frequency generation (reference oscillation) and for frequency selection (Filters). Every wireless communication system requires highly selectively filters for both receiver and transmitter. High quality factor is generally required but the quality factor cannot be too high because of the trade-off b/w Q and coupling of multiple resonators. The types of resonators used today in wireless communication are SAW (Surface Acoustic Wave), ceramic filters, quartz filters, BAW (Bulk Acoustic Wave) and FBAR (Film Bulk Acoustic Resonator).

The rest of the paper is organized as follows: Section 2 describes the main features of three different types of RF MEMS Resonator reviewed. Section 3 presents the performance parameters analysis and comparison. Conclusive remarks are addressed at the end of this paper.

2. THE MAIN FEATURES OF MICROMECHANICAL RESONATOR

This section specially reviews about the three important characterization of RF MEMS resonator given in following lines:

- C-C beam as a resonator
- Free-Free beam micromechanical resonator
- Lateral comb resonator

2.1 C-C Beam as a Resonator

Clamped-Clamped beam resonator is designed for lateral vibration in two-port drive and sense arrangement When an ac source is applied to drive electrode and dc voltage *Vdc* is biased to moving resonator, time-varying force is generated and as the ac drive frequency matches the natural resonant frequency of the beam, the resonator is set into vibration. The capacitive current appears at the sense electrode and it can be detected by a transresistance amplifier [3]. The electro statically actuated clamped -clamped beam resonator’s mechanical structure is described as:

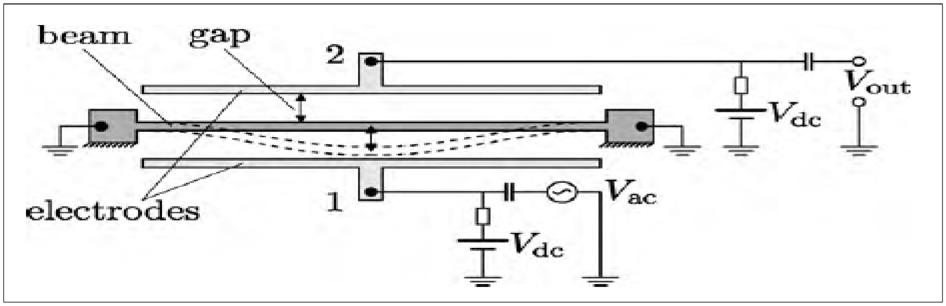

Fig.1 Schematic layout of clamped- clamped beam resonator [3]

The actuation of the resonator is realized by means of a dc (Vdc) and an ac (Vdc) voltage component, which are applied to the electrodes of the resonator by means of bias tees. During measurements, the resonator output voltage Vout is measured. This quantity is a function of the clamped–clamped beam flexural displacement and its first time derivative. The resonators are fabricated by the use of silicon wafers. The fabrication process is as follows:

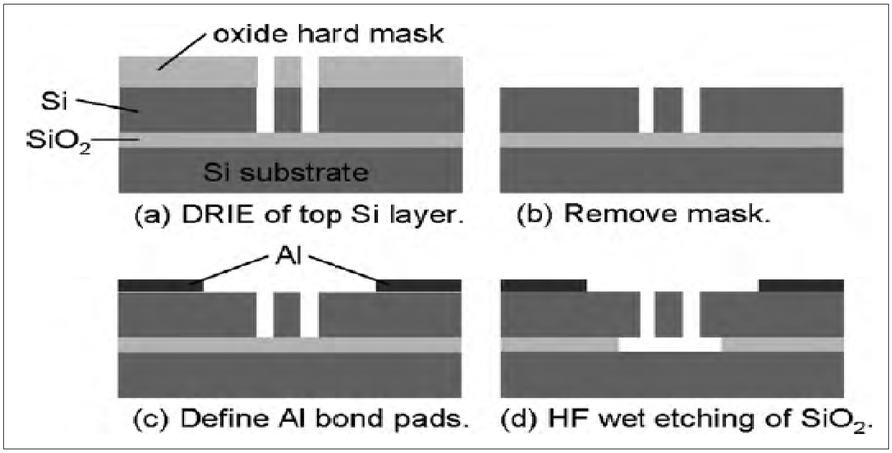

Fig.2 Fabrication of resonator [3]

Oxide hard mask is patterned on the wafer by the use of resist, and then the mask is used for etching the resonator layout, which is into the 1.4µm thick SOI layer down to the buried oxide layer. The etching is done by DRIE (Deep Reactive Ion Etching).Then the hard mask is etched away and Al bond pads are patterned. Then the resonator is removed from the substrate by the use of isotropic etching (it uses the wet HF solution). If we see MEMS resonator it works in vacuum so fluid loss is negligible and under the pressure of 0.01 mbar the Q-Factor is not pressure dependent. So the Q-Factor is depending on two things: Thermo elastic damping (Q_{th}), Anchor loss (Q_a). The high Q- Factor tends to increase the resonator frequency.

2.2 Free-Free beam micromechanical resonator

Among the three resonators the free-free beam resonator is designed to increase the quality factor [5]. The quality factor is increase due to the reduction of the anchor loss or energy loss at the clamps. These resonators are fabricated by using the THELMA MEMS technology, developed at STMicroelectronics [6]. Initially the polysilicon layer is used for electrical connectivity and it followed by silicon dioxide layer and then over it grown the thick ploy silicon layer, which forms the structure of resonator and the electrodes and finally by etching the resonator structure free to move under the electrostatic force. The capacitance depends on the polysilicon thickness i.e. for high polysilicon thickness the capacitance will be high and the more is the electromechanical coupling. The free-free beam resonator is obtained by suspending the main beam with the two support beam i.e. the main beam is clamped at the two ends with the two support beams and which corresponds to the node of free-free mode which has to be excited. Free-free beam are designed in two modes, first FF1 mode and the FF3 mode [3, 4]. There are many difference b/w the FF1 and the FF3 mode like

- The main beam length of the resonator in FF3 mode is longer than the FF1 mode, which results in increase in frequency of the resonator in comparison to FF1 mode.
- FF3 mode have broad electrodes which increases the capacitance b/w electrodes hence increases the electromechanically coupling b/w them.
- FF3 mode has higher Quality factor then the FF1 mode micromechanical resonator.

Hence we can say the FF3 mode resonator is more efficient than FF1 mode resonator.

2.3 Lateral comb resonator

Lateral comb resonator uses silicon because of its flexibility and electrostatic property [7]. Usually electro statically driven actuator has a parallel plate clamped- clamped beam configuration which have a characteristic of nonlinear configuration and the nonlinearity is not suitable for frequency stability hence there is used another actuated electro statically structure at micro scale. There are two resonator configuration can be done with this structure [1, 7, 2],

- A two port configuration, the structure is driven at one of the comb structures and sensed at the other, for capacitance variation.
- Both comb structure are used to drive differentially, while sensing is achieved by monitoring shift in the impedance at resonance.
- The circuit configuration for resonating the lateral comb device is shown in the following figure:

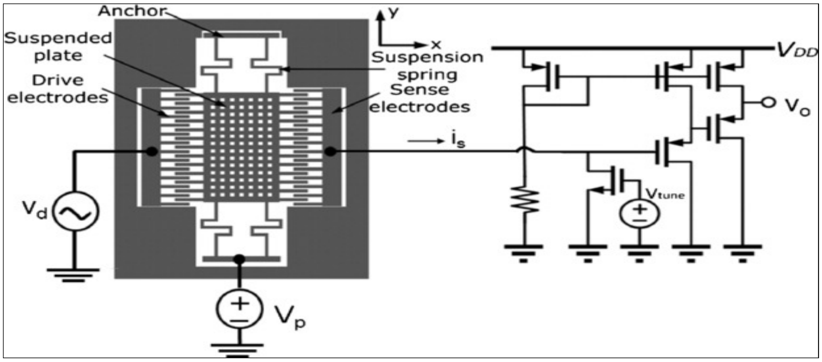

Fig.3 Circuit indicates the CMOS arrangement for driving the microstructure into resonance. [9]

The dotted lines correspond to additionally circuitry required for motional current sensing via electromechanical modulation.

3. PERFORMANCE PARAMETERS ANALYSIS AND COMPARISON

To measure the frequency of the mechanical vibration of beams or diaphragms, we apply strain which causes changes in resonant frequency by which we can measure the input variables such as pressure, acceleration, temperature and rate. The key point i.e. resonant sensing can be understood by measuring the change in the natural frequency of string by changing the tensile force. So in the resonant micro sensor the main cause of generation of strain is change in the natural frequency of the micro beam or diaphragm.

E.g. The natural frequency of flexure resonator with both ends fixed can be obtained from the following [1, 2, 5]:

$$f = \frac{4.73^2 h}{2\pi l^2}\{\frac{E}{12\rho}[1 + 0.2366(\frac{l}{h})^2 \varepsilon]^{\frac{1}{2}}\} \tag{1}$$

Where f = the natural frequency of the basic oscillation mode,
l = the resonator length,
h = the resonator thicknesses,
E= The Young’s modulus,
ρ = the density of the diaphragm material and
ε = the strain generated inside the resonator structure.

If we compare the piezoresistive sensing with resonant sensing we can see that the resonant sensing is more valuable then piezoresistive sensing, it can be proved by the help of the Gauge factor which measures or determines the strain resonant of the resonant sensor and the piezoresistive sensor. There are different methods for measuring the same for resonant and piezoresistive sensors, which are given as follows :

For piezoresistive sensor the gauge factor can be determine as:

$$G = \frac{\frac{\Delta R}{R}}{\frac{\Delta l}{l}} = \frac{\Delta R}{\varepsilon R} \tag{2}$$

For the resonant sensor the gauge factor can be determine as:

$$k_{gf} = \frac{1}{2}\left[\frac{0.2366\left(\frac{l}{h}\right)^{2}}{1+0.2366\left(\frac{l}{h}\right)^{2}\varepsilon}\right] \qquad (3)$$

Dimitiri Galayko et.al [8] have discussed, that one of the important performance parameter is the quality factor which is commonly depended on the resonant frequency, for C-C beam resonator the quality factor decreases with the increase in the resonant frequency. Apart from resonant frequency quality factor also depends on the resonator beam length, width and material used.

D. Paci et.al [6] discussed about the three different kinds of micromechanical resonator and concluded that among the three resonators the free-free beam resonator is designed to increase the quality factor. The quality factor is increased due to the reduction of the anchor loss or energy loss at the clamps.

4. CONCLUSIONS

It concludes that the RF MEMS resonators are essential part of the micromechanical filters. The micromechanical filters structures contain the array of the micromechanical resonator which allows band pass filtering from them. The filtering with the set of resonator usually depends on the key factor which is known as the Q-factor which in turn depends on the resonance frequency of the resonator i.e. with the increment of the resonance frequency the Q- factor will increase. In terms of energy, the Q- factor is expressed as the measure of energy stored in the system to the energy dissipated per cycle. The RF MEMS resonators have a property of nonlinearity i.e. with the increment of time there can be sudden change in the frequency of the resonator, therefore to decrease the non linearity a different resonator technique was developed, known as lateral comb resonator. The original reviews allow us to compare the performance in terms of length of resonator beam, width, material, resonating frequency and most important quality factor.

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