A MICROMACHINED TUNABLE CPW RESONATOR

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Abstract • **This paper presents a novel tunable microwave resonator, consisting of a CPW spiral inductor with a cantilever interconnect structure. Tuning was achieved by applying a DC bias between the input and output of the resonator circuit. An observable resonance tuning between 3 and 7 GHz was accomplished by applying a bias from 0 to 40 V. Corresponding Q-factors between 17 and 20 were obtained in this tuning range.**

I. Introduction

Many microwave circuits, e.g. RF/IF filters and voltage-controlled oscillators (VCO), require stringent control of the desired performance characteristics. Such devices mainly use hybrid tuning components, however recent developments in microelectro-mechanical systems (MEMS) have shown that mechanical tunable components and electronic circuits can be realized on a single integrated chip [1]. Alternative technologies, including ferroelectric materials, have also received considerable interest of late [2].

In this paper, a new tunable resonator is presented that is built around a coplanar waveguide (CPW) spiral inductor and is imbedded in a Pyrex• substrate. Pyrex• provides low loss characteristics at microwave frequencies and a relatively low dielectric constant of around 4 [3]. Instead of using an airbridge to connect the center conductor of the spiral to the outside conductor, a cantilever beam was fabricated using surface micromachining techniques, and suspended over the turns of the inductor. By providing a bias between the input and the output of the inductor, the tip of the beam can be electrostatically induced to make contact with an insulator deposited on the center pad of the spiral. Further tuning can then be achieved by increasing the bias, causing the beam to deflect towards the inductor due to the electrostatic force produced between the beam arm and the spiral turns.

II. Resonator Geometry

A layout of the CPW spiral inductor with a tunable cantilever beam, as well as an optical microscope image of a fabricated device, is shown in Fig. 1. The inner spiral has an approximate footprint of 1 mm^2. The spiral segments were 50 μm wide with a 75 μm spacing between them. The dimensions of the CPW feedlines were found using ***LineCalc*** [4] (360 μm center conductor width and 50 μm conductor to ground spacing) to provide a characteristic impedance of 50 Ω. Also, winged extensions over the spiral segments were added to the beam arm to decrease the voltage needed for tuning. A significant advantage of this geometry is that a wide range of inductance and capacitance can be achieved with relatively simple geometrical modification, thereby controlling the resonance and bandwidth.

III. Resonator Tuning

By applying a voltage between the top plate of the beam and the bottom plate of the spiral, a deflection of the beam towards the spiral pad can be produced due to the resulting electrostatic force. The amount of deflection is a function of the voltage applied and the geometry and mechanical properties of the cantilever beam. Since in the case of the tunable resonators the beam is anchored at one end, maximum deflection will occur at the tip of the beam. Equations for the voltage as a function of beam displacement are reviewed in recent literature, but have been shown mainly for less complex switching applications [5,6].

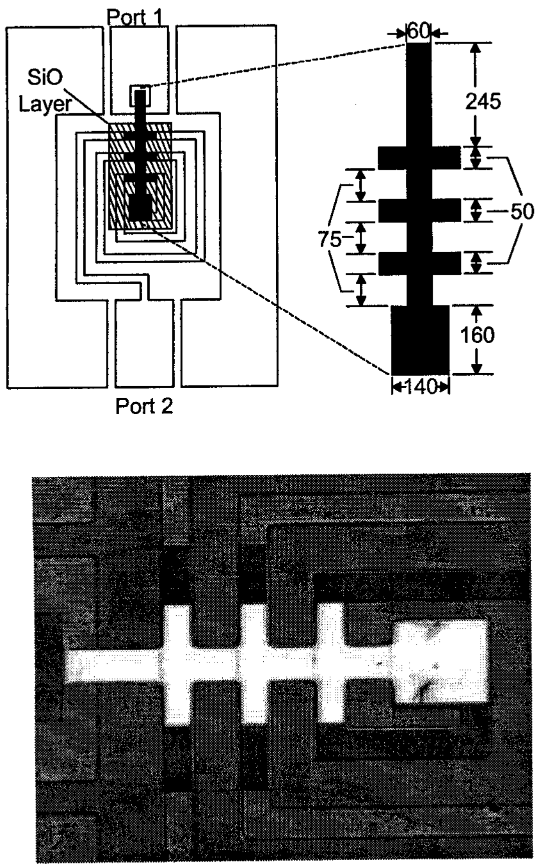

Figure 1. CAD layout (top) and optical microscope image (bottom) of the fabricated tunable spiral resonator showing the suspended cantilever beam. (Dimensions shown are in μm).

Once the appropriate voltage is applied to initiate the deflection of the beam towards the lower plate, the bias can be increased to decrease the distance between the plates. It has been shown that a pull-in voltage exists, at which point the beam actuation overcomes the natural restoring spring force of the cantilever material, causing the beam to deflect toward the lower plate until the gap is closed. After the gap is closed between the two plates, there still exits an electrostatic force of attraction between segments of spiral lines and the beam segments directly above them. The beam arm will thus be drawn closer towards the spiral as the bias is further increased to provide additional tuning. This concept is illustrated in Fig. 2.

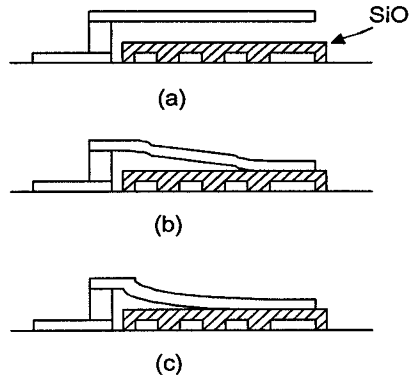

Figure 2. Side view of suspended beam showing the cantilever (a) at 0V bias, (b) in actuated state after the pull-in voltage is reached, and (c) in continual tuning state with increase in bias as the beam arm is pulled down towards the spiral turns.

IV. Fabrication

The resonator is fabricated using standard micromachining and photolithography techniques. Initially the resonator geometry is etched into the Pyrex* substrate to a depth of 2 μm, which corresponds to the line thickness of the circuit, to achieve a near planar level between the Pyrex* and the resonator surface. The Pyrex* is etched using a chromium/gold mask to define the resonator geometry in a Hydrofluoric-Nitric acid and de-ionized water mixture (20:14:66) [7] to etch the exposed substrate surface. After the metal mask is removed, the metal lines of the resonator are gold electroplated to a 2 μm thickness. A 0.4 μm layer of silicon monoxide (SiO) is thermally deposited on the spiral surface to act as an insulating layer between the inductor spiral and the suspended beam. The pedestal needed to anchor the cantilever beam to the center conductor is also gold electroplated to a thickness of typically 2 μm.

The photoresist layer used to define the pedestal in the previous step is used as the sacrificial layer during the release process of the cantilever beam. A 1.2 μm thick layer of aluminum is thermally evaporated on top of a 400 Å chromium adhesion layer (also thermally evaporated). Photoresist is used to define the beam structures and serve as a protecting mask while the surrounding chromium/aluminum layers are removed during etching. The beam is then released using a critical point dryer wherein the dissolving liquid (methanol), used to remove the sacrificial photoresist layer, is replaced with liquid CO_2 and is dried at the supercritical point.

V. Results

Measurements were taken on a Wiltron 360 Vector Network Analyzer (VNA) with a Jmicro probe station and 650 μm pitch GGB (ground-signal-ground) probes. A voltage supply was used to bias the circuit through the VNA's test ports. No change in the S-parameters was observed until the actuation bias of 17 V was reached. The bias was then increased by 1 V increments, causing the center frequency of the first series resonance to shift lower in frequency. The abrupt change of the resonance from a zero bias to the point of actuation, and the consequent tuning of the resonance of the resonator is shown in Fig. 4 and 5, respectively.

The quality factor of the resonator can be calculated by finding the loaded Q at the first resonance (Eqn. 1) and subsequently calculating the unloaded Q (Eqn. 2).

$$Q_{loaded} = \frac{f_0}{BW} \tag{1}$$

$$Q_{unloaded} = \frac{Q_{loaded}}{1-|S_{21}|}, \tag{2}$$

where f_0 is the center frequency at the resonance, and BW the S_{21} 3dB bandwidth at resonance. The calculated Q's are shown in Table 1. For comparison, a non-tunable inductor with the same spiral geometry but with a fixed airbridge was found to have a Q of 47 at 5 GHz [8].

Table 1. Calculated Q's at the first resonance.

Applied Bias	f_0 (GHz)	Q
0 V	6.5	16.3
17 V	4.0	20.4
40 V	3.4	18.9

It was found that the quality factor increased after the actuation voltage was applied. This is due to the decrease in the insertion loss as the tip of the cantilever beam makes contact with the center of the spiral inductor. It can also be observed that the Q of both resonators decreases slightly as the tuning bias is increased, due to the decrease in the center frequency and slight increase of the 3 dB bandwidth.

The response of the resonator at 0 V bias was compared to simulated results using the ***Momentum*** EM field simulation software [9] as shown in Fig. 5. The cantilever height was set to 3 μm for the simulation. The discrepancy between the results is partially due to an inability to properly model the finite SiO pattern in ***Momentum***. Also, the released cantilever beam is not entirely planar as assumed in the model. These issues will be addressed using alternative (e.g. finite element) simulation tools.

VI. Conclusion

A novel tunable microwave resonator, comprised of a CPW spiral inductor and a cantilever beam interconnection, was fabricated using micromachining techniques and tested from 1 to 14 GHz. The actuation voltages occurred at 17 V, and maximum bias of the tuning element was reached at 38 V. In this bias range, tuning of the self-resonance between 3 and 7 GHz was observed. This new geometry should prove useful in the design of circuits such as tunable matching networks and RF filters, and future work will address lowering the actuation voltage.

Acknowledgement

This work was partially sponsored by The National Science Foundation, grant no. ECS 9875235.

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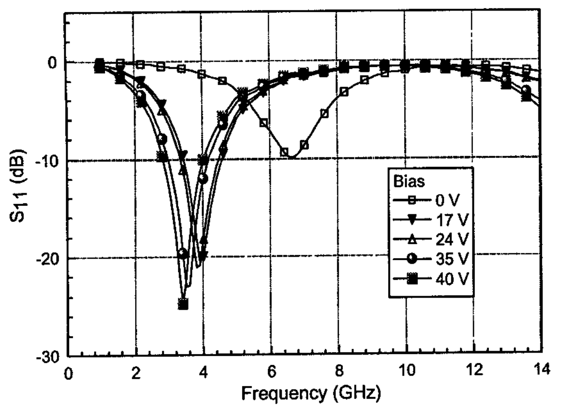

Figure 3. S_{11} of the resonator at various tuning biases.

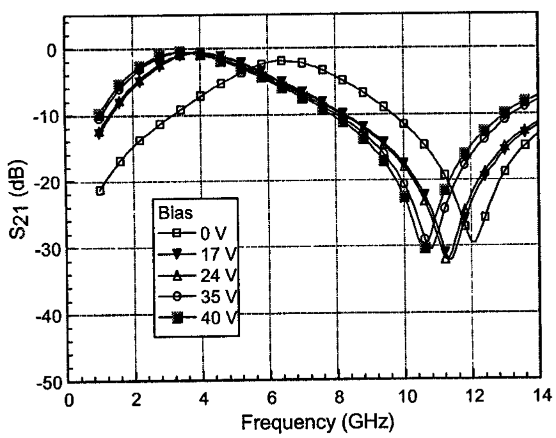

Figure 4. S_{21} of the resonator at various tuning biases.

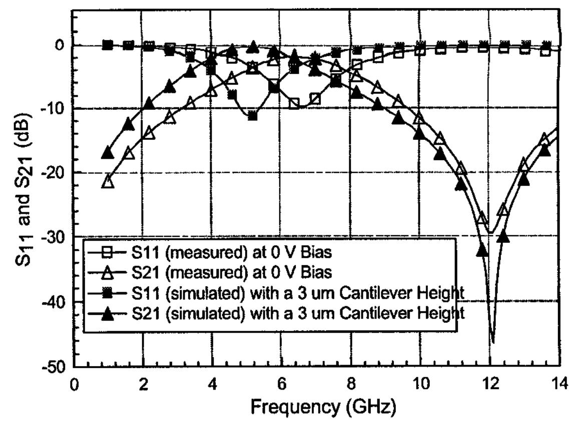

Figure 5. Comparison of the S11 and S21 response of the resonator at 0V bias to corresponding simulated results performed with the beam height set to 3 μm.