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Citation for published version:

Svilli, B, Mastropaolo, E & Cheung, R 2014, 'A MEMS Filter Based on Ring Resonator with Electrothermal Actuation and Piezoelectric Sensing' *Procedia Engineering*, vol. 87, no. 0, pp. 1406-1409. DOI: 10.1016/j.proeng.2014.11.706

Digital Object Identifier (DOI):

[10.1016/j.proeng.2014.11.706](https://doi.org/10.1016/j.proeng.2014.11.706)

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Document Version:

Peer reviewed version

Published In:

Procedia Engineering

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EUROSENSORS 2014, the XXVIII edition of the conference series

A MEMS Filter Based on Ring Resonator with Electrothermal Actuation and Piezoelectric Sensing

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Abstract

We report on the design of a two-port ring microelectromechanical (MEMS) resonator with electrothermal actuation and piezoelectric sensing for filtering applications. The ring resonator has been fabricated in silicon carbide with top platinum electrothermal actuator and lead zirconium titanate piezoelectric sensor. The transmission frequency response measurements have shown that the device with a ring radius of 200 μm resonate in the frequency range 0.4 MHz – 0.6 MHz, in the presence of tuning. By applying DC bias voltage in the range 4 V – 10 V, a frequency tuning range of 330,000 ppm has been achieved.

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Peer-review under responsibility of the scientific committee of Eurosensors 2014.

Keywords: MEMS, filter, ring resonator, electrothermal actuation, piezoelectric sensing, tuning

1. Introduction

Filter electronic components and quartz crystal, for the past decade and so, have been targeted for replacement by MEMS resonator technology [1]. Selection of the overall structural design of a resonator plays a very important role in achieving expected performance of flexural-mode resonators. A ring structure can achieve higher resonant frequency and larger quality factors compared to a beam structure thus motivating its usage for the MEMS filter presented in this paper. Practical implementation of MEMS filters requires the ability for electrical actuation and

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sensing of the mechanical vibration. Electrothermal actuation has been attracting increasing attention as a means of

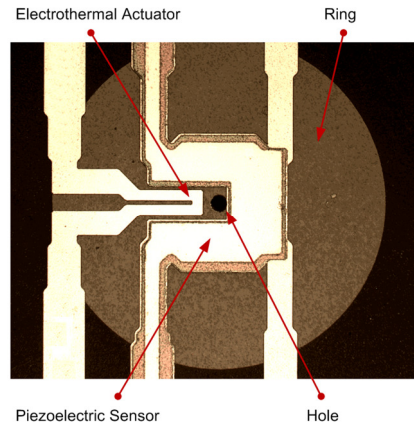


Fig. 1 : Optical micrograph of the fabricated MEMS resonator with the electrothermal actuator (input port) and piezoelectric sensor (outputport) placed on the top of the ring.

allowing simple fabrication process, low actuation voltages, impedance matching and effective frequency tuning. Recently, we have demonstrated the fabrication of bimaterial (platinum and silicon carbide) ring structure and the operation as electrothermally actuated resonator has been detected optically [2]. Moreover, we have demonstrated the piezoelectric sensing of an electrothermally actuated double-clamped beam MEMS resonator [3,4]. The use of piezoelectric transduction for electrical sensing allows active generation of electrical potential in response to an applied mechanical stress, and thus an external bias voltage source is not needed, as is required in piezoresistive and capacitive transductions. In addition, it offers stronger electromechanical coupling, better impedance matching and relatively simpler fabrication compared to electrostatic transduction.

In this paper, we integrate a piezoelectric sensor on a ring MEMS resonator with electrothermal actuation to perform filtering function. The electrothermal actuator is used to tune the device's resonant frequency in order to accommodate operational tuning requirements and possibly to compensate for frequency shifts arising due to changes in the operating conditions. The layout geometries and position of the actuator and sensor ports have been optimized in order to maximize the electro-mechanical coupling. The piezoelectric sensor is formed of a lead zirconium titanate (PZT) layer sandwiched between two platinum (Pt) layers, while the electrothermal actuator is formed from thin Pt layer. Electrothermal actuator and piezoelectric sensor are placed on top of cubic silicon carbide (3C-SiC) ring thus operating as a vertical-mode resonant device (Fig. 1).

2. Experimental details

The device has been designed as a two-port vertical-mode ring resonator. The electrothermal actuator (input port) has been designed with two Pt arms (the arms' width is 10 μm) connected by a perpendicular arm (u-shaped layout). The actuator is placed close to the hole in order to maximize vibration amplitude induced by heating and enhanced by the difference of the two materials' (Pt and 3C-SiC) thermal expansion coefficient [5]. 3C-SiC has been used as structural material due to its excellent mechanical properties that allow SiC resonators to achieve higher resonant frequencies compared to equivalent silicon (Si) resonators [6]. In addition, high thermal conductivity makes it particularly suitable for electrothermal actuation. The piezoelectric sensor (output port) has been designed to

surround the hole and the actuator, as the induced vibration amplitude is the highest close to the centre of the ring. PZT has been used due to its high piezoelectric coefficient, so that the electromechanical coupling is enhanced [7]. Fig. 2 shows the top (a) and the side view schematics (b) of the designed device.

The device has been fabricated with a ring radius of $200\ \mu\text{m}$ and hole radius of $10\ \mu\text{m}$. The fabrication process consists of three main steps: all layers deposition, ports forming and the ring forming. A $2\ \mu\text{m}$ thick 3C-SiC epilayer has been grown on 4-inch Si wafer, followed by the deposition of 100-nm-thick silicon dioxide (SiO_2) passivation

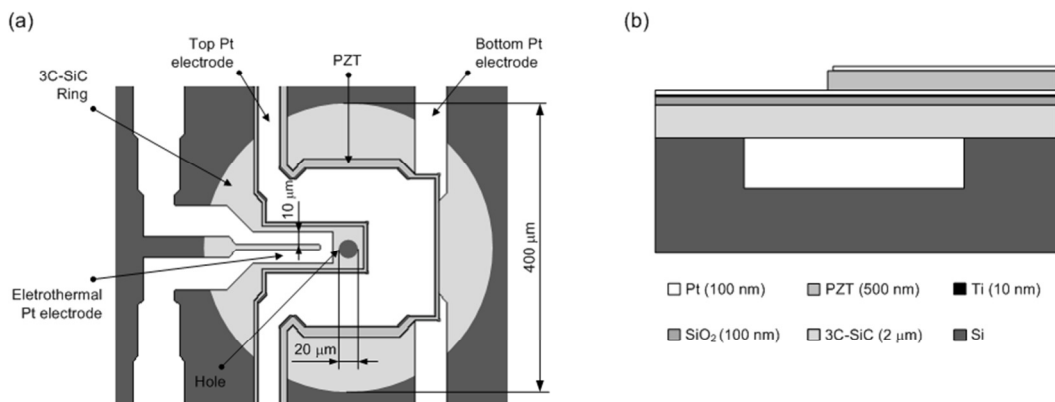


Fig. 2. : Top (a) and side (b) view schematics of the device.

layer and 10-nm-thick titanium (Ti) adhesion layer. The Pt/PZT/Pt stack has been deposited with thicknesses of 100/500/100 nm respectively. The ports have been defined photolithographically. The Pt and Ti layers have been dry etched while the PZT has been wet etched. The hole shape has been patterned photolithographically and the 3C-SiC layer through-etching to release the ring has been performed with inductively coupled plasma. Afterwards, the release of the Si sacrificial layer has been performed with a XeF_2 chemical etching. The detailed fabrication process for the Pt/PZT/Pt/Ti/3C-SiC ring structure is reported elsewhere [8].

3. Results and discussion

The device has been tested by measuring the transmission frequency response with an HP 8753C vector network analyzer. Signal-ground radio-frequency probes have been used and two-port short-open-load-through calibration has been performed before starting the measurements. The device has been directly connected to the network analyzer without any external interface electronics. All measurements have been performed in air, at room temperature and pressure. Fig. 3 shows the magnitude of transmission frequency response of the device actuated with the input signal power of 10 dBm and DC voltage of 8 V. A resonant peak has been measured at 497.5 kHz with a quality (Q) factor in air of 160.

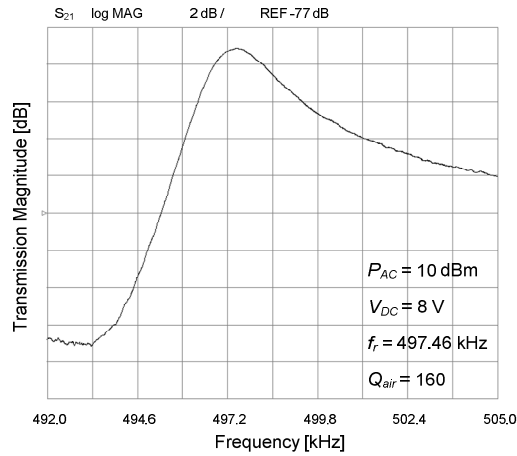


Fig. 3. : Two-port measurement of the transmission frequency response for the electrothermally actuated device using the input AC signal power of 10 dBm and DC bias voltage of 8 V.

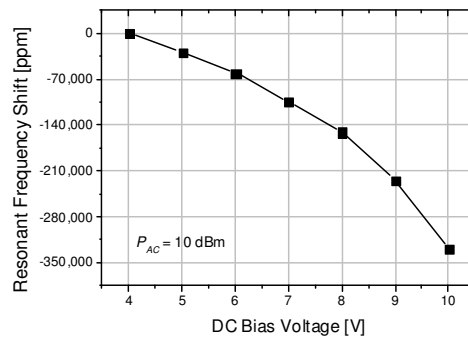


Fig. 4. : Measured resonant frequency shift versus tuning DC bias voltage.

The resonant frequency has been tuned electrothermally by varying the input DC voltage. Fig. 4 shows the resonant frequency shift measured at different DC voltages with AC input power equal to 10 dBm. As the DC voltage increases from 4 V to 10 V, the resonant frequency decreases by -330,000 ppm (from 0.6 MHz to 0.4 MHz). The decrease in resonant frequency detected as the DC bias voltage increases can be explained by increase of compressive stress in the ring, which is caused by the increase in thermal expansion of the structure as the temperature increases [3, 4]. The DC voltage adjustment of the resonant frequency can be used to compensate for a resonant frequency shift caused by fabrication processes and operating conditions. The most important aspect of the results is that the device allows wide frequency tuning range by applying relatively low DC bias voltages.

4. Conclusions

The integration of piezoelectric sensor on a ring MEMS resonator with electrothermal actuation has been demonstrated. The Pt electrothermal actuator (input port) and PZT piezoelectric sensor (output port) have been integrated on the top of 3C-SiC ring, forming a two-port vertical-mode resonator. The design of the actuator and the sensor is optimized to achieve effective electrothermal actuation and high piezoelectric output respectively. The presented device shows relatively high resonant frequencies and wide resonant frequency tuning range with low DC voltages, which makes it a promising candidate for use in filtering applications with the wide tuning requirement.

Acknowledgements

B. Sviličić acknowledges support of Croatian Science Foundation and University of Rijeka (grant 13.07.1.4.01).

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