Ovenized Dual-Mode ZnO-based Solidly Mounted Resonator

A.Tamboli, A. Kale, F. Hrncirik, B.Bakhit, A.J. Flewitt
Department of Electrical Engineering
University of Cambridge
Cambridge, United Kingdom

M. Miguel Ramos
Cambridge Wireless Ltd.
Cambridge, United Kingdom

***Abstract*— In this work, we report a novel ovenized dual-mode solidly mounted resonator for potential applications in gravimetric sensing. We propose using a resistive micro-heater embedded within the resonator structure for ovenization to achieve highly localized heating for frequency tuning. Also, the dual-mode structure has two resonance modes with opposite reactions to temperatures owing to their temperature coefficient of frequency (TCF) which we utilize as a thermometer. In this proof-of-concept work, we demonstrate the frequency tuning achieved by using joule heating resulting from the micro-heater. The tuning efficiency for Mode I and II of the dual-mode device was observed to be 7.6 ppm/mW and -9.641 ppm/mW, respectively.**

Keywords*— *Ovenization; joule heating; micro-heater; solidly mounted resonator; frequency tuning

I. Introduction

In recent times, solidly mounted resonators (SMRs) have been widely studied for applications in RF systems and gravimetric sensing owing to their low-cost, easy fabrication, robustness and compact size [1][2]. The structure of these resonators consists of a piezoelectric layer sandwiched between a pair of electrodes where the acoustic isolation is achieved using a Bragg reflector. But the major limitation in the deployment of these SMR devices for various applications is the temperature dependence of their resonant frequency[3]. These thermally induced frequency shifts are caused due to the temperature coefficient of frequency (TCF) of the piezoelectric transducer layer and affect the stability and performance of the resonator devices.

In order to nullify the temperature effects it is essential to keep the device at a constant temperature using temperature compensation techniques. The two main temperature compensation techniques employed for resonators are active and passive temperature compensation [3]. Passive temperature compensation involves altering the intrinsic material properties and device structures to achieve desired frequency-temperature (*f-T*) characteristics. Therefore, whilst employing the passive compensation techniques the *f-T* characteristics are fixed during the fabrication process and cannot be changed once the device is fabricated. On the other hand, using active compensation techniques allow real-time frequency tuning to compensate for temperature changes [3][4]. Active temperature compensation techniques such as ovenization can also be used for thermal modulation whilst using these resonators for sensing applications leading to enhanced sensitivity and selectivity[5]. In the process of ovenization, a resistive micro-heater is used to achieve fixed, high temperatures via Joule heating. Prior work on ovenized SMRs utilized a thermal camera for temperature measurement which is not a viable option as it is bulky and expensive[5]. Also, the use of external temperature measurement systems such as a thermistor is not suitable as the thermistor itself can act as a heat sink causing thermal losses. Additionally, using an external thermometer requires increased circuitry thereby increasing the system's complexity.

In this work, we report a combination of both active and passive compensation techniques to not only achieve frequency control but also measure the device temperature using intrinsic dual-mode characteristics. The tungsten (W) based resistive micro-heater was embedded within the resonator structure for the ovenization of the device. The micro-heater was placed in the same layer as the bottom electrode to minimize thermal losses. Also, the previously reported passive compensation technique of a dual-mode configuration where the two fundamental resonant modes with opposite TCFs is used in this work as a thermometer[6].

II. Design and Fabrication Process

Figure 1 shows the layout of the fabricated ovenized dual-mode SMR device. The SMR device has been fabricated with an asymmetric acoustic Bragg reflector in order to achieve the dual-mode frequency response. The asymmetric reflector is composed of the top SiO_2 layer of the reflector stack thicker than half of the acoustic wavelength whereas the remaining layers were quarter wavelength each. Both the piezoelectric ZnO layer and the SiO_2/Mo reflector stack were fabricated using High Target utilization sputtering (HiTUS). The bottom

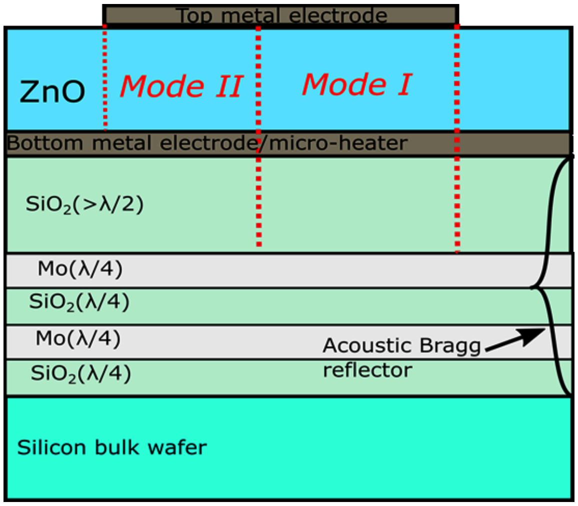

Fig.1. Schematic of the ovenized dual-mode SMR(cross-section).

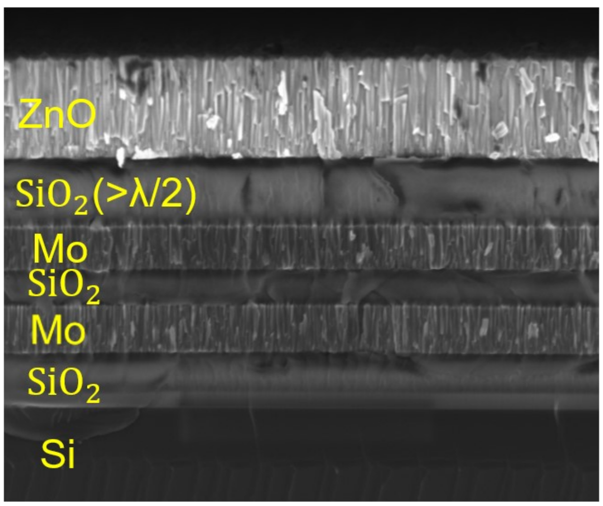

Fig. 2. SEM image of the cross-section of the fabricated device.

electrode and the micro-heater were patterned in the same photolithography step. DC Magnetron sputtering was used for the W deposition for the bottom electrode/micro-heater. The top Au electrode was deposited using a thermal evaporator.

III. EXPERIMENTAL SETUP

A. Electro-acoustic characterization

The frequency response of the fabricated dual-mode SMR device was obtained using a Keysight P9371A network analyzer.

B. Thermal characterization

The dual-mode resonator device was placed on a temperature-controlled hot chuck. The temperature of the hot chuck was varied between 30ºC to 90ºC in steps of 10 ºC. The frequency response of the device was measured at these varying temperatures for determining the device TCF for both resonance modes.

C. Ovenization power characterization

In order to obtain the ovenization characteristics of the device the DC power was supplied to micro-heater using a Keithley 236 source meter unit (SMU). The changes in the resonant frequency of the SMR in response to varying ovenization power to the micro-heater were measured using the network analyzer.

IV. RESULTS AND DISCUSSION

A. Frequency response of the dual-mode SMR

The frequency response of the dual-mode device is shown in Figure 3. Mode I occurs due to the ZnO/SiO_2 bilayer and resonates at 1.6 GHz. Mode II is due to the resonance in the ZnO film alone and has a resonant frequency at 2.2 GHz. The Q factor for Mode I and II are 87 and 62, respectively.

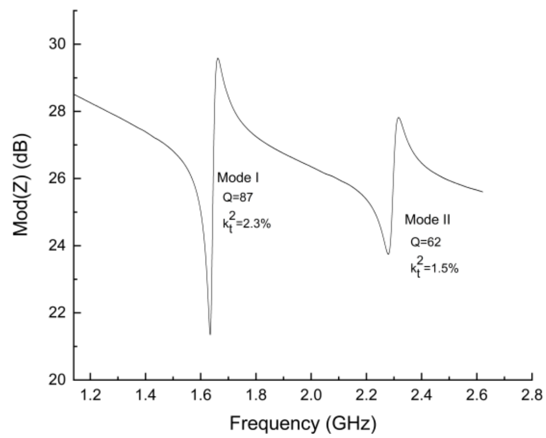

Fig. 3. Frequency response of the dual-mode SMR.

B. TCF measurement

The resonant frequency response for both modes I and II for changing temperatures is plotted in Figure 4. The slope of these curves determines the temperature coefficient of frequency.

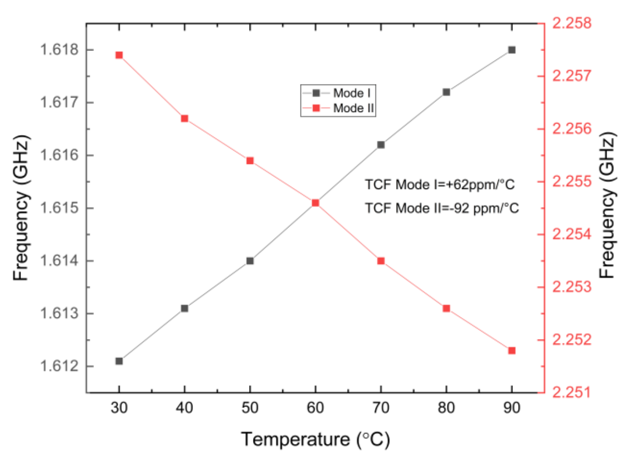

Fig. 4.Resonant frequency of Mode I and Mode II for varying temperatures.

The TCF calculated for Mode I is +62 ppm/ºC whereas Mode II exhibits a TCF of -92 ppm/ ºC. It can be observed that both modes exhibit opposite responses to increasing temperature enabling using their TCFs as a thermometer.

C. *Ovenization power vs frequency response*

The shift in the resonant frequency of both modes in response to an applied ovenization power to the micro-heater is shown in Figure 5.

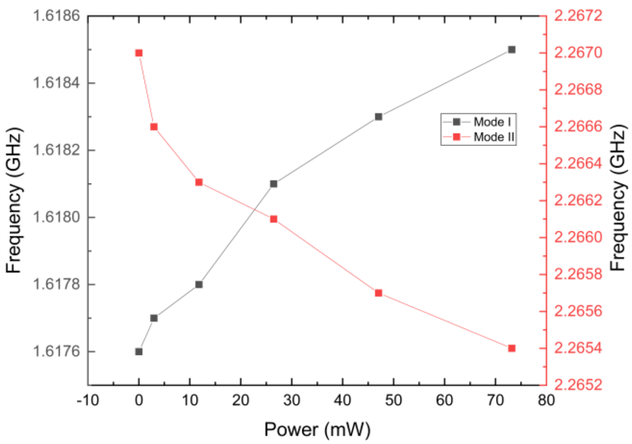

Fig. 5. Ovenization power supplied to the micro-heater vs. resonant frequency of Mode I and Mode II.

A frequency shift of 556 ppm was observed in Mode I for an applied ovenization power of 73 mW indicating a frequency tuning efficiency of 7.6 ppm/mW. Similarly, Mode II exhibited a frequency shift of -705 ppm for the same applied power demonstrating a tuning efficiency of -9.641 ppm/mW.

V. CONCLUSION

The results demonstrate that the frequency in the dual-mode SMR can be effectively tuned using the Joule heating from the embedded micro-heater. Also, the Mode I and Mode II of the SMR device exhibit opposite TCFs and can therefore be used as a thermometer eliminating the need of an external temperature sensor. The ovenized dual-mode SMR presented in this work can be used to develop temperature-controlled gravimetric sensors and also temperature-compensated high-frequency resonators.

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