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Pt/3C-SiC electrothermal cantilever for MEMS-based mixers

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Abstract Microelectromechanical resonators are currently applied as MEMS-based mixers-filter for communication systems. Silicon carbide, as a material with high potentiality to replace silicon material, can be utilised in the design of MEMS-based mixers. A Pt/SiC electrothermal actuator, resonating at fundamental frequency of 117.1 kHz, was fabricated and designed to perform frequency mixing. Two signals were multiplied and the sum, as well as the difference, was used to drive the fabricated cantilever into resonance.

1 Introduction

Mixers present a major part in telecommunication systems since they are used to modulate the frequency at the transmitters as well as at the receivers. Modulation can be performed through mixing the incoming signal (in receivers) or the outgoing signal (in transmitters) with another signal of lower or higher frequency (down-converting or up-converting). Filtering is required to reject the images produced after mixing. However, with the MEMS-based frequency mixers, no filtering is required as the resultant frequency after mixing is the resonance frequency of the micromechanical device (Ahn et al. 1999; Globespanvirata et al. 2004). For example, signals applied to the electrodes of an electrothermal or electrostatic actuated resonator are multiplied and the difference or the sum of the two frequencies drives the resonator into resonance. Electrostatic-based mixers require small air gaps between the plates to reduce the actuation voltage when high frequencies are involved (Burdess et al. 2005; Burdess et al. 2008). This could lead to the plates sticking together if they touch. The high $\sqrt{(E/\rho)}$ ratio for SiC allows resonance at high frequencies (in the range of UHF) which commonly found in communication systems. A resonance frequency of 632 MHz for a 3C-SiC bridge was achieved (Ekinci et al. 2000). The use of silicon carbide as a MEMS mixing filter will open up a wide range of applications in communication systems, especially in harsh environment. Cheung et al. (2010) presented a similar idea by driving an electrothermal Al/SiC cantilever using the sum and the difference of two applied signals. The only drawback of their device is that the maximum achieved actuation amplitude was only 62 nm when the length of the cantilever was only 50 μm and the actuation voltage was as high as 4 volts. In this work Pt, which has a good ohmic contact with SiC (Davis and Porter 1995), was used as electrode. The cantilever was driven to amplitude of few hundred nanometers when applying a voltage of only 0.5 volt.

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2 Fabrication of cantilever with electrothermal actuation

The SiC cantilever was fabricated from undoped 3 μm thick single-crystal 3C-SiC film that was heteroepitaxially grown on a Si (100) wafer. SiO_2 was used as an etch mask layer which was deposited on the SiC film using a plasma-enhanced chemical vapour deposition system. Photolithography was performed to pattern the oxide in the shape of the cantilever. A plasmatherm PK 2440 reactive ion etching system was used to remove the patterned SiO_2 layer exposing the SiC underneath. The SiC was etched with inductively coupled plasma (ICP) using SF_6/O_2 gas

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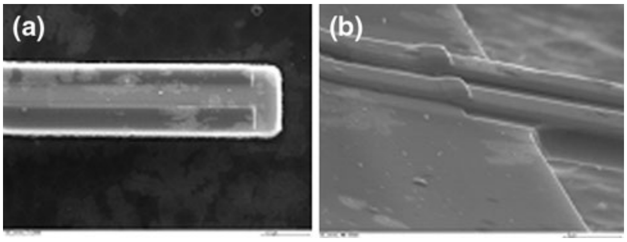

Fig. 1 SEM images of the fabricated electrothermal SiC actuator; **a** is tip of the cantilever and **b** is the base of the cantilever

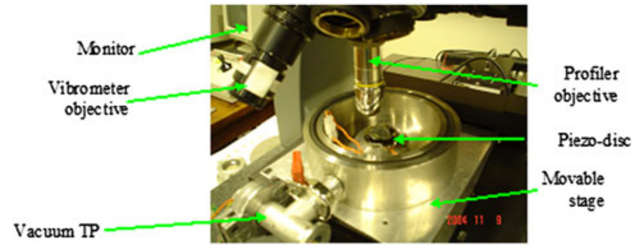

Fig. 3 Testing equipment for actuation

mixtures. The width, length, and thickness of the cantilever are 15, 200, and 3 µm, respectively. A Pt layer of 0.5 µm was deposited over the beam to form the electrodes using FIB (focused ion beam) technology. SEM pictures of the device are shown in Fig. 1. The fabrication process of the Pt/SiC bimorph beams has been reported in detail elsewhere (Burdess et al. 2006).

3 Principle of mixing with electrothermal actuation

Electrothermal actuation of a cantilever depends on the square of voltage applied. Hence, electrothermal actuation could be used to frequency mix two signals. If the applied voltage is:

$$V = V_1 \sin \omega_1 t \pm V_2 \sin \omega_2 t.$$

Thus, the electrothermal actuation force will depend on the square of the voltage and will have components at frequencies $2\omega_1$, $2\omega_2$, $\omega_1 + \omega_2$, and $\omega_1 - \omega_2$. Therefore the sum or the difference between them could also drive the beam into resonance. The fabricated SiC cantilever, which is drived electrothermally, was used to frequency mix two signals. The signals were applied to the deriving electrodes as shown in Fig. 2.

4 Experimental setup

The beam was excited mechanically using piezo disc to determine the location of resonance frequency. This step was carried out prior to application of electrothermal voltages. It is expected that the resonance frequency can be easily detected using external excitation, e.g. piezo disc. All dynamic measurements were carried out in a vacuum using a chamber that is sealed with a rubber O-ring which allows a minimum pressure. The equipment has a piezo-ceramic disc on which samples can be mounted on as shown in Fig. 3. The piezo-disc is used to drive beams mechanically into resonance. Wax was used to fix the samples onto the piezoelectric disc. The vacuum level provided inside the chamber was 0.016 mbar. Devices were viewed on a monitor using the ZYGO profilometer system. The stage control was used to locate the laser beam on the desired part of the device so that the laser beam could be located precisely.

The fundamental resonance was found to be 117.1 kHz. Next, voltage was applied though the platinum electrodes and the cantilever was driven electrothermally at the same resonance frequency (117.1 kHz) successfully.

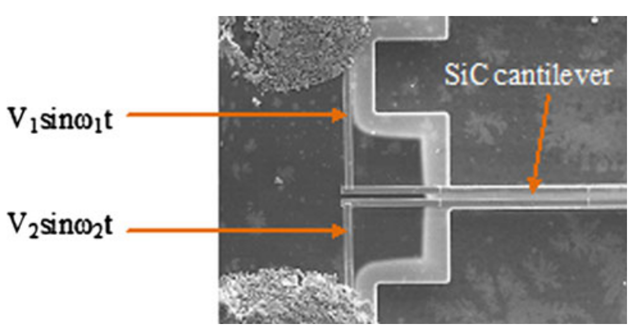

Fig. 2 Applying signals on the cantilever

5 Electrothermal frequency mixing: results and discussion

The electrical characteristics of the device are shown in Figs. 4 and 5 (with positive and negative DC current, respectively) which show a linear voltage current relation with a resistance of less than 2 kΩ in both directions of the current. This low resistance is a good indicator that the

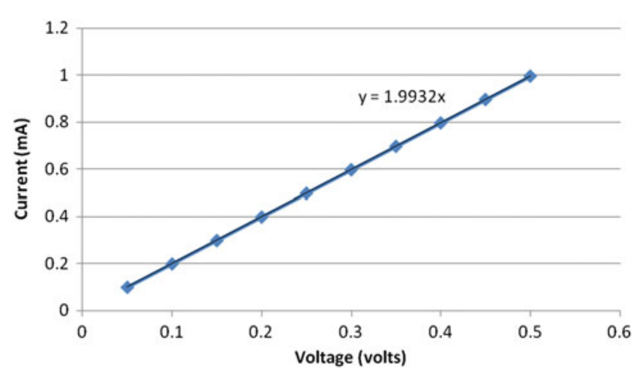

Fig. 4 Voltage characterisation for SiC actuator (+DC current)

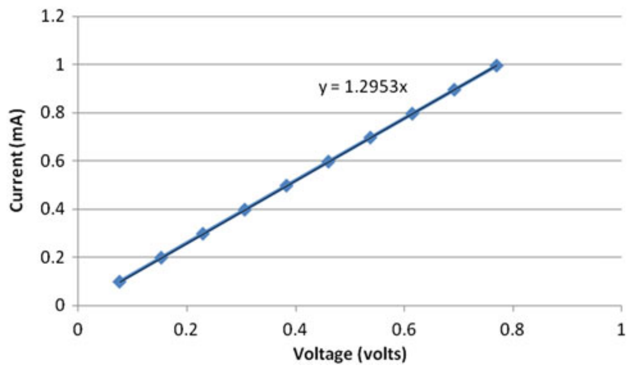

Fig. 5 Voltage characterisation for SiC actuator (−DC current)

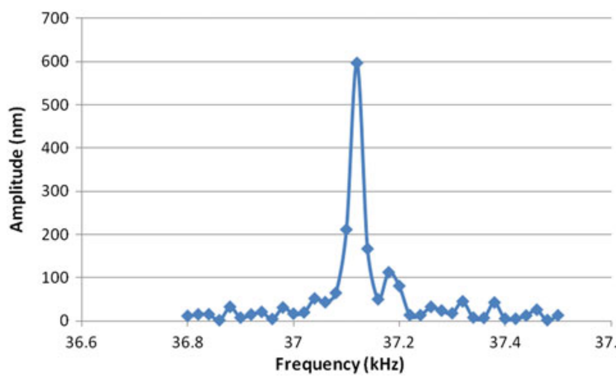

Fig. 6 Signals addition: resonance detected when varying one signal (between 36.8 and 37.5 kHz) while keeping the other signal fixed at 80 kHz

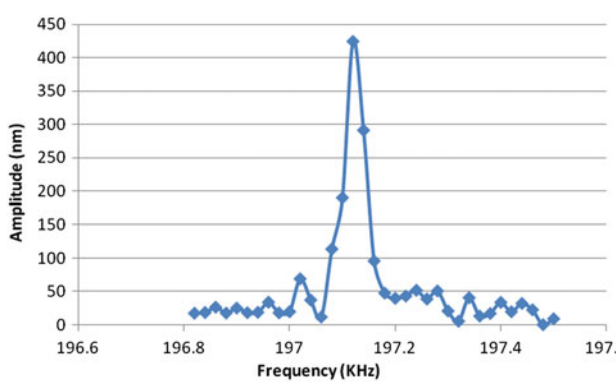

Fig. 7 Signals subtraction: resonance detected when varying one signal (between 196.8 and 197.5 kHz) while keeping the other signal fixed at 80 kHz

actuator will not require a large power to drive it electrothermally. The electrothermally actuated SiC beam presented previously was used to frequency mix two signals. Figure 6 shows the resonance detected when adding two signals while Fig. 7 shows the resonance detected when subtracting two signals. In practice, the multiplication was carried out using two function generators, each connected to one of the cantilever's electrodes. Testing was carried out by fixing one source at 80 kHz and the other signal was varied around 37 kHz. A resonance was detected at 117.1 kHz. To drive the cantilever with the difference of two applied signals, one signal was fixed to a frequency at 80 kHz and the other signal was varied around 197 kHz. A resonance was also detected at 117.1 kHz. The actuation is merely carried out by the sum or the difference of the two applied signals since none of the above frequencies could drive the cantilever into resonance. Two equal AC driving voltages ($V_1 = V_2 = 0.5$ V) both superimposed on a DC bias voltage ($V_{DC} = 0.5$) have been applied. The electrothermal frequency mixers, in the case of subtracting and adding signals, have amplitude of actuation which is in same order of magnitude (few hundred) when similar voltages are applied.

6 Conclusion

Silicon carbide is a promising material for RF-MEMS due to its high young's modulus to density ratio. An electrothermally actuated SiC cantilever was used to perform frequency mixing. Two signals were multiplied. The difference and the sum of the signals was used to drive the device into resonance at 117.1 kHz. The electrothermal frequency mixer has amplitude of actuation of few hundred nanometers when the applied voltage is only 0.5 Volts. This result shows that mixing and filtering, with good actuation amplitude and low power consumption, can be achieved using Pt/SiC thermal actuator.

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