SiC for MEMS-based Filters

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Abstract

Microelectromechanical resonators are finding applications in communication systems as frequency mixers and filters. Silicon carbide, as a material with high potentiality to replace silicon material, can be utilised in the design of MEMS-based filters. A SiC electrostatic actuator, resonating at fundamental frequency of 66.6 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

In communication systems, mixers are widely utilized to facilitate the interface between transmitters and receivers. In traditional approaches, the signals have to be filtered after mixing is performed. Mixing means down-converting or up-converting the signal. Filtering is required to reject the images produced after mixing, as shown in Figure.1. 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 [1 and 2]. A MEMS-based filter replacing the conventional filtering system is also shown in Figure.1. For example, signals applied to the electrodes of an 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. This could lead to the plates sticking together if they touch. The high √(E/ρ) 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 [3]. The use of silicon carbide as a MEMS mixing filter will open up a wide range of applications in communication systems. In this work, signal mixing using electrostatic actuation principle was performed on a SiC fabricated cantilever.

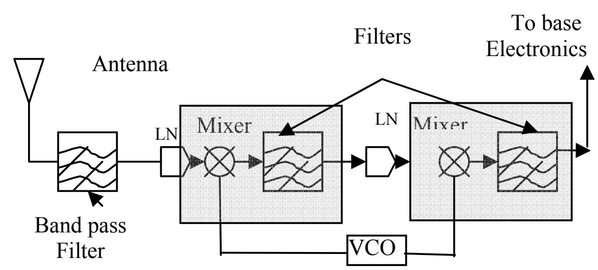

Figure 1. Simple block diagram for wireless receiver, replacing the shaded area with a micromechanical device [2].

2. FABRICATION OF CANTILEVERS WITH ELECTROSTATIC ACTUATION

To achieve electrostatic actuation, the device structure needs to include an insulating layer. This was achieved by employing 3C-SiC deposited on a polySi/SiO_2/Si wafer. The thicknesses were 3μm, 1.5μm, and 500μm respectively. A schematic diagram of the fabricated layers is shown in Figure.2. Nichrome, which had proved to form a good ohmic contact with SiC [4], was deposited at room temperature. The nichrome was also used as a mask for the inductively coupled plasma dry etching process explained in [5]. The SiC layer was anistropically etched and the polycrystalline Si layer was isotropically etched to release the SiC cantilevers. A set of cantilevers with different lengths were released but the tests were carried out on the 200 µm cantilever which has a width and thickness of 15 µm and 2 µm respectively.

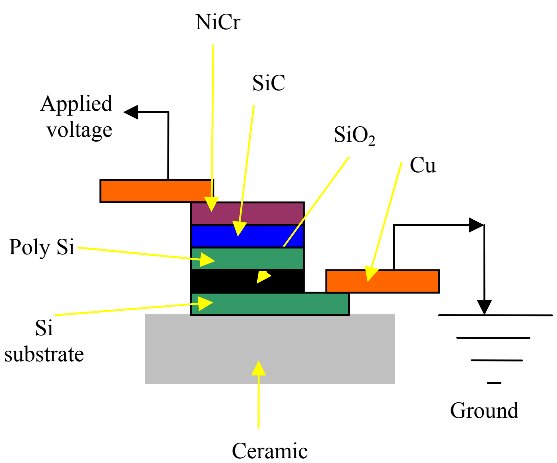

Figure 2. Structure layout

3. THEORY

The electrostatic actuation is dependant on the square of applied voltage [5]. This makes it possible to multiply signals together. For an applied voltage; $V=V_1 \sin(\omega t)$, with a dc component "V_{DC}", the square of the voltage is given as;

$$V^2 = (V_{AC} \sin \omega t + V_{DC})^2$$

$$V^2 = 2V_{AC}V_{DC} \sin \omega t + 0.5V_{AC}^2(1-\cos 2\omega t) + V_{DC}^2$$

If the applied voltage is composed of two signals; $V = V_1 \sin \omega_1 t \pm V_2 \sin \omega_2 t$, the electrostatic actuation force will now be dependent on the square of the above term which will have components at frequencies $2\omega_1, 2\omega_2$, $\omega_1 + \omega_2$, and $\omega_1 - \omega_2$. For a non-zero output the sum or the difference frequency needs to drive the beam into resonance. The capacitively driven cantilever therefore acts as a mixer and filter.

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 electrostatic 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 Figure.3. The piezo-disc is used to derive 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 shown in the above diagram 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 66.6 kHz. Next, voltage was applied though cupper plates as shown in Figure.2 and the cantilever was driven electrostatically at the same resonance frequency (66.6 kHz) successfully.

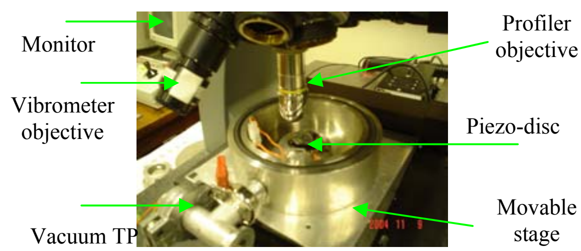

Figure 3. Testing equipments

5. FREQUENCY MIXING: RESULTS AND DISCUSSION

The electrostatically actuated SiC beam presented previously was used to frequency mix two signals. The testing was performed on 3 µm SiC beams on poly $Si/SiO_2/Si$ as shown in Figure.2. NiCr was deposited on the SiC to serve as a masking layer as well as the top electrode for electrostatic actuation. The signals were applied to the driving electrodes as shown in the Figure.2 & 4.

For a particular cantilever that resonates at 66.64 kHz, the two applied signals need to have a difference or sum equal to this frequency. Figures 5 & 6 show the resonance detected, using an optical vibrometer, when adding signals or subtracting signals. One signal was fixed at a certain frequency (40 kHz) which is equivalent to the fixed signal in the filtering system (known as local oscillator frequency). The other applied signal, to drive the cantilever into resonance, was 26.64 kHz. This shows that the two signals have been added successfully to resonate at frequency 66.64 kHz which is the resonance frequency of the cantilever. The same has been applied for subtraction (down-conversion) where in this case the other signal is at 106.64 kHz. It should be noted that none of the frequencies used above was able to drive the beam into resonance, which shows that the actuation was carried by the sum or the difference of the two applied signals.

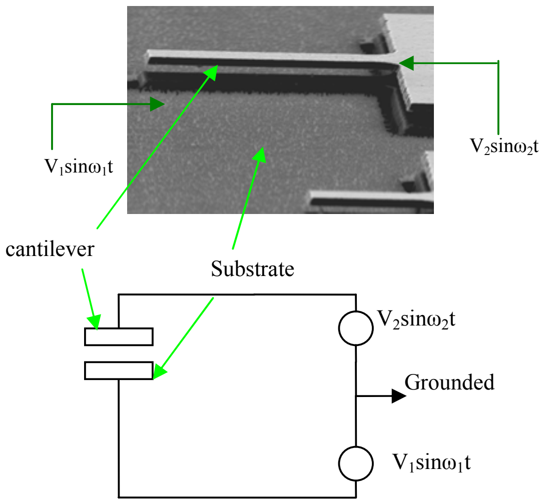

Figure 4. Circuit diagram of the signal multiplication on electrostatic cantilever.

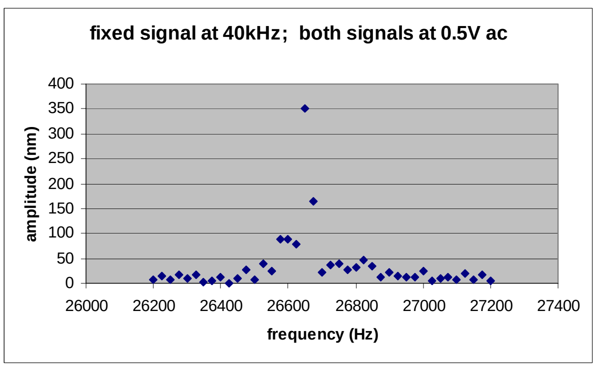

Figure 5. Resonance detected when varying one signal (between 26.2 kHz and 27.2 kHz) while keeping the other signal fixed at 40 kHz.

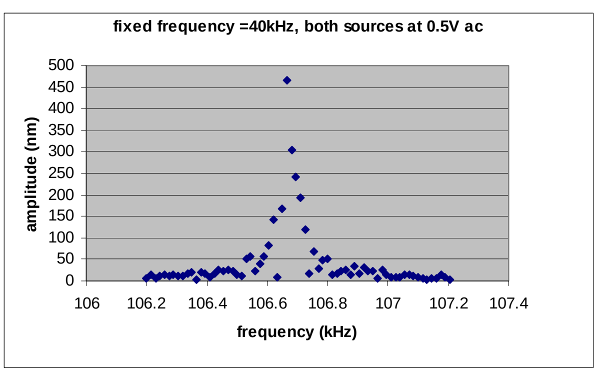

Figure 6. Resonance detected when varying one signal (between 106.2 kHz and 107.2 kHz) while keeping the other signal fixed at 40 kHz.

6. CONCLUSIONS

Silicon carbide is a promising material for RF-MEMS due to its high young's modulus to density ratio. An electrostatically 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 66.6 kHz The electrostatic frequency mixers has an amplitude of actuation of few hundreds nanometers when applied voltage is only 0.5 Volts. These results will have a great impact in telecommunication applications by suggesting the SiC as a design material.

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