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3C-SIC: APROMISING MATERIAL FOR GHZ RESONATORS IN OUT-OF-PLANE RESONANCE MODE

Musaab ZAROG[1]
[1]IEEE senior member Department of Mechanical and Industrial Engineering, College of Engineering, Sultan Qaboos University, P.O. Box 33, Al-Khod,Muscat, 123, Oman
*corresponding author: musaabh@squ.edu.om

Abstract: *Cubic silicon carbide (3C-SiC) has excellent mechanical and electrical properties that make it very promising material/candidate to replace conventional silicon (Si), in many MEMS/NEMS applications including microresonators (e.g. microactuators and microsensors). Attaining high frequency resonators will widen the application of MEMS in signals filtering and mixing besides improving the accuracy of microsensorsers. This paper presents promising results of high resonance frequencies at the out-of-plane mode using 3C-SiC microstructures. The SiC microbridges were successfully actuated up to 2.4 MHz. The paper claims that highest out of plane resonance (of 2.4 GHz) can be achieved with reducing the same 3C-SiC resonator to nanoscale size and considering higher modes of actuation.*
Keywords*: microactuators, microsensors,SiC, high frequency, in-plane vibration, RF MEMS*

Introduction

With the advancement in SiC microfabrication together with its excellent mechanical and electrical properties, SiC is becoming more promising for Micro/Nano electromechanical systems (MEMS/NEMS) applications such as microsensors, microactuators, switches, RF mixers and filters [1, 2, and 3]. Actuation of SiC MEMS devices were attempted with commonly applied principles; electrostatic, piezoelectric, and electrothermal actuation [2, 3, 4 and 5]. Although in the past, devices were mainly fabricated from Silicon due the well-established Si microfabrication techniques, SiC microfabrication has well developed [6] besides its suitability for performance at harsh environment [7]. SiC as material with high Young's Modulus to density ratio allows such high frequencies to be attained. One of the common microresonators are microcantilevers and microbridges and higher resonance frequency can be achieved with microbridges (6 times higher than their microcantilevers counterpart can). If residual stresses are present in the microbridges much higher frequencies can be achieved [8]. Fundamental in-plane resonance frequency up to 1.029 GHz was demonstrated with SiC microbridges of nanoscale size [9 and 10]. However, there is no out-of-plane 3C-SiC resonators were reported in GHz. This paper propose that high resonance frequencies can be achieved in the out-of plane-mode and even much higher resonance frequencies (in GHz) can be achieved at higher modes of vibration in the out of plane direction as well.

2.3 Fabrication of 3C-SiC bridges

The microstructures were fabricated from four-inch diameter wafers of silicon with a heteroepitaxial layer of single-crystal 3C-SiC of nominal thickness 2 μm. Microfabrication was carried at Edinburgh University to form the bridges. The wafers were cleaned in acetone and isopropanol and prepared for the deposition of the mask layer. 2.5 μm of SiO_2 was deposited on the wafer using a plasma-enhanced chemical vapour deposition system. Using photolithography techniques, the beams were patterned to the shape required. The photoresist used was Megaposit SPR2-2FX 1.3. Using the patterned SiO_2 mask, SiC was etched using inductively coupled plasma (ICP) with SF_6/O_2 gas mixtures. The SiC was etched anisotropically and the underlying silicon isotropically. Different sets of bridges were released (their lengths variy from 1000 to 200 μm) and widthis 50 With this method, an etched rate of 276 nm/min was achieved for SiC while Si was etched at a rate of 2.7 μm/min. More details about the fabrication process can be found in [6].

Firstly, SEM images were taken for structures to guarantee successful release of the structures. The SEM images taken of the fabricated SiC micobridges also shows evidence of undercutting. Undercutting contributes to the effective length of the beam and therefore to the frequency at which the beam resonates. Structures were then mounted on a piezo-disc to actuate the beams into resonance.

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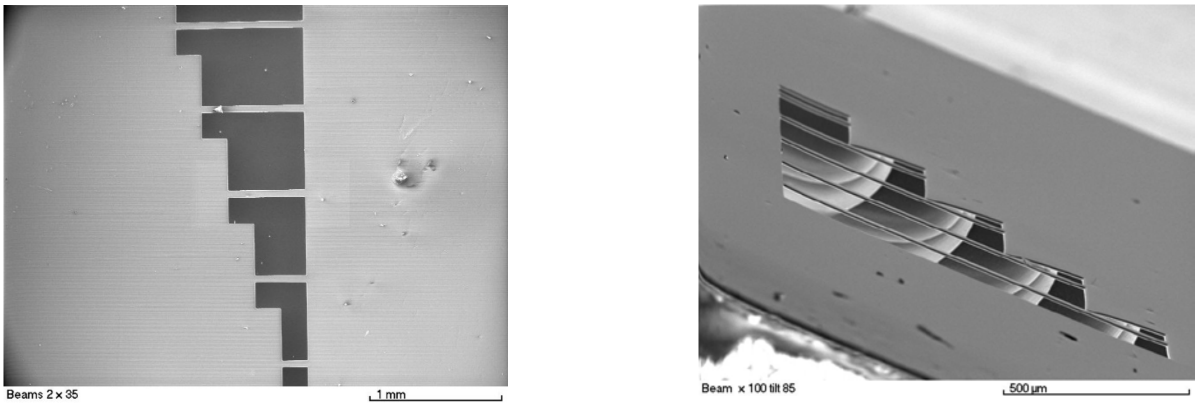

(a) (b)

Figure 2.11 SEM image of SiC cantilevers and bridges; (a): top view, (b): side view.

2.5 Results and discussion

The released microbridges were tested for resonance frequency using an optical vibrometer. Testing of resonance frequency was conducted by mechanically vibrating the structures using a piezo-disc drive. The measured resonance frequencies are shown in Table.1 wherethe first three out of plane modes of vibration are presented. These results indicate that the fabricated SiC bridges were successfully resonating at different frequencies depending on the dimensions of the bridge. For a clamped-clamped micro-beam the fundamental resonance frequency is given by [11];

$$f = 1.03 \frac{d}{L^2} \sqrt{\frac{E}{\rho}}$$

Where; f is the fundamental resonance frequency of the beam, E is the elastic modulus of the material, ρ is the material density, d is the thickness of the beam in the direction of vibration, and L is the length of the beam.

Table.1 Frequencies measured at different bridges lengths.

Bridge length	Calculated 1^{st} mode resonance	measured 1^{st} mode resonance	measured 2^{nd} mode resonance	measured 3^{rd} mode resonance
1000 µm	22.1 kHz	86.1 kHz	180 kHz	320 kHz
800 µm	34.6 kHz	121 kHz	251 kHz	444 kHz
600 µm	61.4 kHz	181 kHz	387 kHz	696 kHz
400 µm	138.2 kHz	321.5 kHz	710 kHz	1272.4 kHz
200 µm	552.9 kHz	802 kHz	1.61 MHz	2409.0 kHz

It is clear from the above results that the measured resonance frequencies for bridges do not match with calculated values using presented in Table.1. An increase in the resonance frequency is observed. For example, the 1000 µm bridge was resonating at a fundamental frequency of 86.1 kHz while it was expected to resonate at 22.1 kHz. The big difference in the results can be attributed mainly to presence of residual stresses as due to the thermal mismatch between the Si and SiC layers. Also, the presence of the oxide layer, which was used as a mask layer during the fabrication process, was not considered in the calculation. Undercutting also affects the resonance frequency of the beams since the effective lengths of beam will be different from the expected lengths. The only high resonance frequencies (up to 1 GHz) was reported only for in-plane mode of vibration.

From the above equation and the measured resonance frequencies, it is clear that a 3C-SiC microbridge with same properties in nanoscale (200 nm in length and 50 nm in thickness) would have the first fundamental resonance frequency in out-of-plane mode at 0.8 GHz (compared with 802 kHz for 200 µm) and it could reach up to 2.4 GHz in the third mode.

Conclusion

This paper shows that SiC is promising material to break the GHz barriers in the out-of-plane mode of vibration if higher modes of actuation are considered. 3C-SiC microbridges were successfully actuated on a

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piezo-disc up to a frequency of 2.4 MHz, and the response was measured optically. A 2.4 GHz third mode resonance in out-of-plane can be achieved with similar device in nanoscale.

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