Extended Abstracts of the 2016 International Conference on Solid State Devices and Materials, Tsukuba, 2016, pp675-676

Development of Single Crystalline 4H-SiC MEMS for Harsh Environments

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Abstract

In this paper, we report the development of single crystalline 4H-SiC MEMS devices including a series of actuators and resonators and characterization results of their static and dynamic properties. In order to overcome the superior chemical resistance of 4H-SiC to undercut and release the suspended MEMS structures, p-n and n-p-n homoepitaxial configurations combined with a photoelectrochemical etching process were applied.

1. Introduction

Microelectromechanical systems (MEMS) capable of operating reliably in harsh environments, such as high temperature, high pressure, chemical and biomedical, radiation, etc. are demanded by a variety of applications. In order to satisfy these needs, the materials for MEMS are critical. Among different materials, SiC, a wide bandgap semiconductor, has been identified as a desirable material of choice for such MEMS devices due to its superior electrical, mechanical, and chemical properties. These properties include the wide bandgap energy (3.2 eV in 4H-polytype), high thermal conductivity (close to copper), large Young's modulus (500 GPa), excellent resistance to mechanical wear and almost all chemicals, and inertness to corrosive medium and radiation. Among different SiC poly-types, single crystalline 4H-SiC fully exploits the superior material properties including thermal and chemical stability, mechanical and radiation hardness, etc. Therefore, it is imperative to develop 4H-SiC based MEMS components.

Due to the extreme hardness and chemical inertness of 4H-SiC to almost all chemicals, it is challenging to undercut and release suspended 4H-SiC MEMS structures. Unlike other SiC polytypes such as 3C-SiC with SiC grown on Si or SOI substrate, undercut of Si or SOI will release the 3C-SiC MEMS. 4H-SiC has homoepitaxial layers grown on single crystalline SiC substrate, not possible to add SiO_2 in between as a sacrificial layer. In this paper, we applied a dopant-selective photoelectrochemical (PEC) etching process on 4H-SiC with p-n and n-p-n homoepitaxial configurations to realize the actuator and resonator structures, and characterized their static and dynamic properties.

2. Device Fabrication and Characterization

Single crystal 4H-SiC with p-n and n-p-n homoepitaxial structures were used in the fabrication. The schematic diagram of the starting material and fabrication process is shown in Fig. 1. Standard photolithography, metal mask deposition and lift-off, and RIE plasma etching were applied to pattern the lateral layout, and followed by a PEC etching process to release the suspended MEMS structures. More details about the fabrication process and PEC etching are given where else [1, 2]. For n-p-n configuration, the middle p-type layer is not only as a sacrificial layer during releasing by PEC etching, but also as an insulating layer to electrically isolate the top n-SiC layer from the bottom n-SiC substrate to achieve electrostatic actuation. Ti/Ni ohmic contacts were used to form anode and cathode on the front and backside.

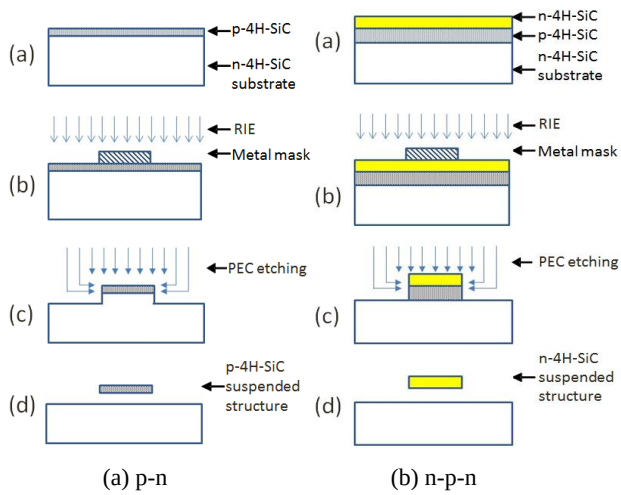
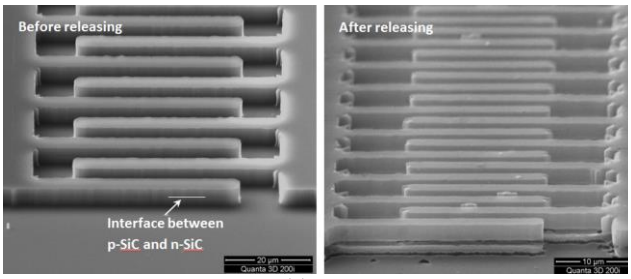


Fig. 1 4H-SiC p-n and n-p-n MEMS fabrication process.

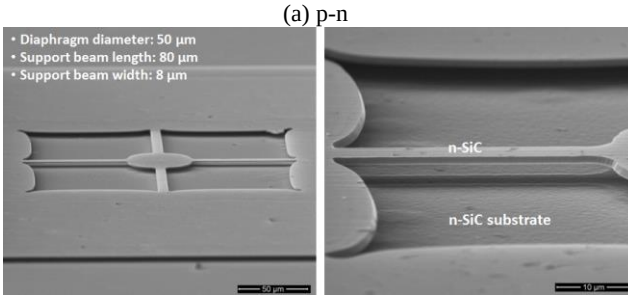
SEM images of some typical p-n and n-p-n suspended structures after fabrication are shown in Fig. 2. For p-n 4H-SiC in Fig. 2(a), it is clearly to see the interface between p-type epitaxial layer and n-type substrate before releasing. During PEC etching, the n-type substrate was undercut and p-SiC cantilevers were successfully released. For n-p-n 4H-SiC in Fig. 2(b), the p-type epitaxial layer in the middle acted as the sacrificial layer and was removed by PEC etching to release the top n-SiC structure. Flatness and straightness of the cantilevers indicate no internal stress or strain gradient existing in the released thin films.

The resonance characteristics of some fabricated resonators were measured by a laser Doppler vibrometer with device housed in a vacuum chamber. The fundamental frequency of a cantilever actuator driven by electrostatic actuation under different pressures is shown in Fig. 3. In order to

locate the resonant frequency, mechanical actuation was applied to the p-n 4H-SiC resonators, and electrostatic actuation was applied on the n-p-n 4H-SiC resonators. For mechanical actuation, the sample was attached on a piezo-disc. A sinusoidal voltage with frequency swept by a function generator was applied on the piezo-disc to mechanically actuate the cantilever beam. For electrostatic actuation, a sinusoidal voltage was directly applied on the electrodes (Ti/Ni Ohmic contacts) of the cantilever actuator through the ports of the vacuum chamber. In both cases, the laser Doppler vibrometer collected the vibration displacement signal of the cantilever beam under different driving frequency, with out-of-plane resonant frequency clearly displayed by the resonant peak shown in the frequency response. Fig. 4 shows the images of two 4H-SiC n-p-n electrothermal actuators, and their operations while voltage bias were applied on the anchor electrodes. The detail characterization results will be presented in the conference.



(a) p-n



(b) n-p-n

Fig. 2 4H-SiC suspended MEMS structures after fabrication.

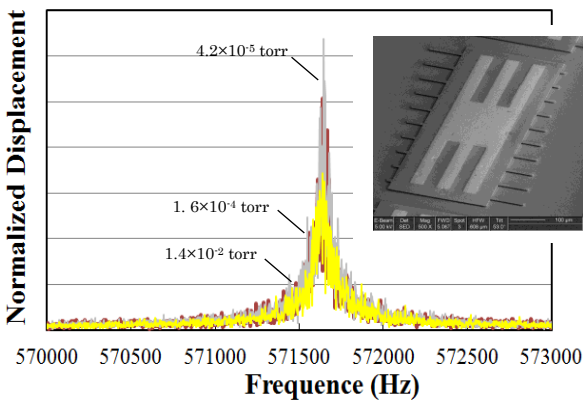
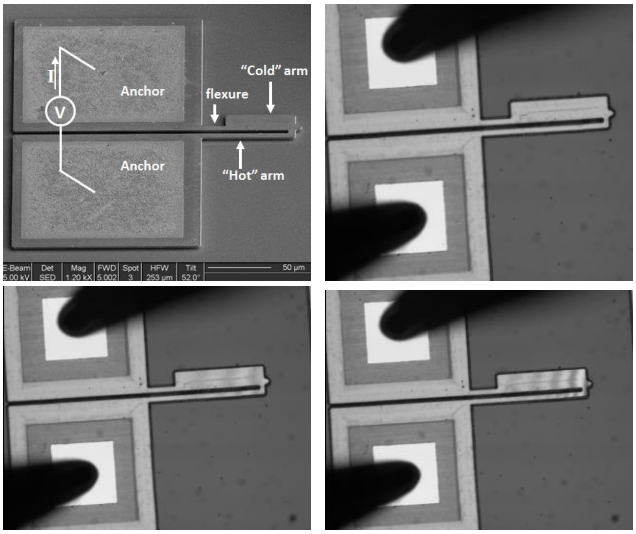
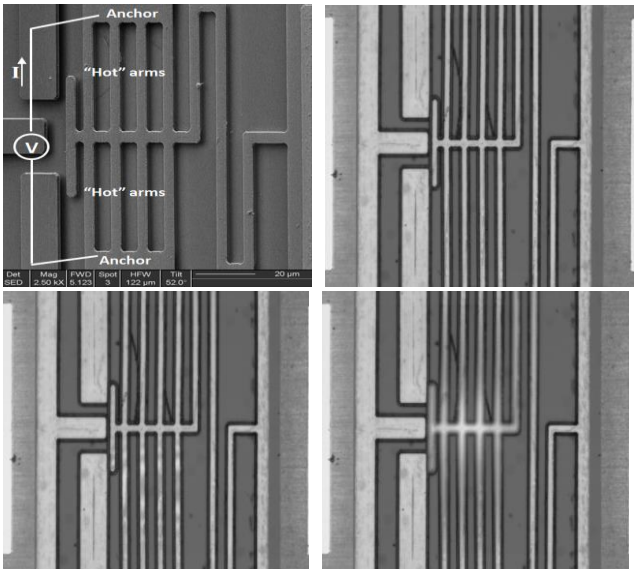


Fig. 3 Fundamental resonance of a 4H-SiC cantilever actuator (thickness: 1μm, length: 50μm) by dynamic characterization.



(a)



(b)

Fig. 4 4H-SiC n-p-n electrothermal actuators and their operations under voltage bias on the anchor electrodes.

3. Conclusions

A series of single crystalline 4H-SiC MEMS resonator and actuator devices were fabricated and tested. The suspended structures were realized by p-n and n-p-n homoepitaxial layers released by a dopant selective PEC etching process.

Acknowledgements

We would like to express sincere thanks to the support from National Science Foundation (ECCS-1307237).

References

[1] F. Zhao, M. M. Islam, and C. F. Huang, Materials Letters **65** (2011).

[2] F. Zhao, A. Lim, Z.B. Chen, and C.F. Huang, Proceedings of MRS Spring Meeting (2014) vol. 1693.