Electrostatically Driven Microbeams for Low Frequency Applications

A. Al-mashaal, G. S. Wood and R. Cheung
Institute for Integrated Micro and Nano Systems, School of Engineering, University of Edinburgh, Edinburgh, EH9 3FF, UK
Asaad.al@ed.ac.uk

Fixed-fixed beam resonators based on microelectromechanical systems (MEMS) have been applied extensively in different sensing and actuation applications[1]. Most of these resonators, however, operate in a relatively high resonant frequency regime (up to MHz) and have relatively high power consumption. For particular applications such as audio sensors, seismic accelerometers, radio frequency (RF) switches, digital inverter and energy harvesters[2–4], low frequency response is highly desirable. Tantalum (Ta) has promising physical and chemical properties such as a high melting point, high fracture toughness, and low ratio of Young's modulus to mass density that make it ideally suited for low frequency applications. To achieve fixed-fixed beams that resonate at low frequencies, it is necessary to increase the length or reduce the thickness of the beams. However, the fabrication process for making long suspended beams is extremely challenging. In order to realize straight and long suspended beams, the processed-induced stress should be controlled, and the aspect ratio of beam length to static vertical deflection needs to be minimised. In our previous study, the influence of stress in the Ta films as a result of deposition and fabrication processes has been optimised [5,6].

In this study, we present the design, fabrication and characterization of an array of electrostatically driven fixed-fixed microbeams of tantalum. The design of our resonators include suspended beams integrated with a large bottom actuation electrode and a metal-oxide-semiconductor field-effect transistor (MOSFET). Figure 1 shows the schematic process flow optimised for the fabrication of electrostatically driven resonator. The final structure consists of a silicon substrate, titanium/aluminium actuation electrodes, with polyimide serving as a sacrificial layer and a dielectric medium, and microbeams of tantalum suspended over the actuation electrodes. Figure 2 is a scanning electron microscopy (SEM) image of the released device after removing the sacrificial layer, showing relatively straight Ta beams. Laser Doppler vibrometry has been used to measure the resonant frequencies of the fabricated devices by applying a bias voltage between the suspended beams and the actuation electrodes. For an applied voltage of 3 V, the lowest resonant frequency of a 3.2 mm-long beam has been measured to be at 780 Hz, as shown in figures 3 and 4. The vertical deflection profile of the fabricated beams will be characterized optically using a white light interferometric profilometer. The mechanical static (deflection) and dynamic (vibration) behaviours under electrostatic actuation will be measured experimentally. Moreover, the implemented device is expected to be capable of modulating the output drain current in the transistor's channel region between the source and drain terminals during electrostatic actuation. A detailed description of the fabrication and measurements will be presented.

[1] W.C. Chuang, H.L. Lee, P.Z. Chang, and Y.C. Hu, Sensors **10**, 6149 (2010).
[2] R. Abdolvand, B. Bahreyni, J. Lee, and F. Nabki, Micromachines **7**, 160 (2016).
[3] S. Chakraborty and T.K. Bhattacharyya, *24th Internatioal Conf. VLSI Des.* (IEEE, 2011)
[4] C. Collette, S. Janssens, K. Artoos, and M. Guinchard, ATS/Note (TECH)(2011).
[5] A. Al-Masha'al, A. Bunting, and R. Cheung, Appl. Surf. Sci. **371**, 571 (2016).
[6] A. Al-masha'al, E. Mastropaolo, and R. Cheung, J. Micromech. Microeng. **27**, (2017).

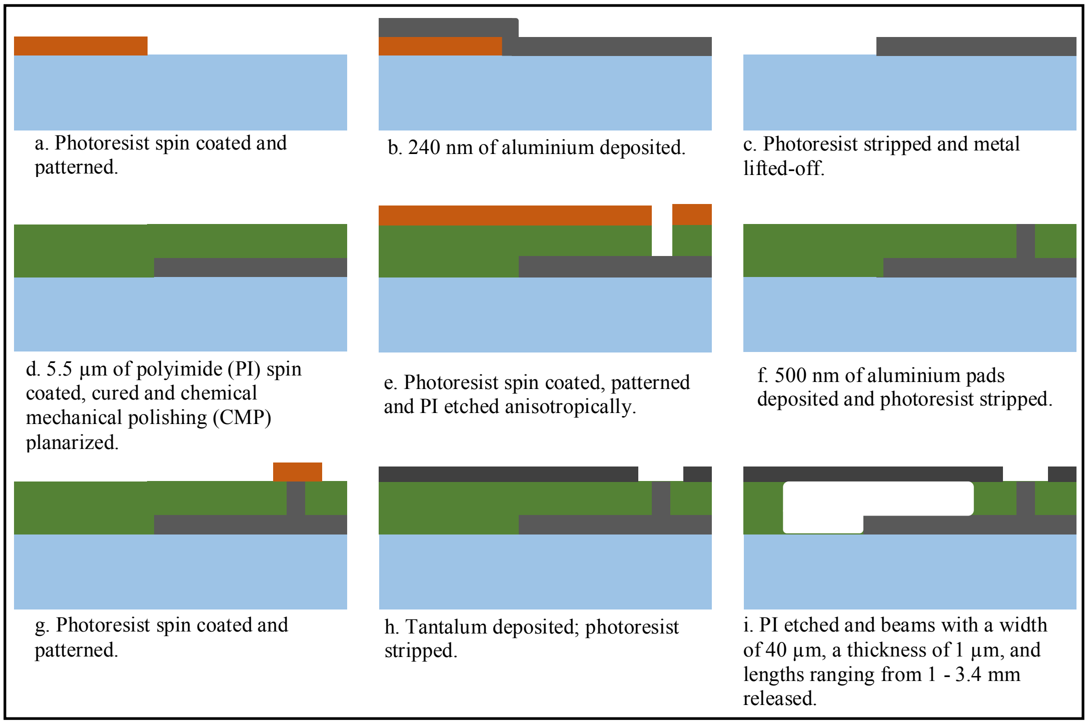

Figure 1: Schematic process flow of MEMS-based tantalum resonator.

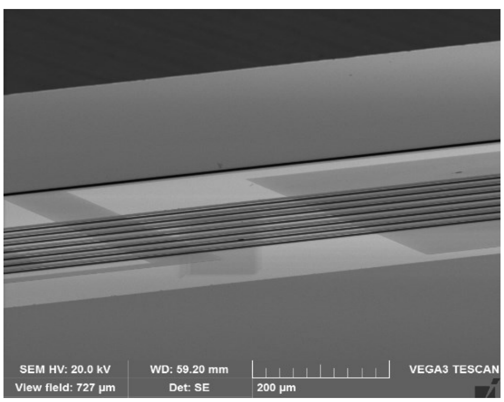

Figure 2: SEM image of fully released microbeams of tantalum (1-3.4 mm long).

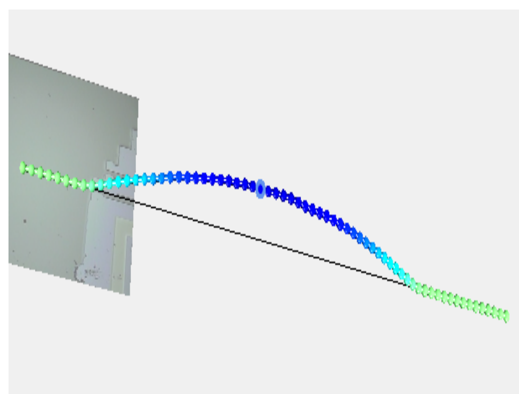

Figure 3: Dynamic 1st mode shape measured for a 3.2 mm long beam resonating at 780 Hz with 3 V A.C. actuation voltage.

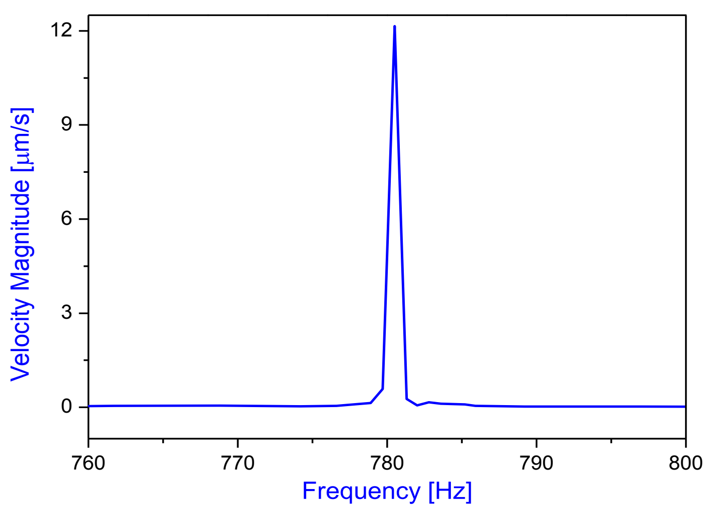

Figure 4: Dynamic measurement of resonance frequency response for a 3.2 mm long beam resonating at 780 Hz (1st mode) with 3 V A.C. actuation voltage.