Tantalum electro-mechanical systems for low frequency sensing in biomimetical applications

Rhonira Latif, Enrico Mastropaolo, Thomas Koickal,
Alister Hamilton and Rebecca Cheung
Institute for Micro and Nano Systems, The University of Edinburgh, EH9 3JF, UK

Michael Newton and Leslie Smith
Department of Computer Science and Mathematics, University of Stirling, FK9 4LA, UK

In the last decade, physical and mathematical models of the human cochlea have been developed. Few works have reported on the physical modeling of the cochlea using micro-fabrication technology[1,2,3]. From the biological viewpoint, the ability to reproduce the behavior of the human auditory system electro-mechanically would help to understand the ear's excellent sensitivity and selectivity towards sounds. From the engineering viewpoint, micro-electromechanical (MEMS) beams that are able to mimic the behavior of the basilar membrane could simplify the design of the speech processor in cochlear implants. Our research has been motivated by the possibility of controlling the gain and the frequency of the acoustic signal directly thus enabling a self-adjusting function of the cochlear response. We propose a new type of cochlear model based on the sensing of acoustic pressure with resonant gate transistors (see Fig. 1)[4,5]. The model enables the self-adjusting function of the gain (sensitivity) and frequency (selectivity) of the system. The direct sensing, amplification and triggering of the input signal will help to overcome the major drawbacks related to the digital signal processing that affect the current systems. However, the direct sensing of the acoustic signal on the beams requires robust MEMS devices to operate in the low frequency (LF) audible range.

In this paper, we report the development of tantalum (Ta) as a structural material for the fabrication of robust MEMS beams operating in a frequency range 20 Hz – 20 kHz. Ta has been chosen because of its superior mechanical properties (Young's modulus and mass density) compared to other metals commonly used in IC fabrication[6]. Double clamped beams (bridges) have been fabricated with lengths in the range 500 µm – 1.6 mm, with 100% yield using photoresist sacrificial layer. Photoresist and polyimide are promising materials to be employed as sacrificial layers for CMOS-MEMS integration[5]. Fig. 2a illustrates a schematic of the fabrication process flow. The fabricated bridges (Fig 2b) have been found to buckle upwards, probably due to residual stress. Fig. 3 shows the resonant frequency measured when the structures have been excited mechanically. The modal behavior of the bridges has been studied focusing particular attention on the mode shapes (Fig. 4). Preliminary fitting of the measured frequency to a higher harmonic indicates a Young's modulus (E) of 100 GPa and a compressive stress (σ) of 330 MPa. The relationship between the residual stress and the modal behavior of the structures will be studied and presented. Knowledge of which will be critical for the design of MEMS cochlea system.

---

[1] M.J. Wittbrodt *et al.*, Audiol. Neurotol., **11**, 104 (2006)
[2] R.D. White *et al.*, Proc. Natl. Acad. Sci. U.S.A., **102**, 1296 (2005)
[3] D. Haronian *et al.*, Proc. TRANSDUCERS '95, Stockholm, Sweden, **2**, 708 (1995)
[4] H.C. Nathanson *et al.*, IEEE Trans. Electron. Dev., **14**, 117 (1967)
[5] R. Latif *et al.*, JVST B, **28**, C6N1 (2010)
[6] S. Sedky *et al.*, Mat. Res. Soc. Symp. Proc., **729**, 89 (2002)

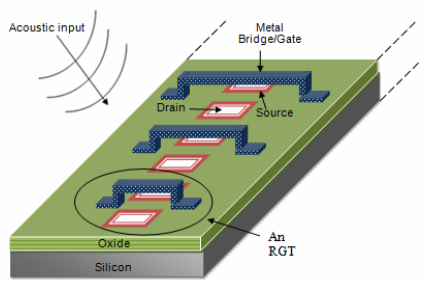


Fig. 1: Schematic of the resonant gate transistor cochlear system.

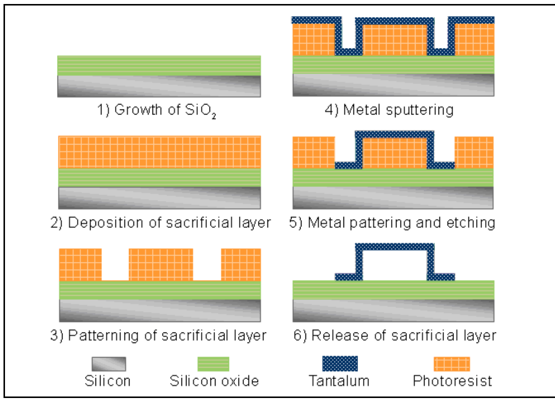


Fig. 2a: Fabrication process flow for tantalum bridges.

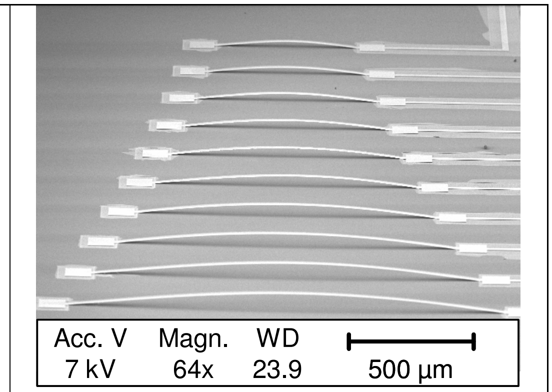


Fig. 2b: Scanning electron micrograph of the fabricated structures.

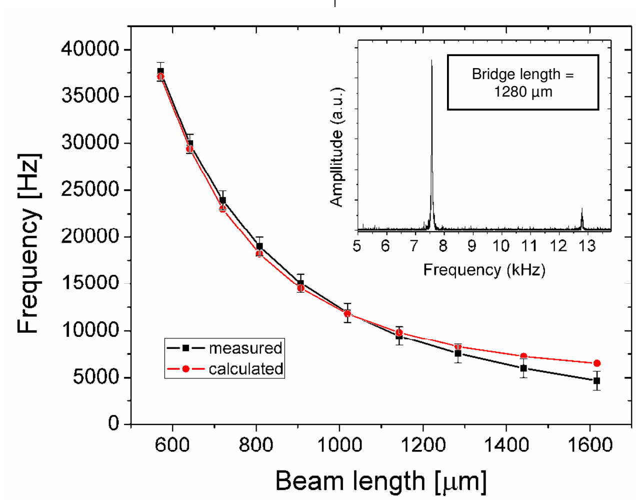
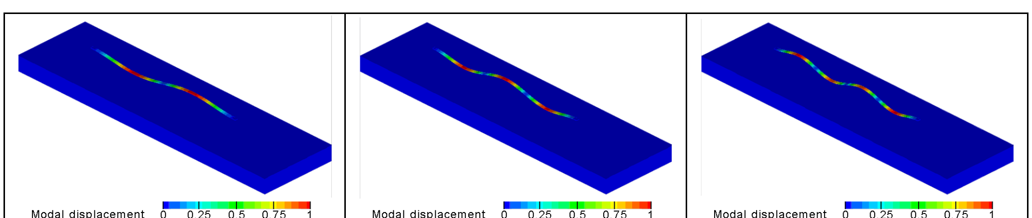


Fig. 3: Measured resonant frequency as a function of the bridge length (inset: resonant peaks detected for two different modes at ~ 7.5 and ~ 12.7 kHz).



First mode (Fig. 4a) Second mode (Fig. 4b) Third mode (Fig. 4c)

Fig. 4: Simulated mode shapes.