Control of stress in sputtered tantalum films for MEMS applications

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Tantalum (Ta) thin films can be used for a variety of micro-mechanical and electronic applications. Due to its chemical and wear resistance and high melting point, Ta can be used in the field of micro electro-mechanical systems (MEMS) as a material for thin-film encapsulation as well as harsh environment devices[1]. Ta can be used for X-ray lithography masks due to excellent X-ray absorbance or as diffusion barrier layer for copper (Cu) films due to low electrical resistivity and reactivity with Cu[2,3]. The main drawback limiting the use of Ta is found in the relatively high residual stress existing in sputtered thin-films causing issues related to adhesion to other films and unwanted electrical resistivity variations. In particular, Ta films are affected by a gradual increase of compressive stress during annealing processes[4] and during exposition to oxygen in atmospheric conditions[5]. Although few groups have reported on the influence of oxygen and thermal cycling on the evolution of stress in Ta films[2,6], studies on the influence of sputtering conditions on the residual stress are not readily available in literature[7]. The understanding of stress evolution and the ability to control and tune the residual stress in Ta films is essential for enhancing its use in the micro-fabrication industry. In our work, we investigate the influence of sputtering conditions on Ta film deposition aiming to control the residual stress for fabricating flat or buckled structures depending on the requirements of the target application.

In this paper, we report on the residual stress in Ta films together with the fabrication of Ta MEMS beams. Magnetron sputtering power and argon pressure in the range 100 W – 500 W and 5 mTorr – 20 mTorr, respectively, have been used for depositing films with thickness in the range 1000 – 3000 A. Film stress characteristics have been evaluated by performing wafer curvature measurements and using Stoney's equation. Atomic force microscopy investigations have shown an increase of film roughness as the sputtering pressure increases. Preliminary results have shown that the film stress gradually increases towards compressive values as a function of time when exposed to atmospheric conditions (Fig. 1). We are able to fix the as-deposited stress magnitude by annealing the sputtered films at relatively low temperatures (< 200 ºC) in oxygen. Fig. 2 shows the stress magnitude as a function of argon pressure for sputtering power values of 200 W and 300 W. The stress has been shown to be tensile when the film is sputtered at low pressure and to decrease towards compressive values as the pressure increases. By controlling the film stress during sputtering, we are able to fabricate flat or buckled MEMS beams using a surface micromachining approach (Fig. 3). Fig. 4 and Fig. 5 show flat (planar) and buckled Ta beams obtained using sputtered films with tensile and high compressive stress, respectively. The outstanding strength and mechanical stability exhibited by the fabricated buckled beams (Fig. 5) can be used for implementing robust self-adjusting microstructures for adaptive optics applications[8] or for encapsulation of MEMS devices. Details of the Ta films deposition and structures fabrication process will be presented. The influence of sputtering parameters on film morphology and stress will be discussed along with the impact of stress on the resulting structures' shape.

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[1] K. Najafi, Proc. SPIE, Micromachining and Microfab. Proc. Tech. VIII, **4979**, 1 (Jan. 25, 2003).
[2] M. H. Cheng *et al.*, J. Vac. Sci. Technol. B, **25**, 147 (2007).
[3] A. Lakatos *et al.*, Vacuum, **84**, 130 (2010).
[4] L. A. Clevenger *et al.*, J. Appl. Phys., **72**, 4918 (1992).
[5] Yoshihara *et al.*, J. Vac. Sci. Technol. B, **11**, 301 (1993).
[6] R. Knepper, J. Appl. Phys., **100**, 123508 (2006).
[7] A.A. Navid *et al.*, Surface & Coating Technol., **205**, 2355 (2010).
[8] E. Quévy, Sens. and Act. A, **95**, 183 (2002).

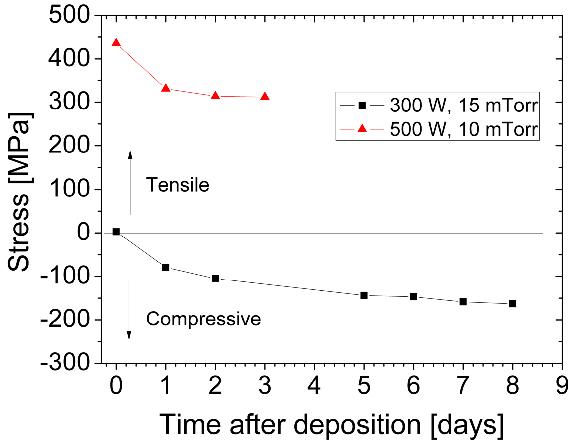

Fig. 1: Stress as a function of time after deposition for tantalum films exposed to atmospheric conditions.

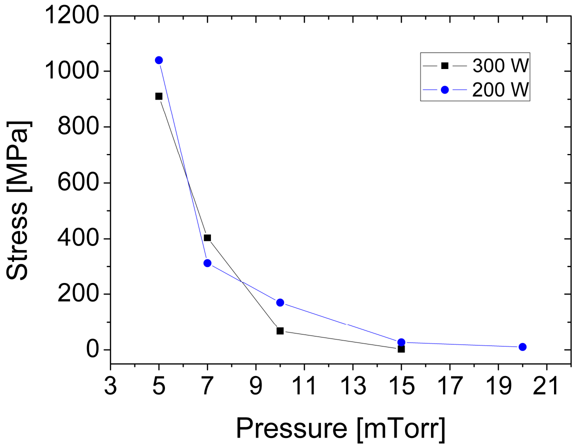

Fig. 2: Stress in tantalum films sputtered at argon pressure in the range 5 mTorr – 20 mTorr and power of 200 W, 300 W.

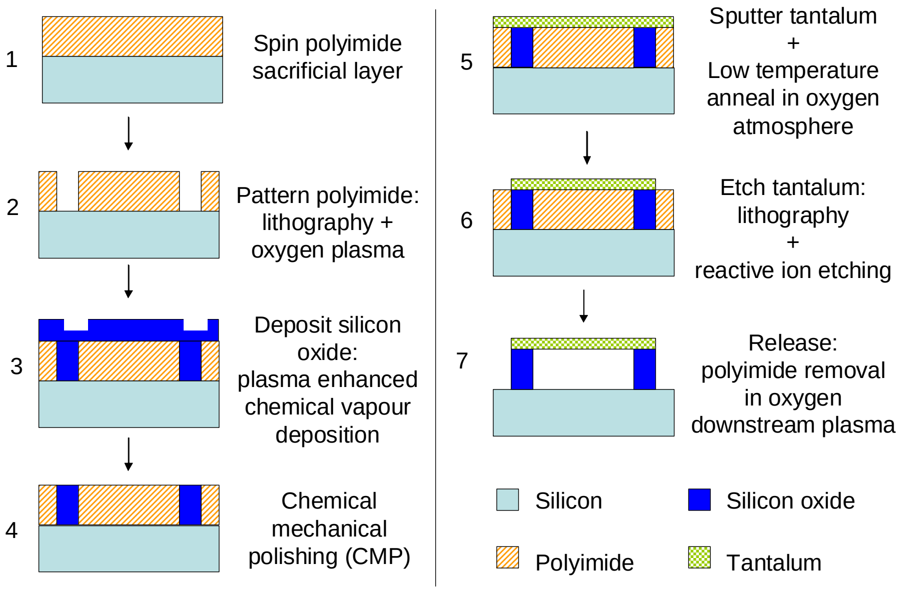

Fig. 3: Schematic of the fabrication process

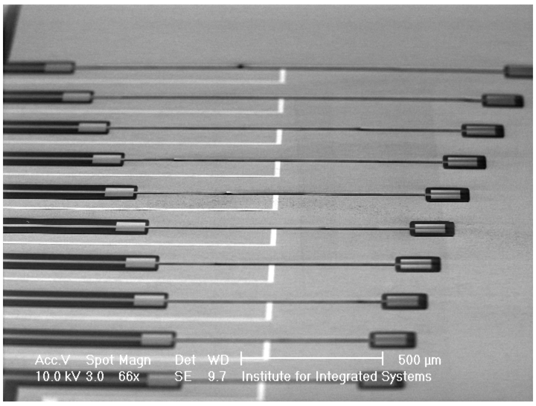

Fig. 4: Flat clamped-clamped beams fabricated with Ta films exhibiting tensile stress (+ 200 MPa). The beams length ranges between 600 µm and 1800 µm. An aluminum electrode has been fabricated under the beams for electrostatic actuation

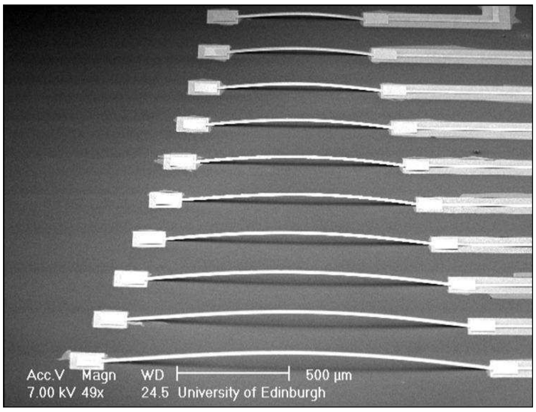

Fig. 5: Buckled clamped-clamped beams fabricated with Ta films exhibiting very high compressive stress (– 850 MPa). The beams length ranges between 600 µm and 1800 µm.