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Rupture Mechanism for Thin Shells based on Ultrasound Activation for Subcutaneous Controlled Drug Delivery Systems

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Introduction

Implantable controlled drug delivery devices based on Micro-Electro-Mechanical-Systems (MEMS) have been proposed for a number of clinical applications that require sustained release [1]. Batch controlled release mechanism relies on selectively actuating single reservoirs of an implanted reservoir array as demanded by the pharmacological therapy. Several electro-thermal actuators have been proposed to burst membranes that seal reservoirs, controlled electronically from within the implantable device [2].

Device

A novel device for subcutaneous implantation is proposed to eliminate the use of internal electronics and power source, which uses an external ultrasound source to cause catastrophic failure of the sealing membranes.

Reservoirs are manufactured using Si_3N_4 Low Pressure Chemical Vacuum Deposition (LPCVD) and subsequent anisotropic silicon etch using KOH. Membranes are supported in a SCS wafer (0.5mm) and exhibit residual stresses (100MPa– 400MPa) due to the fabrication process [3]. Membrane dimensions are key parameters for single reservoir activation and to ensure hermeticity prior to activation. Lateral dimensions are in the 250µm-1mm range and thickness is in the 50nm-250nm range.

Numerical Model

From structural point of view, membranes are thin shells with axial and bending stiffness. The 4 node shell element with Mixed Interpolation of Tensorial Components (MITC-4)[4] under Reissner-Midlin hypothesis is adopted. The manufacture residual stress is introduced into thin shell dynamic through the stress stiffening matrix [5].

Laser interferometry is used to determine the deformed shape of the vibrating membrane. The image is filtered and mid-side and diagonal deflection profiles are obtained. The residual stress is calibrated performing a forced vibration harmonic analysis of the membrane and adjusting the results to the interferometry ones, sees Figure 1. Best fit is found when the boundary condition adopted is free rotation.

Failure criteria are applied to find that rupture conditions are not met neither by yielding or fracture mechanics conditions [6]. Rupture is reached by local addition of nonstructural mass to the membrane to increase modal strain energy.

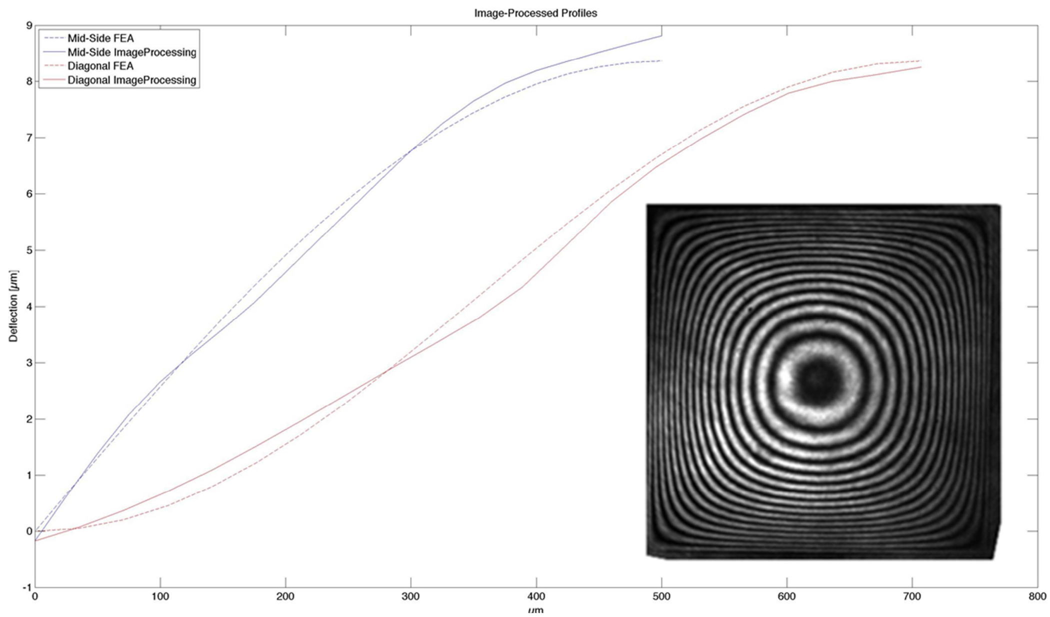

Figure 1 – Laser interferometry and model adjustment and validation for 20.2KHz

Conclusions and future work

Ultrasound induced dynamic failure is a feasible actuator technology to be used in micro-devices. Concept has been simulated, manufactured and tested.

As thin shells mechanics can be accurately reproduced, future work will focus on tailoring failure conditions using modal strain energy so that the device can be activated at discrete frequencies.

REFERENCES

[1] N.M. Elman and U.M. Upadhyay, Medical Applications of Implantable Drug Delivery Microdevices Based on MEMS (Micro-Electro-Mechanical-Systems). *Current Pharmaceutical Biotechnology* , 11, 398-403, 2010.

[2] N.M. Elman, B.C. Masi, M.J. Cima, R. Langer, Electro-thermally induced structural failure actuator (ETISFA) for implantable controlled drug delivery devices based on micro-electro-mechanical-systems. *Lab Chip*. 10(20):2796-804, 2010.

[3] A.G. Noskov, E.B. Gorokhov, G.A. Sokolova, E.M. Trukhanov and S.I. Stenin, Correlation between stress and structure in chemically vapour deposited silicon nitride films. Thin Solid Films, 162, 129-143, 1988.

[4] E. N. Dvorkin, K. J. Bathe, A continuum mechanics based four-node shell element for general non-linear analysis, *Engineering Computations*, Vol. 1 Iss: 1, pp.77 – 88, 1984.

[5] E. Hinton, N. Bićanić, A comparison of Lagrangian and serendipity Mindlin plate elements for free vibration analysis, *Computers & Structures*, Volume 10, Issue 3, Pages 483-493, 1979.

[6] T.X. Yu, F.L. Chen, Failure of plastic structures under intense dynamic loading: modes, criteria and thresholds, *International Journal of Mechanical Sciences*, Vol 42, Issue 8, Pages 1537–1554, 2000.