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Morphology of Metal-Coated Silicone Films

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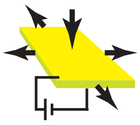
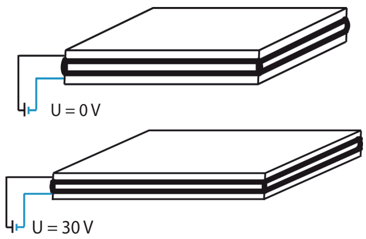
INTRODUCTION



Electrically activated polymer (EAP) thin film structures are promising alternatives to the currently used, mechanically driven artificial urinary sphincters. In order to reach voltages smaller than 42 V suitable for clinical use, the thickness of the EAP has to be reduced to around 1 µm or even below. The thickness homogeneity of the films should be better than 2% to guarantee a constant electrical field in the polymer structure. State-of-the-art spin coating of biocompatible silicone can provide such precision over 2-inch wafers. The bending of the asymmetric microplate structure relates to a well-defined force generated by the thin EAP-actuator. Finally, the bending could be related to voltages applied.

EAP-ACTUATOR

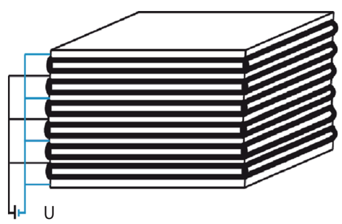
The Electically Activated Polymer (EAP) is basically a capacitor: it consists of two electrodes and a polymer, for example silicone, in between. When a voltage is applied to the electrodes, they attract each other due to electrostatic forces and squash the incompressible polymer, which becomes longer owing to volume conservation.



The stress σ induced in a membrane of thickness *d* by applying the voltage *E* is given as

$$\sigma = \varepsilon\varepsilon_0 \cdot (E^2/d^2)$$

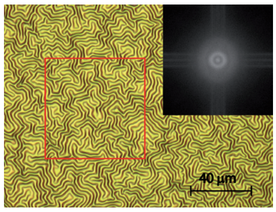
For in-vivo applications, the voltage must not exeed about 40 V. In order to generate electrostatic forces high enough to squash the polymer in spite of these low voltages, the EAPs must be thin (about 1 micron). In addition, to achieve a maximal force, the homogeneity of the film thickness of about 2% has to be granted. If the strain is not distributed equally across the film, the latter can relax in undesired directions, resulting in a reduced planar expansion.



As the mechanical force generated by a single layer of polymere is not high enough for an artificial sphincter, a multilayer structure is used. To achieve an uniform mechanical force output, the electrodes have to be poled alternatively to the opposite voltage sign. Poling the electrodes to the same sign to obtain a repelling force would move all the electric charge to the outer electrodes, like in a Faraday cage, resulting in no force output.

SURFACE RIPPLES

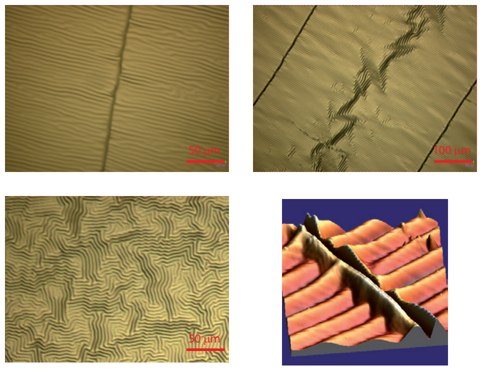
The first contact layer of the EAP structure, i.e. Au, Au/Cr or Ti each 50 nm thin, was deposited onto a 30 µm-thick part of 4”-Si(100) (Waferworld Inc.) by sputtering or thermal vapour deposition (Nordiko Ltd. NS 2550 and Pfeiffer ONF 010, respectively). Subsequently, the micrometer-thick silicone film was fabricated using spin coating (Laurell WS-400A 6NPP). The EAP structure, which is asymmetrically positioned on one side of the wafer piece, was finalized forming the second contact like the first one. The physical vapour deposition onto the silicone film, i.e. sputtering or thermal techniques, did not result in homogeneous and flat EAP structures, but in a periodic ripple morphology.



Based on Fourier transforms it has been found that 50 nm Au leads to 2.5 µm periodicity, 50 nm Ti to 4.0 µm and 50 nm Cr to 6.0 µm. The corrugation in the silicone-metal film is caused by the different thermal expansion coefficients of the two materials, which differ by more than one order of magnitude. During the metal deposition the silicone is heated and expands. When cooling down, the contraction in the silicone film is higher than the contraction in the metal. A strain is induced in the silicone-metal structure, leading to the ripple-pattern. The wavelength of the pattern formed depends on the choice of metal coating and thickness [1].

CRACKS FORMED

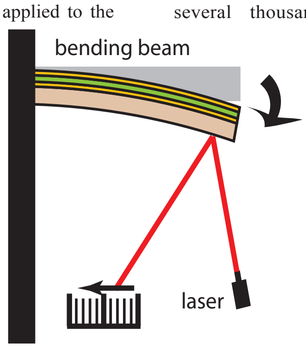
For the specimens sputtered with Ti a remarkable amount of cracks in the silicone film was observed while these cracks did not appear in the Au/Cr coated films, nor before the coating.



The orientation of the ripples was arbitrary and only directed at defects such as cracks. While the height variation of the ripples corresponds up to 10% of the silicone film thickness, the cracks were more than 30% of the film thickness deep. The cracks with distances varying between 0.2 mm and 10 mm run parallel across the whole specimen. With a distance between cracks up to 300 µm, the ripples are alligned. When the distance between cracks increases, the ripples start to show an increasingly disordered behaviour until the distance between cracks exceeds 600 µm, where no preferential orientation can be observed. The bulging at the edges of the cracks indicates that significant mass transport has taken place.

BENDING MICROPLATE

The asymmetric structure of the actuator on the silicon wafer causes the beam to bend when a voltage is applied to the actuator. When the EAP becomes longer due to applied voltage, the stress forces induce a bending in the silicon plate. By measuring the bending radius of the plate, the forces acting on it can be evaluated. The bending radius is measured by light pointer methode. A laser beam is reflected at the uncoated side of the silicon plate. When the plate bends, the laser beam is deflected, and the deflection is detected by photosensitive detectors. By using different filters to tune the laser intensity, bending radii of up to several thousand meters can be measured. To get a relation between force vs. bending radius, the Stoney formula is used [2], which relates the bending of a metal plate and the surface strain acting on it. The formula is slightly modified to fit the experimental setup. The setup is rotable by 360° to achieve different levels of pre-bending of the silicon plate and to calibrate the entire system. The effects of pre-bending of the microplate are still to be examined by future experiments.



CONCLUSION AND ACKNOWLEDGEMENT

The ripples originate from the different thermal expansions of the silicone and the deposited metals. The periodicity of the corrugation depends on the thickness and the Young’s modulus of the deposited metal. Higher Young’s moduli and thicker films result in larger periodicities. Regular pattern of desired periodicity can be manufactured selecting the suitable metal and film thickness. The crack formation is associated with local charges that are generated during the sputtering process but not by thermal deposition.

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