Resistance Components of Elastically Stretchable Electrodes on Silicone Membranes

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1 Introduction –

Stretchable electrodes are conducting metal films which retain their conducting properties for strains on the order of 50%. Stretchable Micro-Electrode Arrays (SMEAs) may be used as a research tool for the study of the effects of traumatic brain injury (TBI) caused by the sudden deformation of brain tissue (1, 2). Attempts to model posttraumatic alterations caused by TBI often involve rapidly stretching brain cells cultured on a silicone membrane, and then measuring the resulting cellular response[1]. Because of their ability to stretch, SMEAs allow simultaneous mechanical deformation and neuronal recording of the brain tissue, and thus facilitate more accurate models of the injury-induced neuronal dysfunction.

Unfortunately, the resistance of stretchable electrodes increases with strain and poses a limit on their functionality. The total electrical resistivity of thin film conductors is made up of several components: a) bulk, b) thin film, c) grain boundaries and d) surface roughness. For thick film or wires, the bulk resistivity is the main contributor to total resistivity, while thin film, grain boundary and surface effects can generally be neglected. However, for thin film conductors such as microelectrodes, these components can have a significant contribution to the total resistivity.

With decreasing feature size, the surface roughness may have a particularly large contribution to the overall resistance for SMEAs (3). The contribution of surface roughness to the overall resistance is determined by the thickness of the electrode and the surface roughness of the silicone membrane substrate. We would like to obtain a quantitative relationship which estimates the contribution of surface roughness to the overall resistance of the electrodes as a function of their thickness. Finding such a quantitative relationship is the first step towards the development of techniques to minimize the overall electrical resistance of elastic thin-film electrodes on silicone.

2 Experimental Overview –

Our approach to obtaining the quantitative relationship discussed above will be to systematically compare gold lines of various thickness on silicone membranes with those on glass. Such a comparative strategy relies on the small surface roughness of glass, and thus allows for a simple way to measure the surface roughness component of the electrodes' resistance. We implicitly assume that the difference in the amount of grain boundaries for thin films deposited on glass and on silicone is negligible. In addition, we compare electrodes with a large range of thicknesses, ranging from thicknesses on the order of ~10 Å to ~10000 Å.

3 Fabrication –

The gold lines are fabricated on elastomeric silicone substrates using microelectronic planar technology. The substrate is a bio-compatible, polydimethylsiloxane (PDMS) membrane of thickness on the order of ~250 µm (2, 4). A clean glass slide is first coated with a hydrophobic self assembled monolayer (SAM) in order to facilitate the removal of the PDMS membrane. The SAM is made by reaction of the glass surface with 1H, 1H, 2H, 2H-Perfluorooctyltrichlorosilanin Hexadecane as described

[1] The cellular response is a cell staining technique that can only distinguish between living and dead cells.

in (4). Next, the PDMS membrane is created by spinning on roughly 3 g of a mixture of Silicone Elastomer Base (Sylgard 184, Dow Corning) and Crosslinker (ratio 10:1), and curing overnight at 60°C. Blanket metal films are deposited directly onto the PDMS substrate by means of electron-beam evaporation. A 25 Å thick Cr layer is deposited prior to the gold film to serve as an adhesion layer. Gold lines 600 µm wide and 1.8 cm long are subsequently patterned using AZ5214 photoresist. After patterning the gold lines are etched with GE-6 gold etchant. Gold lines on the glass substrate are created in a similar fashion with the exception of the SAM and the PDMS membrane. In order to minimize discrepancies due to differences in processing, the metal films on glass and PDMS were deposited together.

4 Results and Discussion –

We measured the resistance of the fabricated gold lines with a simple 2-point probe system[2], and then extracted the corresponding resistivity values. Figure 1 shows the results obtained along with some literature values from (5) for lines on a glass substrate.

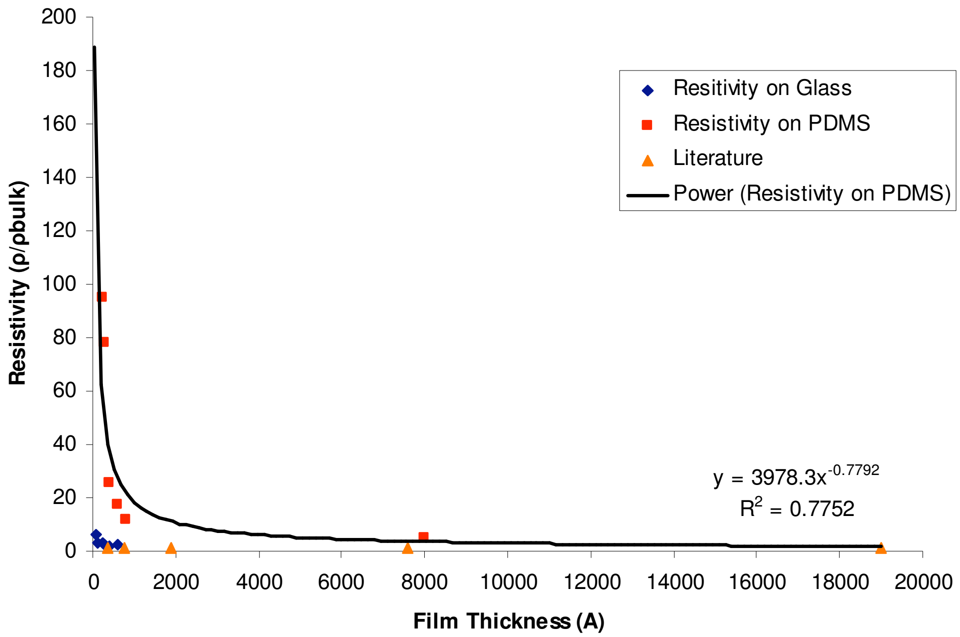

Figure 1: Resistivity of Au lines with varying thickness on PDMS and glass substrates

As expected, the contribution of the surface roughness to the resistivity is largely dependent on the thickness of the gold lines. At very high thickness, the effect of electron scattering on the surface is negligible because the large conducting path provided by the thick film. However, with decreasing thickness, a significant fraction of conduction electrons are scattered at the surface and effective electronic transport is significantly diminished. At very low thicknesses, there is limited or no conductivity due to the effect of surface scattering, as well as the very narrow conduction path Hence, within the thickness range that is usually of interest, (~200 Å to ~3000 Å), the surface roughness is largely responsible for low conductivity.

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[2] Contacts for the resistance measurement were made with the use of silver ions paste and thing gold wires.

5 Concluding Remarks –

We report advances in understanding the contribution of surface roughness to the aggregate resistivity of micro-electrodes on a PDMS substrate. We have seen that the precise contribution of surface roughness to the overall resistance varies significantly depending on the thickness of the electrode. Unfortunately, practically feasible electrodes such as those fabricated in (2), fall under a thickness region where surface scattering plays a large role in limiting conductivity. This situation demands stringent attention to developing fabrication techniques which limit the surface roughness of the PDMS membranes. Such efforts would greatly enhance the electrodes' functionality.

6 References –

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7 Acknowledgements –

I would like to thank Dr. Oliver Graudejus and Joyelle Jones for their guidance during this research. Thank you to Dr. Sigurd Wagner and the Princeton Particle Physics Laboratory for the research internship that made this project possible.