Biocompatible Dry Adhesives Mimicking Gecko Spatulae for EEG Electrodes

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Introduction:

Electroencephalography (EEG) electrodes record the electrical activity along the scalp, rendering them important tools in diagnosing the cerebral origins of neurological disorders such as epilepsy. Compared to other methods of monitoring neural activity, EEG is noninvasive and inexpensive, but suffers from a low signal-to-noise ratio and poor long-term skin adherence.

This project developed a polydimethylsiloxane (PDMS) dry adhesive which was coated in a conducting polymer, poly (3,4-ethylenedioxythiophene) doped with poly(styrene sulfonate) (PEDOT:PSS) to increase the accuracy and durability of the electrodes. The PDMS polymer was cast onto a patterned photoresist mold.

Modeled after naturally occurring adhesives such as gecko foot pads, the synthetic micro-pillars are reusable, less irritating than current adhesive pads, and can stay on the skin for longer periods of time. The presence of microstructures on the surface of the electrodes increases the effective area of the electrodes, increasing the conductivity and lowering the electrode impedance.

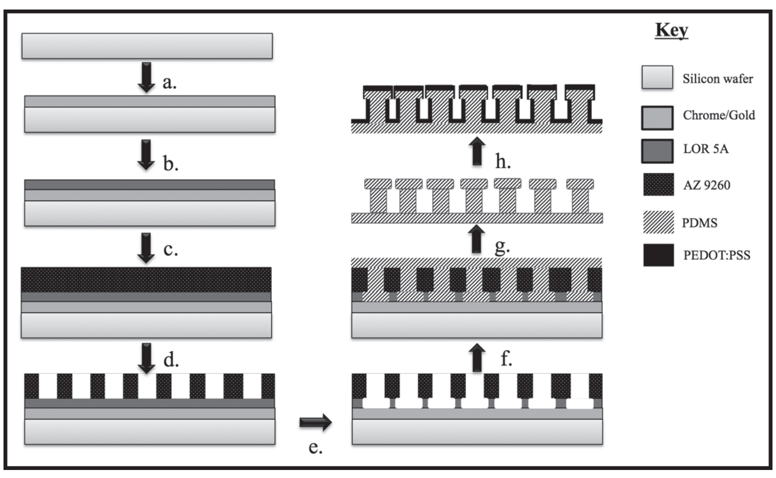

Figure 1: Schematic of mold fabrication and polymer casting. a) Metal evaporation. b) LOR 5A photoresist deposition. c) AZ 9260 photoresist deposition. d) UV exposure and AZ development. e) MF-26A development. f) PDMS casting. g) Cast removal. h) PEDOT:PSS spin-coating.

Methods:

A silicon wafer was cleaned by oxygen plasma using a reactive ion etcher (RIE) (Oxford Instruments PlasmaLab 80+) followed by UV-light treatment (Nanonex) and acetone wash. A layer of chrome followed by a layer of gold was evaporated onto the wafer using a metal evaporator (Alliance Concept EVA450) (Figure 1). A 1.5 μm layer of LOR 5A photoresist was spin-coated onto the wafer (1000 rpm/45 seconds). The wafer was soft-baked at 150°C for five minutes and exposed with UV light for 30 seconds. A layer of AZ 9260 photoresist was spin-coated onto the substrate (1000 rpm/30 seconds) resulting in a thickness of 15 to 20 μm, followed by a two minute soft bake at 100°C. The samples were exposed to UV light again for 30 seconds using a mask.

The wafers were developed in 1:1 diluted AZ developer, rinsed, and underwent a second development for 40 seconds in MF-26A developer. An optical microscope (Nikon) was used to image the molds. The depth of the molds was quantified using an optical profilometer (Veeco-WYKO NT1100).

PDMS was mixed at a 10:1 elastome to curing agent ratio. After degassing, the PDMS was spin-coated onto the mold at 250 rpm for 30 seconds and cured in an oven at 70°C. When cool, the PDMS was peeled off of the mold by hand and placed onto a glass slide with the microstructures facing up. The PDMS surface was activated with a 100 W, 30 seconds oxygen plasma etching. Conducting polymer PEDOT:PSS (Clevios PH 1000, HC Starck) was spin-coated onto the PDMS, soft-baked at 110°C for one minute, and hard-baked for 45 minutes at 145°C.

Following fabrication, the microstructures were imaged with a scanning electron microscope (SEM, Carlos Zeiss 55). A voltammeter was used to examine the resistivity of sections of PEDOT:PSS coated PDMS (0.5 × 1.5 cm). A potentiostat (Metrohm Autolab) was used to measure the impedance.

A goniometer (Apollo OCA 200) was used to calculate the contact angle for structured and flat PDMS with four different substances (water, ethylene glycol, 40% ethylene glycol by volume, and diiodomethane).

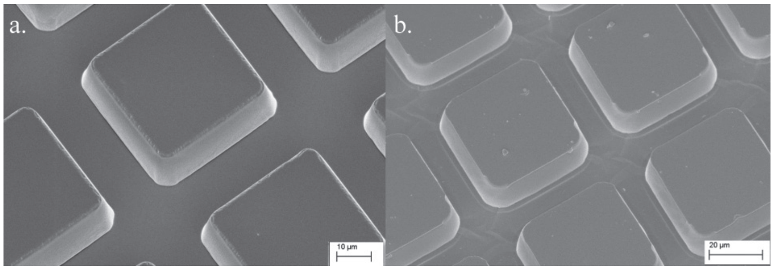

Figure 2: SEM images of (a) PDMS microstructures and (b) PDMS microstructures coated with PEDOT:PSS.

Results:

An adhesive comprised of 40 μm pillars with a spacing of 20 μm was successfully fabricated. An optical surface profiler /profilometer was used to determine that the depth of the molds was 14 μm on average. The mold and resulting PDMS cast had identical topography.

SEM was used to image the PDMS cast before and following the deposition of PEDOT:PSS. Figure 2 demonstrates that a thin spin-coated layer of PEDOT:PSS does not obscure the form of the structures.

Surface activation by oxygen plasma rendered the PDMS temporarily hydrophilic due to the SiOH groups on its surface, allowing for the deposition of PEDOT:PSS. Following PEDOT:PSS deposition, electrical characterization revealed that the surface conductivity of the PDMS/PEDOT:PSS structures was higher than the flat PDMS/PEDOT:PSS samples.

Impedance tests demonstrated a marked difference between flat and structured PDMS coated with PEDOT:PSS. This effect lessened as the PEDOT:PSS layer thickness decreased (Figure 3).

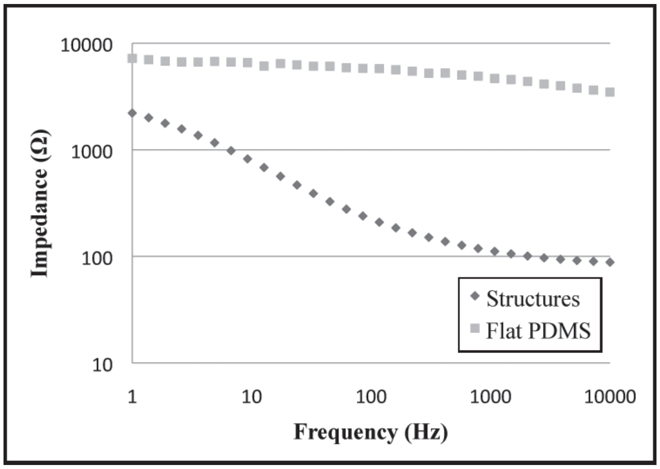

Figure 3: Impedance measurements for flat PDMS and microstructures coated in PEDOT:PSS.

The contact angle data was used to calculate the surface energy of structured (14.95 mN/m) and flat PDMS (19.41 mN/m). A lower surface energy corresponds to a higher contact angle, indicating that the surface with the micropillars is more hydrophobic than the flat PDMS. The hydrophobic surface of PDMS allows for the adhesive to be rinsed with water to remove any dead skin or dust without damaging the microstructures. These adhesives are therefore reusable as well as nontoxic.

Conclusions and Future Work:

We successfully fabricated photoresist molds and PDMS casts with 40 μm features. The photoresist mold fabrication is less expensive than other methods [1] and easily adaptable to different feature sizes. This research has demonstrated that the increased surface area of the microstructures lowers the impedance compared with flat PDMS, and initial tests have also demonstrated lower electrical resistance.

Future work will focus on decreasing the size of the structures and increasing the aspect ratio. Previous research has demonstrated that increased aspect ratio will increase the adhesiveness of the microstructures [1]. Smaller micropillars would also increase the micropillars per unit area, further increasing adhesiveness and surface area.

References:

[1] Kwak, M.K.; "Rational Design and Enhanced Biocompatibility of a Dry Adhesive Medical Skin Patch"; Advanced Materials, 23, 3949-53 (2011).