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Technical note

Photoresist-less patterning of silicone substrates for thick film deposition

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ABSTRACT

Traditionally, fabrication processes to produce microelectrode arrays for neural stimulating electrodes have employed photolithography and a photoresist layer to produce a pattern on a substrate which subsequently has a metal layer deposited. The deposited metal layer is then used to create stimulating electrodes that will ultimately be in close contact with neural tissue. While the process enables accurate fabrication at a reasonable cost, the use of photoresist in the process presents a number of issues. Photoresist is a contamination risk with the potential for chemicals to be absorbed into the silicone, which will then subsequently be in close proximity to neural structures, introducing a risk of toxicity. In addition, due to the use of flexible substrates such as silicone elastomer, patterning of films greater than 1 μm thick can be difficult.

Whilst an obvious solution would be to avoid using photoresist in the fabrication process, few alternatives have been systematically investigated. We investigated use of shadow masks fabricated from glass, brass and silicone elastomer, and exploitation of the natural tackiness of the silicone substrate for mask adhesion. All three mask materials attached well to silicone, but each presented differing degrees of difficulty during alignment and mask removal.

Subsequently, thin gold films (∼20 nm) and thick platinum films (∼8 μm) were deposited on the silicone substrates using the shadow masks. We discuss the mask fabrication, pattern definition, the difficulties which arose, and the benefits of using shadow masks for the fabrication of medical devices.

1. Introduction

Patterning techniques that utilise photoresist and photolithography are common practices used in microelectromechanical systems (MEMS) processing. Using this process, micron-size features can be produced on silicon wafers and, as such, the technology is frequently used to fabricate neural recording and stimulating electrodes.

Photolithography patterning involves high costs due to a number of factors: preparation of the masks; availability of the photolithography equipment; multiple processing steps including application of the photoresist application, a bake, UV or X-ray exposure and development and removal [1]. In addition, major difficulties can arise when thicker films than traditional thin films are required for patterned deposition of polymer substrates. For example, a 6–7 μm photoresist layer is required to pattern a 100 nm thick platinum film with good resolution. In the case of a sputtered film of several microns being required, the associated thickness increase of the photoresist layer can create difficulties in coating and patterning. Although there are photoresist formulations available for producing greater thicknesses, these photoresists cannot easily be removed [16]. In addition, the chemicals and radiation involved with the lithography process can result in swelling or in extreme cases, dissolution of the polymer substrate [2].

Silicone elastomer is a biocompatible material commonly used in neural prostheses such as cochlear implants. It is chemically resistant and has been used previously in combination with photoresist to fabricate electrodes for use in neural implants [3–6]. In applications such as cochlear implants and other neural devices, these electrodes are in close proximity to neural tissues, and may remain in contact for extended periods up to 70 years. Photoresist is toxic to neural tissue, and long-term leaching of even small

Abbreviations: MAE, microelectrode array; MEMS, microelectromechanical systems.

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amounts of residual chemicals into the cochlea or brain may have a negative impact on the tissue. As such, there is strong interest in the development of safe alternatives to the use of photoresist in fabricating neural electrodes for long-term use in neural prostheses.

Several unconventional patterning methods for microelectrode arrays (MAE) have been investigated, including soft lithography [7,8], microprinting [9] and stencil lithography [10], all of which avoid application of photoresist in the final processing. However, these new techniques focus primarily on producing features of ever-diminishing size. There remains a need to investigate alternative techniques to enable fabrication of features of hundreds of millimetres with films several microns thick.

Within the broad field of soft lithography, one promising method that has been investigated is fabrication of a silicone elastomer shadow mask to pattern the non-planar surfaces of silicon wafers [11]. The feature size was 10 or 20 μm diameter. Silicone elastomer was chosen for its flexibility to adapt to the non-planar features. An alternative method used a shadow mask replica to transfer a pattern from a stainless steel mask to silicone elastomer, masking silicon wafers during the sol–gel deposition of CdS thin film [12]. Silicone elastomer was chosen for its superior adhesion to the substrate. These masks showed no blurring or halo build up around the edges of the pattern, primarily due to the good adhesion of the mask to the substrate. Based on these findings, it was suggested that this technique was a potential candidate for patterning of thicker films.

This paper describes our investigation of static adhesion to attach masks produced from different materials onto a silicone substrate. Three material types, each of which could exploit the natural tackiness of silicone substrate were trialled: glass, brass and silicone elastomer. We evaluated the adhesion and alignment of each of the three mask materials to a silicone substrate, as well as whether the mask attachment was robust enough to enable loading of the samples into a sputter coater for film deposition. Initial trials were conducted by depositing a thin gold film approximately 20 nm thick. For the masks found to be suitable for the process, an 8 μm platinum film was then deposited. The difficulties arising from the method applied, and the solutions investigated are presented.

2. Experimental methods

2.1. Silicone substrate fabrication

The silicone substrates were made from MED 4860 (Nusil, USA) mixed with *n*-heptane (Sigma Aldrich) to reduce viscosity. They were made by spin-coating on glass slides. The thickness of a single spun-coat layer was approximately 13 μm at a spin rate of 1500 rpm. Immediately after spinning, the sample was placed on a hotplate at 100 °C for a duration of 20 min, allowing the solvent to evaporate and the silicone to cure. Three individual single layers were coated for each substrate sample, producing a substrate thickness of approximately 40 μm.

2.2. Shadow mask fabrication

The glass masks used cover slips of 100 μm thickness.

Brass shims 50 μm thick were used for the brass masks.

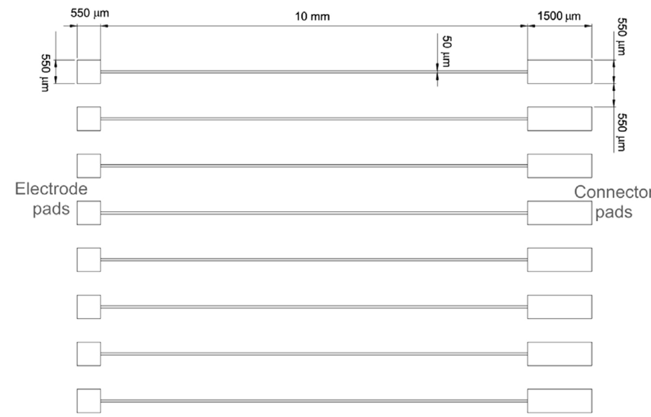

Fig. 1. Pattern used to create shadow masks with square electrode pads. Two patterns were used to create electrodes with surface areas of approximately 0.3 mm^2: (1) circular electrode pads of 620 μm diameter (not shown) and (2) square electrode pads with sides of 550 μm (above). Both patterns had 7 electrode pads, 7 connector pads (1500 μm × 550 μm) and 50 μm × 10 mm tracks between the two.

The silicone masks were made using silicone MED4210 (Dow Corning, USA), selected due to its low adhesion to the glass substrate, aiding removal. The silicone was degassed for a duration of 1 h and spin-coated at 2000 rpm. The samples were cured on a hotplate at 100 °C for 20 min. Each single layer was approximately 80 μm thick. Two sample thicknesses were produced for investigation: a single layer (80 μm), and a double layer (∼170 μm). The silicone masks were peeled off the glass substrate after laser machining.

2.3. Laser micromachining of masks

Masks were patterned using the 4th harmonic of a Nd:YAG laser with a wavelength of 266 nm. The typical duration of the laser pulses was 15 ns. The beam was brought to focus on the target substrate with a 5× objective lens, producing a spot size of 6 μm. The glass masks required 300 mW of power on average, with 10 passes at a pulse repetition rate of 2500 Hz. The silicone masks were fabricated using a pulse repetition rate of 2000 Hz, with an average laser power of 50 mW. The brass masks were produced with a lower repetition rate of 500 Hz, and a corresponding average power, 50 mW. A summary of the processing conditions used for producing masks in the three materials is shown in the Table 1.

Two patterns were used to create electrodes with surface areas of approximately 0.3 mm^2: (1) circular electrode pads of 620 μm diameter; and (2) square electrode pads with sides of 550 μm. Both patterns had 7 electrode pads, 7 connector pads (1500 μm × 550 μm) and individual tracks between each pair of electrode and connector pad (50 μm × 10 mm). Fig. 1 illustrates an example of the square electrode pad pattern.

2.4. Film deposition

A thin gold film, 15–20 nm thick, was sputter-deposited (Edwards S150B) through the masks to investigate the pattern definition and the adhesion of the masks to the silicone substrate during

Table 1
Laser machining parameters for the three mask materials.

Material	Pulse (ns)	Pulse rep rate (Hz)	Power (mW)	Energy (μJ)	Spot size (μm)	Fluence (J/cm^2)	Passes	Pass rate (mm/min)
Glass	15	2500	300	120	6	425	10	50
Brass	15	500	50	100	6	350	5	50
Silicone	15	2000	50	25	6	90	5	50