Fabricating microelectrode arrays by laser-cutting of platinum foil and silicone rubber

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Abstract

A method for the fabrication of microelectrode arrays exclusively made of medical grade silicone rubber and platinum foil was developed. The method is based on laser-cutting and offers an integration density of down to 50 µm track pitch. The proof of principle was established by way of fabrication of a two-channel microelectrode array consisting of an 18 µm platinum foil sandwiched between two 20 µm layers of silicone rubber.

1 Introduction

Micromachined electrode arrays for electrical interfacing with the nervous system have already demonstrated great potential toward future neural prostheses, especially when the targeted tissue restricts the electrodes to a minimum size or when high integration densities are required. However, micromachining is a complex technology, involving a variety of toxic chemicals and expensive clean room facilities. The substrates (e.g. silicon, polyimide) processed to electrode arrays are not established as biomaterials through prior regulatory approval and this prohibits or delays their use in the human body.

Precise laser-cutting of established biomaterials could overcome the aforementioned drawbacks. With the exception of a YAG laser, no expensive equipment is required. Fabrication materials include medical grade silicone in combination with ultra-pure platinum foil. Laser-patterned foil sandwiched between sheets of silicone rubber has been described in [1] as a fabrication method for neural cuff electrodes. Inspired by this work, we developed a substantially simplified process for fabrication of microelectrode arrays by laser cutting using only two layers of spin-on silicone rubber and platinum foil.

2 Methods

2.1 Laser

The 1064 nm wavelength of a Nd:YAG laser was halved using a frequency doubling crystal. The beam was reduced to a cross sectional diameter of 1.5 mm and focused by a plano-convex lens (50.8 mm focal length) upon the sample surface. The laser emitted pulses of 7-9 ns duration at a repetition frequency of 30 Hz. The time-averaged power of the focused beam was set to 9.5 mW. A constant stream of N2 was directed to the target location on the sample surface. In this way, the sample was cooled and vapour or dust from the laser cutting was dissipated.

2.2 X-Y Table

The samples are mounted to a x-y table driven by stepper motors, enabling two-dimensional movement of the samples perpendicular to the laser beam. The stepper motors as well as a solenoid driven shutter that interrupts the beam on demand were controlled by a PC. Custom-made software translated AutoCAD™ plot files to movements of stepper motors and state of the beam shutter.

2.3 Carrier

Standard microscope glass slides were used as carrier for the microelectrode structure during processing. Since silicone adhesive was used as substrate for the microelectrodes and this material adheres strongly to glass, Scotch Tape™ (3M) was laminated onto the glass slide acting as an adhesion inhibition layer (figure 1 a).
2.4 Fabrication Process

The viscosity of MED-1000 silicone adhesive (NuSil) was reduced by mixing with n-Heptane at a volume ratio of 1:1. 2 ml of this mix was spun onto the Scotch Tape™ laminated glass slide using a spin coater (figure 1 b). After curing of the silicone rubber, 18 µm thin platinum foil was pressed on the silicone surface (figure 1 c). No adhesive was used, the foil kept in place only by the adhesion of the cured silicone surface. The sample was mounted on the x-y table against fixed locating stops and the platinum foil patterned by the laser (figure 1 d) by way of indexing the sample beneath the beam. The sample was removed from the table and excessive foil was peeled off using forceps (figure 1 e). A second layer of n-Heptane diluted silicone adhesive was spun on and cured (figure 1 f). The sample was remounted to the x-y table against the fixed locating stops and parts of the top silicone layer were removed by the laser to expose electrode sites and contact pads. Subsequently, the outer geometry of the microelectrode array was defined by cutting through both silicone rubber layers (figure 1 g). Finally, the structure was released from the carrier using forceps (figure 1 h).

3 Results

The viscosity of the n-Heptane diluted silicone adhesive was appropriate for spin coating. Different spin rates led to different layer thicknesses as shown in figure 2. For fabrication of prototypes, a layer thickness of 20 µm was chosen in this study.

![Figure 2: The spin rate determines the layer thickness of the silicone rubber](image)

The speed of the sample relative to the laser beam was the parameter used to selectively cut different materials and set the depth of the cut. In doing so, it was possible to cut platinum foil without cutting through the underlying silicone substrate beneath. However, cutting through silicone on top of platinum led to some ablation of platinum. The effect was minimised by defocussing the laser beam by 2 mm. In this way, the degree of platinum ablation became insignificant. Unlike [5], the whole area of the, e.g. electrode opening, was removed by the laser using meander-like traverses with 25 µm pitch. As such, no manual removal of silicone parts was required.

<table>
<thead>
<tr>
<th>Task</th>
<th>Cutting Speed</th>
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<tbody>
<tr>
<td>patterning Pt foil</td>
<td>65 µm/s</td>
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<tr>
<td>removing top silicone layer to open electrode sites and contact pads</td>
<td>250 µm/s (2 mm de-focused)</td>
</tr>
<tr>
<td>cutting a hole through platinum and silicone underneath</td>
<td>30 single pulses without movement of the sample</td>
</tr>
<tr>
<td>cutting outer geometry (two layers of silicone)</td>
<td>30 µm/s</td>
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</tbody>
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Table 1: Cutting speeds.

Cutting through two layers of silicone to determine the outer geometry of the structure led to ablation of material from the surface of...
the Scotch Tape™, but the tape was not cut completely. The parameters found for fabrication of a microelectrode consisting of an 18 µm platinum foil sandwiched between two 20 µm layers of silicone rubber are listed in table 1.

Cutting through platinum led to a cut width of approximately 30 µm. The minimum achieved track pitch was 50 µm. The width of cuts through the silicone varied with the depth of the cut to between 50 µm and 150 µm. Cutting through platinum and underlying silicone using 30 single laser pulses to provide a through-hole for MicroFlex interconnects [2] led to a hole diameter of 40 to 50 µm.

Figure 3: A two channel microelectrode fabricated by laser-cutting of silicone rubber and platinum foil. 
A: contact pads, B: tracks, C: electrode sites, D: through-holes, E: silicone rubber substrate.

Figure 3 shows a simple two channel microelectrode prototype fabricated with the method and parameters described above. Two 600 µm x 600 µm contact pads (A) are connected via 80 µm wide and 18 µm thick tracks (B) to the electrode sites (C, 100 µm diameter). Each contact pad has a 50 µm diameter through-hole (D). The whole device is made of 2 layers of 20 µm thin medical grade silicone rubber (E).

4 Discussion and Conclusions

The mechanical properties of the prototypes manufactured in this study are dominated by the 18 µm platinum foil. Since the silicone is only 40 µm thick, it does not provide elastic properties to the structures. Elastic properties can be obtained, however, by increasing the silicone layer thickness or combining laser-fabricated microelectrodes with silicone bodies like cuffs (cuff electrodes), spheres (e.g. retina electrodes) or planar sheets (2D-array, e.g. for cortical recordings) by gluing or plasma-bonding [3].

The prototype presented herein is comprised of two electrodes. Future work will determine whether or not the level of complexity can be increased to contact numbers in the range of 100 in order to realise electrode arrays for visual prosthesis. A suitable 100 channel implant-sized stimulator with telemetry has been previously reported by one of the authors [4] and is envisaged to be utilized in in-vivo testing of microelectrode arrays fabricated by the methods described herein.

Prior to this, however, the biocompatibility of the laser-patterned structures is to be investigated. Laser-ablation of silicone rubber with 532 nm wavelength is a thermal process that could alter the biocompatibility. However, we are encouraged by the good acceptance of laser processed cuff electrodes chronically implanted in cats [5].

References


Acknowledgements

This work was funded by a research visitor grant provided by the University of Newcastle, Australia, and by way of a grant from the Australian Research Council.