STRETCHABLE, CONFORMAL MICROELECTRODE ARRAY FABRICATED WITH PATTERNED FLEX CIRCUIT TECHNOLOGY

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ABSTRACT

Flex circuit technology enables robust and low cost fabrication of flexible electronics, and therefore offers significant benefits over more complex fabrication techniques. Current complex processes can enable standard integrated circuit materials to achieve high performance over large strains, but such devices can be difficult to manufacture, handle, and interface with standard circuit boards. Herein we present the design, fabrication, and electromechanical testing of a flex circuit-based stretchable microelectrode array. Stretchability is achieved by perforating the device with laser cut, micropatterned through-holes. This rationally designed perforated geometry enables the device to maintain planarity and constant electrical properties under strains up to 15%.

KEYWORDS: stretchable electronics, flexible electronics, microelectrode array, biocompatible devices

INTRODUCTION

Researchers in the field of stretchable electronics typically take one of two approaches to overcome the rigidity-related limitations of standard metal-on-wafer electrodes: they introduce non-standard materials into the microfabrication process or they invent novel fabrication techniques [1]. Devices that can both flex and stretch are better suited than conventional integrated or printed circuits for integration with compliant biological tissues. Such devices have applications in implantable medical devices, electrophysiological studies in biomimetic environments, or more broadly for wearable electronics.

Innovative fabrication processes such as metal deposition on silicone [2] and transfer of silicon-based electronics onto skin-like backing layers [3] have been used to create electronics that can bend and stretch for in vivo brain and heart studies. In addition to the complexity of their fabrication, a major engineering challenge of working with such devices involves handling and manipulation, because these devices can be damaged easily when not encapsulated. Stretchable electronics must be robust and biocompatible to gain wide acceptance. In this work, we present such stretchable device designs.

DESIGN AND FABRICATION

A stretchable 4 by 4 element microelectrode structure was designed as a flex circuit whereby the substrate is structured to consist of domains, which experience negligible strain, and domains with hinge-like geometries, which accommodate the macroscopic strain on the device. Copper traces running along the neutral axes of each hinge connect electrodes to their bond pads, which are located in the low strain domains [4]. Designs were simulated in ABAQUS to investigate the effect of applied strain on peak in-plane electrode strains (Figure 1) and out-of-plane rotation. Square electrodes are 305 µm wide with a 1.4 mm lattice constant. Simulations of a copper and polyimide flex device predict in-plane principal strains in the electrodes remain less than 1% for external global strains up to 15%; further, no out-of-plane rotation due to hinge deformation occurs for strains up to 15%.

Flex circuit fabrication was chosen because passivated flex devices can be implanted in the body, and designs can readily be rapidly prototyped by flex manufacturers. The stacked device consists of a polyimide base layer, copper trace layer, adhesive layer, and a cover film layer with a total thickness of 105 µm. A Yag laser with a 20 µm spot size and 25 µm entry beam was used for perforation before lamination (Altaflex, CA). A device is shown next to penny for scale in Figure 2.

Figure 1: Stretched device (top) and simulations (below) showing peak in-plane strains in electrodes of 0.8% for macroscopic device strains of up to 15%.

Figure 2: Device is 26 mm by 16 mm and is surrounded by a handling structure that is cut before use.
EXPERIMENTAL SETUP

We stretched devices using a micromanipulation stage (ST-Japan) with a computer-controlled linear actuator (Zaber). We perform 4-point resistance measurements of the ultra low-resistance traces during stretch tests using a source measure unit (Keithley SMU-236). Both the linear actuator and SMU-236 were controlled via custom MATLAB software. We imaged the devices with a USB microscope (Dino-Lite). Thermocompression wire bonding formed electrical contacts with the device; the wirebonds were protected via encapsulation with epoxy (5 Minute Epoxy, Devcon). During electrical testing, the electrodes were wirebonded in series to create current loops.

RESULTS

Stretch tests revealed that inter-electrode strain was proportional to applied strain and consistent from electrode to electrode for strains up to 15%. The electrodes also maintained their planarity for strains up to 15% (Figure 3). Unlike many stretchable electrode devices whose resistances increase with applied strain, our device resistance remained unchanged for applied strains up to 18%. After destructive stretch testing to 100-150% strain, intact current loops still maintained functionality demonstrating device robustness. In the future, such devices could be interfaced with membrane-based strain systems or even a biological system such as the heart, which undergoes regular cyclic strains up to 10 or 15%.

CONCLUSIONS

We have designed, manufactured and tested a stretchable microelectrode array. Using a novel perforated geometry, we have transformed a flex-circuit into a fully stretchable device. These designs maintain planarity and constant electrical properties for strains up to 15%. The device materials are biocompatible, robust and appropriate for both in vitro and in vivo studies.

REFERENCES