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Surface-Micromachined Neural Sensors with Integrated Double Side Recordings on Dry-Etch Benzocyclobutene(BCB) Substrate

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***Abstract*— a neural sensor with novel structure and capable of double side recordings has been designed and fabricated using surface micromachining technique. Dry-etch Benzocyclobutene (BCB) was selected as the substrate and packaging material for its excellent electrical, mechanical and thermal properties. Positive photoresist (AZ4620) was used as the sacrificial layer during the formation of backside recording sites , and the lift-off process combined with BCB dry etch technique was developed to open the recording sites on the backside. The finished device has intracortical recording sites on both sides, and also epidural recording sites on the front side. The total channel number doubled compared to that of single side electrode structure. Three dry-etch BCB layers were applied to insulate the front side conduction traces from the backside trace layer, and package the entire devices. The developed process shows reliable and high fabrication yield, and results suggest that this newly developed neural sensor could improve the performance and efficiency of neural recording.**

Keywords: Dry-etch BCB, Double-side recording, Neural Sensors, Biocompatible polymer, RIE etch, Via angle

I. INTRODUCTION

ADVANCES in neural interfacing technology have enhanced our ability to investigate the operation of neural circuits in brain by providing simultaneous recordings from large numbers of neurons. Among different materials investigated as the substrate for neural sensors, Dry-etch Benzocyclobutene (BCB) is a desirable material due to its high flexibility, biocompatibility, low water uptake and high planarization level. The Dry-etch Benzocyclobutene (BCB) resins are derived from B-stages bisbenzocyclobutene monomers and originally developed for use in microelectronics applications. They are commercialized under the trade name Cyclotene ® and are now widely used in many applications such as MCM-D [1], and flat panel displays [2]. Some properties of Dry-etch BCB and other commonly used material (Silicon, Polyimide) are listed in table 1.

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Recently, we reported fabrication of dry-etch BCB based neural implant for cortical and epidural recording.[3] The structure of this implant, in its simplest form, comprises a metal pattern sandwiched between two BCB layers with recording site and via opened on the top layer (Figure 1a).

TABLE I
PROPERTIES OF VARIOUS COMMONLY USED MATERIALS AS NEURAL SENSOR SUBSTRATE

Property	Polyimide	Dry-etch BCB	Silicon
Dielectric Constant	3.5	2.6	15
Water Uptake(wt%)	4	0.12	>10
Planarization Level	70%	90%	
Young's Modulus (Gpa)	7.5	3	110
Breakdown Voltage (V/m)	3×10^6	3×10^6	6×10^7

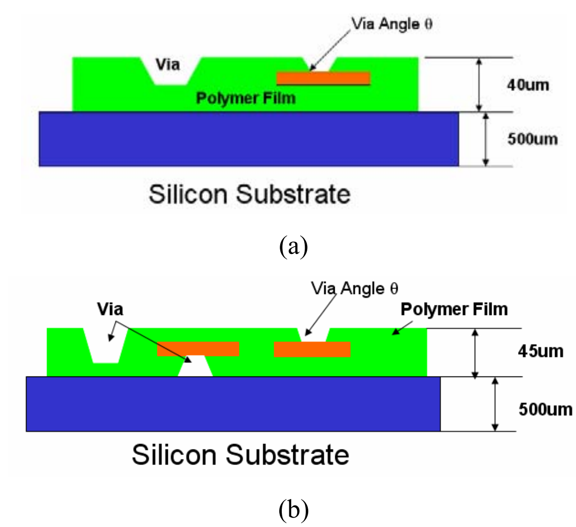

Figure 1. Schematic of BCB based neural sensor with (a) single conduction traces, (b) Double side conduction traces.

To reduce damage to the brain tissue and electrode itself during surgical insertion, the penetrating tip of the electrode has to be controlled within 50um-100um in width. The recording sites are arranged in certain depth range to acquire most efficient recording from targeted neural structures. Therefore, only a limited number of recording sites can be incorporated on each shank. Figure 1b shows the schematic view of a new electrode structure with another conduction trace layer incorporated on the bottom side. Without increasing the dimension of the penetrating tip, the channel density can be doubled.

In this paper, we report the fabrication of this double sided, BCB based neural sensors using surface micromachining technique. Compared to that of single sided electrodes, only one additional mask is required and sacrificial layer lift-off process combined with Plasma dry etch process is used to open the recording sites on the backside. All processes are compatible with existing CMOS process and performed at CSSER (Center for solid state electronic research) in Arizona State University.

II. PROBE STRUCTURE DESIGN

Figure 2 shows the schematic view of the designed electrode structure. Three penetrating tips are integrated with the device and each tip is designed to be 2mm in length to make the recording site goes to layer V of the cortex. Four recording sites (two on each side) including one ground and one via are incorporated on each tip. Each recording site is 20um×20um to provide proper impedance for good recording of neural signals. The vias (40um×40um) are incorporated for the purpose of seeding the bioactive components for improving the performance of the electrodes. All three tips can be bended over 90º to make them vertical to the brain surface during the surgery. There are two bigger recording sites (60um×60um) integrated in the middle for the purpose of epidural neural recording. They are designed to remain flat on the brain surface to collect the field potential.

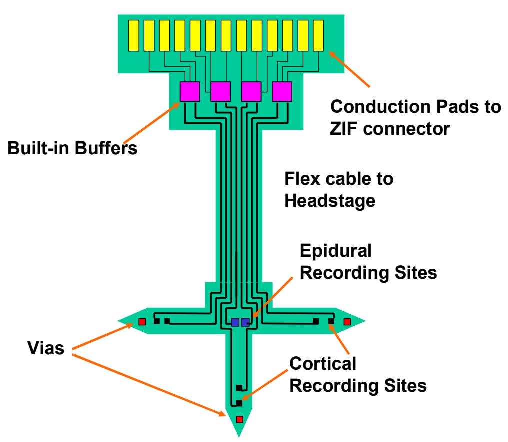

Figure 2. Schematic top View of the BCB based electrode with 10 channels on the front side and 8 channels on the backside.

The integrated signal conditioning is designed to improve signal to noise ratio and allow stable signal transfer over distance. The dimension specs are 5mm in width and 3mm in length to meet the requirement used for rat, and can be easily modified to meet the need of other applications. Based on this dimension requirement, three LMC6035IBP low power 2.7V single supply CMOS Op Amp chips are used to form the buffer circuit (figure 3) to reduce the signal attenuation and noise coupling. Since the signal collected is typically as small as 50-500uV, this on-chip buffering can reduce the channel impedance and the parasitic shunt capacitance. These buffers are connected as voltage followers as shown in figure 4. It has a high-drive capability and low output impedance. Each buffer is 1.4mm ×1.4mm in dimension and contains two Op Amps. The headstage is connected to the outside micro-connector through integrated conduction pads, and signal collected by recording sites transferred to the headstage through a long flexible cable (10mm in length and 1mm in width) which is totally flexible to avoid the moving of the headstage during the connection.

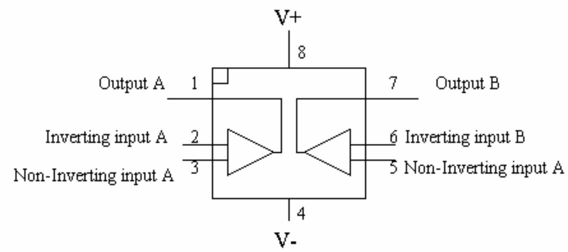

Figure 3. Schematic view of the single unit-gain buffer

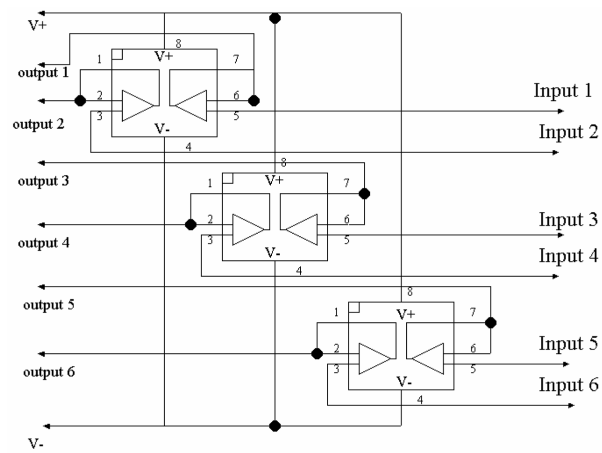

Figure 4. Schematic view of the head stage circuits

III. FABRICATION PROCESS

Figure 5 and 6 shows the process flow for this electrode on BCB substrate. This process can be characterized by three steps, BCB layer application, Au/Cr metallization, and Lift-off/Etch process. The fabrication process started from quarter 4-in (100) oriented n-type Silicon wafer with resistivity of 10-25 Ω-cm, 0.5um thick silicon dioxide was grown on the surface by wet oxidizing. 10um thick photoresist (AZ4620) was then spin-coated on the sample surface. Traditional photo-lithography technique was used to pattern the photoresist as the sacrificial layer for backside recording sites (Figure 6a). The first BCB layer (Cyclotene 3022 from DOW Chemical) was spin-coated at 2000 rpm to obtain about 15um thick BCB layer after curing (Figure 6b) Usually thicker BCB layer can give better mechanical strength, but the related etch time will be longer which will lead to difficulty in lateral etch control. This 15um thick BCB layer fully encapsulates the bottom PR layer.

The sample was then partially cured for 40 mins at 210°C in N_2 gas environment to provide a suitable surface for metal deposition. Partially cure of base BCB layer and fully cure of the final BCB layer terminates any route for water transmission through the boundary between the base and top BCB layers. Excellent planarization and small volume shrinkage on the BCB layer was observed. 2000Å thick Aluminum layer was E-beam deposited onto the BCB surface (figure 6c) to serve as the BCB dry etch mask. Traditional photolithography technique was used to pattern the aluminum layer followed by the wet etching.

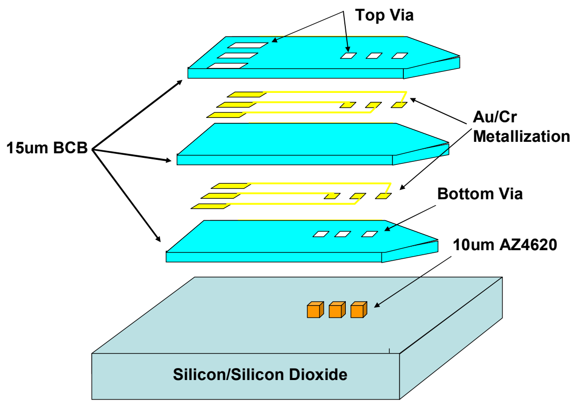

Figure 5. Structure Layout of BCB electrode

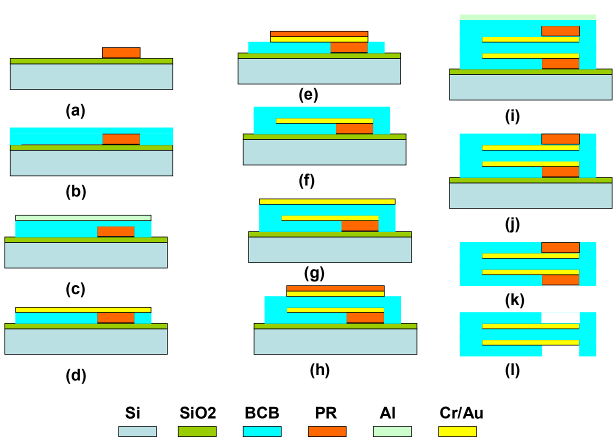

Figure 6. Process Flow of the double side BCB electrode

The Plasma RIE (200W/100mT/20sccm O2/5sccm CF4) was used to etch the BCB down to the silicon substrate and electrode shape was defined in this step. In RIE, reactive species are accelerated toward the surface, which results in a more anisotropic etch. Moreover, physical sputtering and chemical reaction combination can give higher etch rates. Unlike most other polymers, BCB requires F radicals in addition to O radicals for etching because of the presence of Si in the polymer matrix. This precludes the use of PECVD SiOx or SiNx as etch masks [4]. After the plasma etch, the aluminum was removed and another RIE etch was used to thinner the BCB layer from 15um to 10um until the bottom PR layer was exposed. The thickness was monitored by Tencor P2 long scan profiler with a series of testing samples.

2000Å gold and 20nm Cr were then thermally deposited on the sample as the first conduction trace layer. (Figure 6d)The Cr layer served as the glue layer to improve the adhesion between the BCB and gold. Gold was used for recording sites because it has excellent surface inertness and it provides no native oxide. However, gold is soft material, so long term corrosion issues should be examined. Traditional photolithography technique was used to pattern the conduction traces and the recording sites. (Figure 6e) The second 15um BCB layer was spin-coated and partially cured to completely encapsulate the bottom conduction trace layer followed by the 40min partially cure. (Figure 6f) 2000Å thick aluminum layer was then deposited as the etch mask and patterned using wet etching. After another 15 mins RIE dry etch to pattern the second BCB layer, aluminum was removed and 2000 Å gold/ 20nm Cr was deposited as the second conduction trace layer followed by wet etching. (Figure 6g, 6h).

10um thick AZ4620 was then spin-coated and patterned on the sample surface as the sacrificial layer for the front-side recording sites. (Figure 6i), 2000 Å thick aluminum layer was then coated on the sample followed by wet etch and 15mins BCB RIE dry etch. After removal of the aluminum layer, another 5mins RIE etch was performed to thinner the top BCB layer and expose the front side PR layer. (Figure 6j) After that, the samples were fully cured for one hour at 250°C in N_2 gas environment to covert 90% BCB to polymer. 49% HF was then used at last to etch away the bottom silicon dioxide layer, and the device was lifted off the silicon substrate. (Figure 6k)

To remove the sacrificial layer and expose the recording site on both sides, the samples were immersed into the Microstrip 2001 heated by hot plate. The bottle dropper was used to drop 1ml microstripper solution onto the sample surface. The temperature was controlled to be 80ºC and iteratively stripping was required since the stripper will evaporate as the temperature goes up. After 3-4 trials, the PR layer on both sides can be fully removed and the underneath recording sites were fully exposed. (Figure 6L)

IV. RESULTS AND DISCUSSION

The Fabricated device was visualized through optical microscopy and SEM as shown in figure 7. Figure 7a shows the SEM image of the vias opened by RIE etch combined with lift-off technique. The via angle is controlled to be 63ºC and the aspect ratio is 2:1. Figure 7b shows top view of one of the penetrating tip, two recording sites (20×20um) and one via (40×40um) were incorporated inside the tip portion (2mm in length and 0.15mm in width). Figure 7d shows the headstage with three Op Amps soldered by flip chip bonder (Finetech, Germany). The headstage is 3mm in length and 5mm in width with each Op Amps in 1.4mm by 1.4mm. The flexible cable connects the penetrating tips (Figure 7c) to the headstage. The end part of the connector pads (20mm in length and 5mm in width, Figure 7e) is exposed for connection with micro-connector. The finished electrode has total thickness of about 45um and shows no curve-up problem. The total fabrication time is only one week, and the electrode yield is close to 95%.

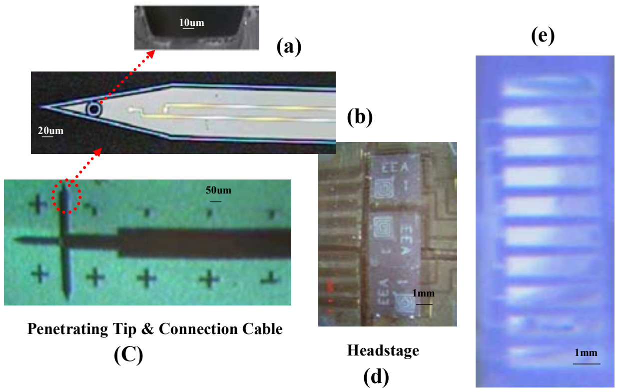

Figure 7. Finished BCB electrodes with double side conduction traces and integrated on-chip buffers

V. CONCLUSION

A new neural probe aimed to improve recording efficiency and performance, realize intra-cortical and extra-cortical neural recording was designed and fabricated for reliable and stable long-term implant function. Compared to single side BCB electrodes, this probe has highly increase channel density. The sacrificial layer lift-off combined with optimized BCB dry etch process was developed to open the recording sites on both the front side and backside. In this case, no backside silicon etch is required which highly reduce the process time and shortened the prototyping time which in turn improved the fabrication efficiency.

On-chip buffers are integrated with the electrode to improve the signal-to-noise ration reduce the noise coupling. Flexible long BCB cable was integrated with the electrodes to absorb the stress from any micro-motion between the brain tissue and the electrode. Further research will involve the penetrating test and acute recording test to demonstrate the recording performance improvement.

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REFERENCES

[1] T. Miyagi, Y. Iseki, etc. “MCM-D/L Copper/Photosensitive BCB Multilayer for upper microwave band systems”, 1996 Electronic Components and Technology Conference, pp149

[2] D. Perettie, M. McCulloch, and P. E. Garrou, “BCB as a planarization resin for flat panel displays,” *Proc. SPIE,* 1992, vol. 1665, p. 331.M. Young, *The Techincal Writers Handbook.* Mill Valley, CA: University Science, 1989.

[3] H.Zhu, J. He, B. Kim, “High Yield BCB Based Neural Implant for Simultaneous Intra- and Extra-Cortical Recording,” Proceedings of 26th Annual International Conference of the Engineering in Medicine and Biology Society, Volume: 2, Pages:4341 – 4344, 1-5 Sept. 2004

[4] P. Chinoy, J. Tajadod, “Processing and Microwave Characterization of Multi-Level Interconnects Using Benzocyclobutene Dielectric”, IEEE Transactions on Components, Hybrids, and Maufacturing Technology, VOL.16, NO.7, 1993.