A TSV-Based Heterogeneous Integrated Neural-Signal Recording Device with Microprobe Array

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Abstract

Highly integrated and miniaturized neural sensing microsystems are crucial for brain function investigation and neural prostheses realization. This paper presents a TSV-based heterogeneous integrated neural-signal recording device with microprobe array. By TSV, microprobe array and CMOS circuit make connection on the opposite sides of the chip. By measurement results on electrical characteristics of devices and TSV, this recording device is ready for bio-medical applications.

Keywords: TSV, CMOS MEMS, Bio-Signal Probe.

Introduction

Bio-signal probes that provide stable observation with high quality signals are crucial for understanding how the brain works and how the neural signal transmits. Solutions usually include bio-sensors and CMOS circuits. However, the length of the connected string between sensor and CMOS circuit has significant impact on the quality of the inherently, weak and noisy bio-signal. The collected weak signals from the sensor need to pass through a string of interconnections and interfaces that introduce noises and lead to bulky packaged systems. This paper presents a TSV-based heterogeneous integrated neural-signal recording device with microprobe array for brain neural sensing applications.

Integrated Microsystem and Circuit Design

Figure 1 illustrates the structure of the integrated microsystem. The MEMS neural microprobe array and low-power CMOS sensing circuit are fabricated on the opposite sides of the same silicon substrate. Cu TSVs are used to form low impedance interconnection between the microprobe and CMOS circuitry [1-2].

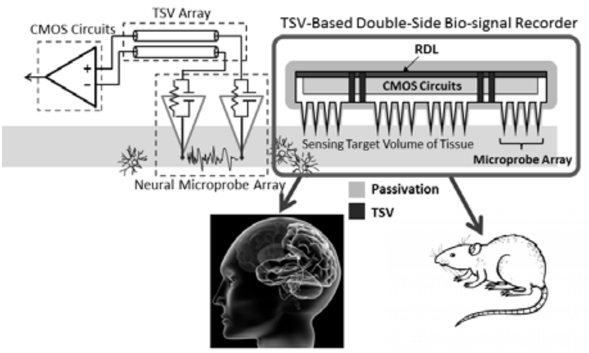

Fig. 1 Structure of the integrated microsystem used to recording human or rat's brain neural signal.

Figure 2 shows the cross-section view of the structure. The overall chip is 5x5mm^2, 350μm in thickness including 150μm probe height and 200μm TSV height, respectively. A total of 480 microprobes is fabricated and divided into 2x2 and 4x4 sensing areas, forming 4 and 16 bio-signal recording channels [3].

The 16-channel low noise and low power read-out circuitry is designed using 16 two-stage Analog Front-End (AFE) circuits as shown in Fig. 3. TSV array and input of AFE circuit are connected by RDL on the front-side. Impendence of single TSV is 5.5 mΩ and 34.2 fF, much smaller than that of conventional long transmission wires. Thus, the voltage drop and noise are reduced significantly. CMRR of 168 dB and PSRR of 72 dB are achieved to suppress common mode noises from human bodies and power supply noises.

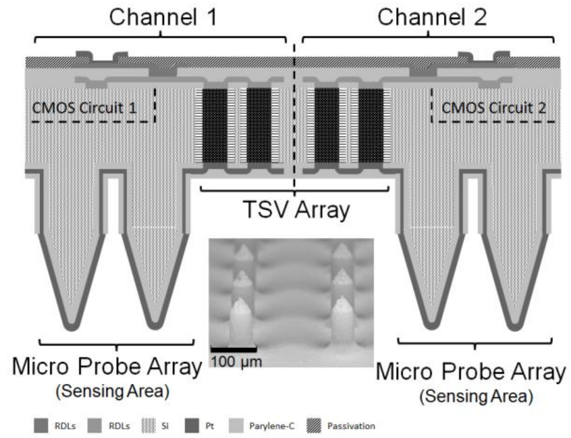

Fig. 2 Cross-section view of the structure. Total thickness is 350μm including 150μm probe height and 200μm TSV height.

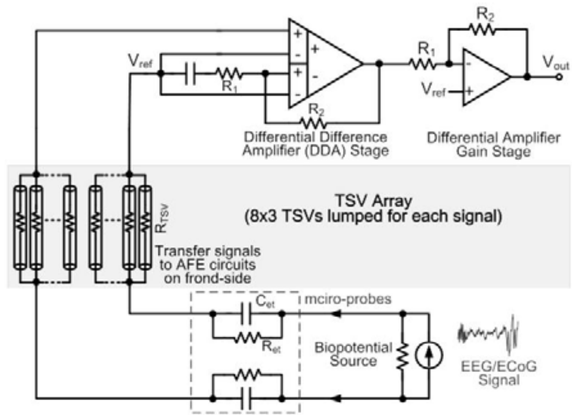

Fig. 3 16-channel low-noise, low-power read-out circuitry using two-stage Analog Front-End (AFE) circuits.

Fabrication of Integrated Probe-TSV-CMOS

Figure 4 illustrates detailed process flow. In Fig. 4(a), CMOS circuits are fabricated using UMC 0.18 m process, followed by front-side and fully-filled Cu plating process to fabricate Cu TSVs with 200μm depth (height) and 25-30μm diameter. Next, RDL is fabricated for the connections between TSV arrays and circuit input pads. Then, a deep ICP etching process is applied on the back side of the wafer to form the microprobe array (Fig. 4(b)). A 5 μm thickness biocompatible parylene-C is deposited to isolate different channel (Fig. 4(c)). O_2 plasma is then used to open the TSV area for signal transfer (Fig. 4(d)). Fig. 4(e) shows the Pt sputtering and lift-off process used to define the different channel area. Fig. 4(f) shows the dicing and final package. Figure 5 shows the image of device including TSV array and microprobe arrays. The height of TSV is

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200μm and the height of μ-probe is 150μm, respectively.

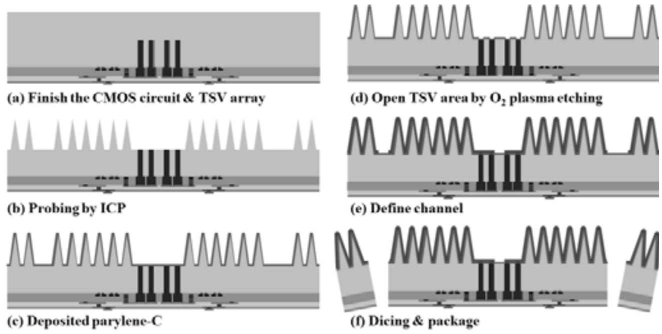

Fig. 4 Detailed process flow, including post processing.

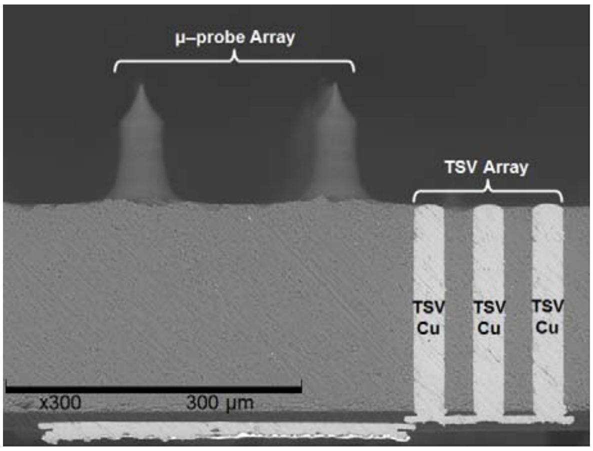

Fig. 5 Cross-section view of the device.

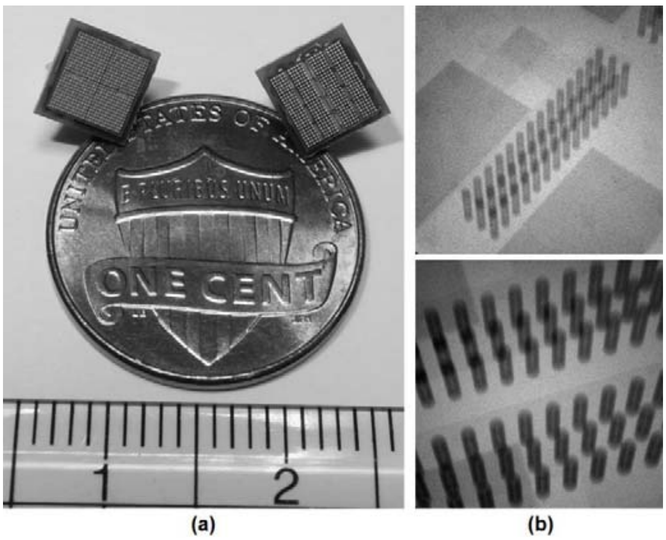

Fig. 6 (a) Photograph of the integrated probe microsystem with a total size of 5mm x 5mm, including 480 microprobes; (b) The bio-microsystem chip and TSV array under X-ray microscopy investigation.

Figure 6(a) is the TSV-based heterogeneous integrated neural-signal recording with μ-probe array, PCB and connector. In this design, it is available to extend the number of channels in 5x5 mm^2 area, and the number of TSV and neural probes can be reduced for a recording channel. The total size is 5mm x 5mm for each device. The microprobes are divided into 2x2 and 4x4 sensing areas, forming 4 and 16 bio-signal recording channels. Figure 6(b) is the X-ray microscopy image showing the bio-microsystem with Cu TSVs without visible voids, indicating Cu TSVs are fully filled for fabrication quality.

Electrical Characteristics of Devices and TSV

Electrical characteristic of CMOS devices and TSV used in the bio-microsystem are investigated. Figure 7(a) and 7(b) show I_D-V_D and I_D-V_G behaviors of PMOS and NMOS, respectively. Both results indicate stable and reliable electrical performances for the bio-microsystem operation.

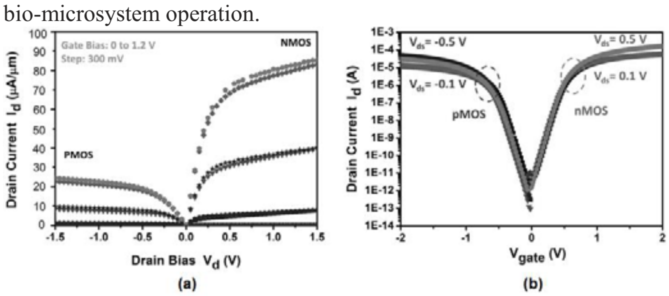

Fig. 7 (a) I_D-V_D behaviors of PMOS and NMOS; (b) I_D-V_G behaviors of PMOS and NMOS.

Figure 8(a) presents the TSV impedance value is 0.17Ω with phase of -0.5° at 1KHz. Figure 8(b) is package impedance measurement result, including μ-probe array and PCB/connector, in 0.9% saline which emulates the in-vivo environment [4]. The impedance is 1.2KΩ with phase of -23° at 1KHz.

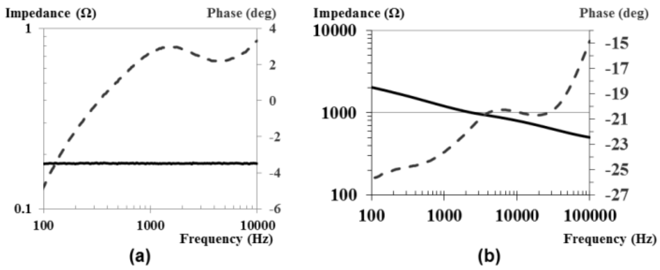

Fig. 8 (a)TSV impedance measurement results; (b) Measured impedance and phase of the probe.

Summary

In this work, a TSV-based heterogeneous integrated neural-signal recording device with microprobe array is proposed. All process has been done and the device is ready for neural-signal recording application. There are 4/16 channels in 5 x 5mm^2 area. Impedance measure result for TSV is 0.17Ω with phase of -0.5°, and for package is 1.2KΩ with phase of -23° at 1KHz, respectively. The device can record EEG, ECoG or neural spike for neural transfer model analysis. For more biomedical applications, this bio-signal recording device also allows stacking other circuit vertically. Successful fabrication and experimental results presented in this work can become a heterogeneous integration platform in a single chip.

References

[1] K. Hozawa, et al., *Symposium on VLSI Technology*, p175, 2012.
[2] K. N. Chen et al., *IEDM,* p2.4.1, 2010.
[3] C. W. Chang et al., *ISSCC,* p.102*,* 2013.
[4] N. Sindhwani et al., *IEEE Trans. Biomedical Eng.* vol. 58(3), pp. 626, 2011.