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A Three-Dimensional Microassembly Structure for Micromachined Planar Microelectrode Arrays

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Abstract- **We present a new three-dimensional (3-D) microassembly method for planar silicon micromachined electrode arrays, which can be used in implantable neuroprosthetic devices for neural recording and stimulation in the central nervous system (CNS). The new microassembly technique is particularly useful when a modular system architecture is adopted to reduce the number of interconnects between modules (probes). The need for a supporting platform and lead transfer between perpendicular planes has been eliminated by stacking the planar probes with insulating glass or polyimide spacers in between and transferring the leads across the spacer sheets with electroplated gold beams. A 3-D 7 × 4 × 4 microelectrode array is fabricated using mock up Interestim-3 [1] probes and 500 µm-thick glass spacers.**

Keywords- **microassembly, microelectrode, neural recording, neural stimulation, neuroprosthesis, micromachining, modular architecture, three-dimensional.**

I. Introduction

One of the most important factors in establishing an effective and efficient extra-cellular electrical interface with the central nervous system (CNS) is the size and geometrical arrangement of the stimulating or recording (S/R) sites with respect to the neurons that constitute a particular neural structure. The goal is to place the S/R sites as close as possible to the neural cell bodies and their extremities (axon and dendrites) with minimal damage or displacement [2]. Cortex has a distinctive situation for neuroprosthetic applications among other parts of the CNS because there is a topographic representation of each sensory modality over the appropriate region of the sensory cortex [3]. Similarly, the motor cortex contains a priori information about movements and intentions [4]. Therefore, cortex is an excellent target for both neural stimulation and neural recording. However, considering the complex laminar, non-uniform, and non-homogeneous structure of the cortical neural tissue, probably the best way to be close to a large population of neurons, without moving the sites which may cause more damage, would be placing a uniform distribution of a large number of small S/R sites in a 3-D volume of the targeted cortical tissue.

Historically, stimulation of the visual cortex started with surface electrodes [5]. In early 90's, however, surface cortical electrodes were almost entirely replaced by penetrating intracortical electrodes for visual prosthesis application after a group of researchers concluded that the current thresholds needed for intracortical stimulation are one to two orders of magnitude lower than those needed by surface electrodes [6]. Therefore, it is possible to save significant amount of power by penetrating the cortex and also eliminate side effects of high current injection. Around the same time, Normann's group developed a 3-D microelectrode out of silicon using thermomigration technique with S/R sites uniformly distributed on a 2-D array at the tip of each shank [3]. A 3-D distribution of the S/R sites with 200-400 µm separations was realized for the first time by Hoogerwerf and Wise, by vertically mounting an array of lithographically defined, planar, micromachined silicon probes on a single micromachined platform [7]. The major challenge in this 3-D microassembly method was lead transfer between the probes and the supporting platform since they were in orthogonal planes. Hoogerwerf used nickel-electroplated bridges between tabs on the probe and pads on the platform on a per-lead basis after assembling the 3-D structure. Bai enhanced and facilitated Hoogerwerf's 3-D microassembly method by using bending electroplated gold beams as part of the planar microelectrodes [8], [9]. Nevertheless, the platform-based 3-D microassembly technique is still labor-intensive due to the large number of probe-platform lead transfers, and the need for ultrasonic bonding on a per-lead basis. It also requires sophisticated microassembly tools and a fair amount of experience, which will eventually affect the overall yield and cost of each 3-D probe in mass production.

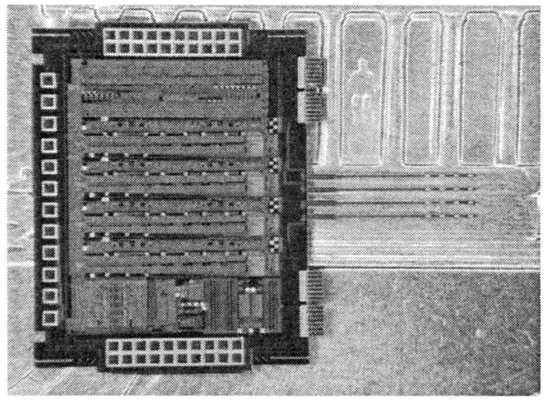


Fig. 1. Interestim-3, a 16-site micromachined planar active wireless microstimulating probe with a modular architecture [1].

In this paper we present a novel 3-D microassembly technique for micromachined, planar, active silicon

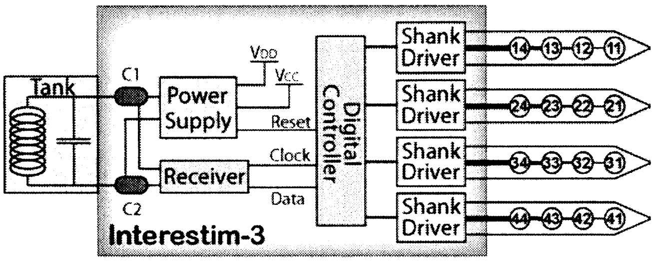


Fig. 2. Modular architecture of the Interestim-3 wireless micro-stimulating probe with only two interconnects (C1, C2) per probe [1].

microelectrodes such as Interetim-3, which is shown in Fig. 1 [1]. This method eliminates the need for the supporting platform and orthogonal lead transfers by taking advantage of the microelectrodes modular architecture, thus greatly facilitating the microassembly process as well as the mechanical robustness of the 3-D probe structure.

II. Modular Microelectrode Architecture

Adopting a modular architecture in circuit design of the 3-D recording or stimulating microelectrode systems reduces the number of required interconnects between individual modules and the central components of the system. In addition, since each module can be assigned a unique address, many of the required interconnects can be shared among all modules.

Fig. 2 shows a simplified block diagram of Interetim-3, the active planar microelectrode array that is used in the 3-D microassemblies of the present paper [1]. Each Interestim-3 probe, as an individual module, has all the necessary components to operate as a 16-site stand-alone wireless microstimulator. Therefore in this specific design, the number of required interconnects to each Interestim-3 probe is reduced to only two: *C1* and *C2*. These are the two nodes of an implantable miniature hybrid LC-tank circuit, which are shared between all Interestim-3 probes that are connected in parallel to form a 3-D microstimulating array.

It should be noted that in this design we also integrated part of the LC-tank capacitor on each module. Therefore, the sum of these capacitors, which will be connected in parallel after microassembly, plus parasitic capacitors, form the capacitive part of the LC-tank circuit. These capacitors are shown as a lumped sum in Fig. 2. Since C depends on the number of probes connected in parallel, the L value should be chosen according the desired carrier frequency.

III. Stacking Probes and Spacers

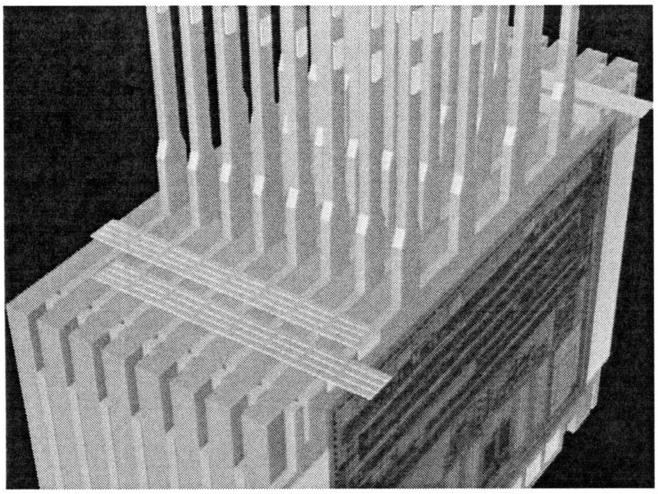
The basis of the new 3-D microassembly method is stacking the planar micromachined probes with dielectric sheets of glass or polyimide in between. The insulating spacers are cut to the same size as the planar probes backend, and their thickness, T, indicates the spacing between adjacent probes. In order to facilitate the stacking process, this microassembly technique can be done in a jig that has a rectangular trench as large as the probe backend to collate and gently align the probes and spacers while they are being stacked in the trench. The lead transfer between probes is formed by the electroplated gold-beams that are part of the planar probes, similar to [8], and extend out of the probes backend. The gold-beams are bent over the thickness of the spacers to partially overlap and form electrical contacts with the gold-beams of the adjacent probes. Finally, the bending gold-beams are covered with conductive epoxy using a sharp-tip brush to secure the electrical connections. A different option would be ultrasonically bonding the gold-beams in the overlapping areas.

IV. 3-D Microassembly of Interestim-3 Probes

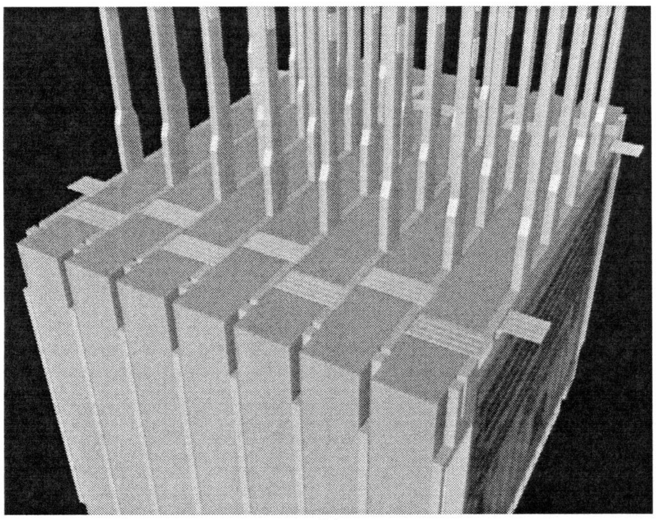
Interestim-3 probes are equipped with micromachining features required for 3-D microassembly on a platform such as four bending electroplated gold beams with 100 μm × 300 μm fingers and four spacer notches [1]. However, due to the small number of interconnects, which are also shared, the stacking 3-D microassembly method could be much easier. The range of T depends on the length of the electroplated gold beams, L. Considering that the gold-beams extend 300 μm out of the Interestim-3 probe backend, T can be chosen between 200 to 500 μm. The gold beams on each side of the probe are connected to one of the Interestim-3 coil inputs (*C1* and *C2*). As shown in Fig. 3a, if the desired spacer thickness, $T < 250$ μm, all the outer beams (those that are further apart from the shanks) are bent in one direction similar to dominoes, and all the inner beams (those that are closer to the shanks) are bent in the opposite direction over the spacers to partially overlap with the bottom of the adjacent probe gold-beams. On the other hand, if the spacer thickness is chosen 250 μm $< T <$ 500 μm, then the adjacent probe beams should be intermittently bent towards one another so that their tips overlap on the spacer walls as shown in Fig. 3b.

The next step is to cover the overlapping gold beams with conductive epoxy or to ultrasonically bond each pair of overlapping beams together to secure the electrical connections, while the probe shanks are positioned upward. Finally, the 3-D array backend is inserted into a cylindrical coil that is priorly wound and fixated on a mold with the same size as the 3-D probe backend. The insulations over the ends of the coil wire are then removed before being soldered or epoxy-glued to the parallel rails of gold-beams formed on each side of the array as shown in Fig. 3c.

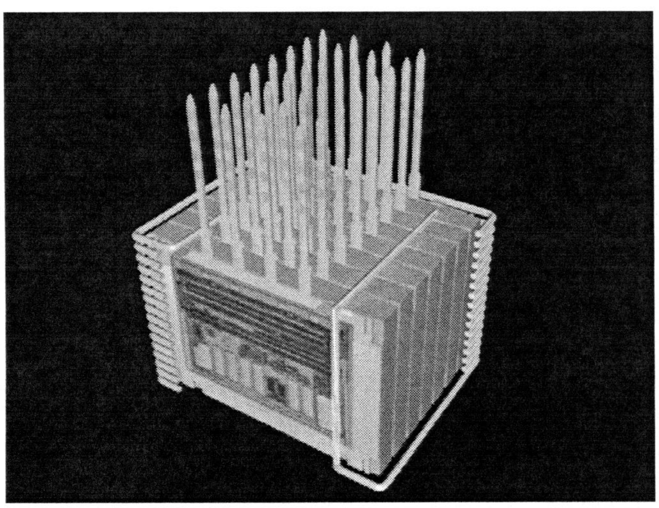
A prototype 3-D probe was microassembled with glass spacers using passive mock up silicon probes with the same geometry as the Interestim-3 probes. A 500 μm-thick glass wafer (T = 500 μm) was diced into rectangular 6.5 mm × 5 mm spacers, which is the same size as the Interestim-3 probe backend. It would be better to select the height, H, of the spacers slightly larger than the height of probe back-ends (H = 5.01 mm in this case) to eliminate



(a)

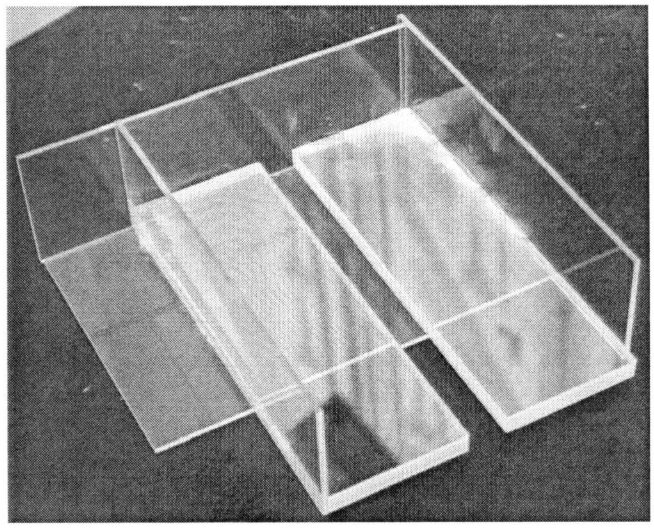


(b)

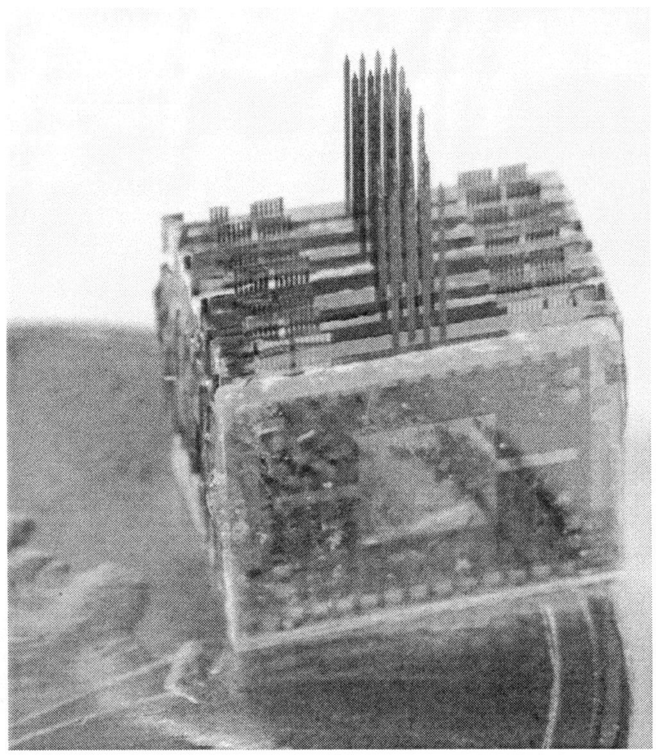


(c)

Fig. 3. Conceptual drawing of the new 3-D microassembly of planar probes (a) spacer thickness, $T < 250$ μm (b) 250 μm $< T <$ 500 μm (c) 3-D assembled Interestim-3 probe with the receiver coil wound around the probe back end and soldered to C1 and C2 inputs.



(a)



(b)

Fig. 4. Glass jig to help stacking probes and spacers in its rectangular trench. (b) A microassembled 3-D probe with seven mock up (passive) IS-3 probes and 500 μm glass spacers on a U.S. penny.

gold beams from bending at their base, where they might be less malleable.

A glass jig was fabricated using 1 mm-thick glass slits, as shown in Fig. 4a. The rectangular trench, in which Interestim-3 probes and glass spacers are to be stacked, was carefully sized slightly larger than the probe width, W = 6.5 mm, such that probes and spacers can be laid inside the trench, while they were tightly held and collated by the trench vertical walls. After a desired number of Interestim-

3 probes are stacked with glass spacers in between, they are pressed with a Teflon twizzer, while applying instant glue to the stack of vertical sidewalls for fixation. The resulting structure is shown in Fig. 4b on a U.S. penny. In this specific case, the spacers were diced slightly smaller than the desired size. The next steps would be bending the vertical electroplated gold beams to electrically connect all *C1* and *C2* input nodes, applying ultrasonic pressure, inserting the probe backend in a pre-wounded cubical coil, and soldering the coil wire ends to *C1* and *C2* input rails.

V. CONCLUSIONS

A new method for three-dimensional microassembly of planar silicon micromachined electrode arrays has been presented. These electrode arrays are now capable of long-term monitoring of neural activity *in vivo*. They can also be used for insertion of electrical stimulation pulses into the neural networks at the cellular level, making possible significant advancements in our understanding of the nervous system. The ability to have on-chip circuitry, signal processing, wireless interfaces, and even microfluidics on these electrode arrays forms the basis for a family of integrated neural prostheses that can be significantly smaller and less invasive than today's hybrid systems [2]. The new 3-D microassembly technique along with modular system architecture, which is adopted to reduce the number of interconnects between modules, can considerably reduce the time and effort in fabricating microelectrode arrays. This in turn will result in higher yield and lower cost of manufacturing the aforementioned neuroprostheses.

The presented 3-D microassembly method is based on stacking the planar silicon micromachined electrodes with insulating glass or polyimide spacers in between. Lead transfers between adjacent probes are performed with electroplated gold beams that bend across the spacer sheets. This eliminates the need for a supporting platform and lead transfer between perpendicular planes required in previous methods [7]-[9].

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REFERENCES

[1] M. Ghovanloo, K.D. Wise, and K. Najafi, "Towards a button-sized 1024-site wireless cortical microstimulating array," *1st Intl. IEEE/EMBS Conf. Neural Eng. Proc.*, pp. 138-141, Mar. 2003.

[2] K.D. Wise, D.J. Anderson, J.F. Hetke, D.R. Kipke, K. Najafi, "Wireless implantable microsystems: high-density electronic interfaces to the nervous system," *IEEE Proc.*, vol. 92 , no. 1 , pp. 76-97, Jan. 2004.

[3] P.K. Campbell, K.E. Jones, R.J. Huber, K.W. Horch, and R.A. Normann, "A silicon-based, three-dimensional neural interface: Manufacturing process for an intracortical electrode array," *IEEE Trans. Biomed. Eng.*, vol. 38, no. 8, pp. 758-767, Aug. 1991.

[4] M.A.L. Nicolelis, "Actions from thoughts," *Nature*, vol. 409, pp. 403-407, Jan. 2001.

[5] G.S. Brindley, W.S. Lewin, "The sensations produced by electrical stimulation of the visual cortex," *J. Physiology*, vol. 196, pp. 479–493, 1968.

[6] M. Bak, J.P. Girvin, F.T. Hambrecht, C.V. Kufta, G.E. Loeb, and E.M. Schmidt, "Visual sensations produced by microstimulation of the human occipital cortex," *Medical and Biol. Eng. and Comp.*, vol. 28, pp. 257-259, May 1990.

[7] A.C. Hoogerwerf and K.D. Wise, "A three-dimensional microelectrode array for chronic neural recording," *IEEE Trans. Biomed. Eng.*, vol. 41, no. 8, pp. 1136-1146, Dec. 1994.

[8] Q. Bai, K.D. Wise, and D.J. Anderson, "A high-yield microassembly structure for three-dimensional micro-electrode arrays," *IEEE Trans. Biomed. Eng.*, vol. 47, no. 3, pp. 281-289, Mar. 2000.

[9] M.D. Gingerich, "Multi-dimensional microelectrode arrays with on-chip CMOS circuitry for neural stimulation and recording," Ph. D. dissertation, in Dept. Elec. Eng. Comp. Science, University of Michigan, Ann Arbor, 2002.