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Active Floating Micro Electrode Arrays (AFMA)

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Abstract— Neuroscientists have widely used metal microelectrodes inserted into the cortex to record neural signals from, and provide electrical stimulation to, neural tissue for many years. Recently, the demand for implanting electrode arrays within the cortex, for both stimulation and recording, has rapidly increased. We are developing *Active-floating-micro-electrode-arrays* (AFMA) that are intended for use as a multielectrode cortical interface while minimizing the number of wires leading from the array to extra-dural circuitry or connectors. When combined with a wireless module, these new microelectrode arrays should allow for simulation and recording within free-roaming animals. This paper mainly discusses the design, fabrication, and packing of the first generation AFMA. Our long-term vision is a wireless-transmission electrode system, for stimulation and recording in free-roaming animals, which uses a family of modular active implantable electrode arrays.

Keywords— active floating micro electrode arrays, AFMA, FMA, application specific integrated circuits, ASIC, leakage current, encapsulation

I. INTRODUCTION

This paper discusses development of an assembly method for placing *Application-Specific-Integrated-Circuits* (ASIC) within a *floating-microelectrode-array* (FMA), creating the complete structure of AFMA. We have several microelectrode arrays, for stimulation and recording, under development. Presently portions of the assembly process have been verified and we expect to evaluate the first completed AFMAs in the next few months. The AFMA design and fabrication can be explained in three main stages: The first stage is to fabricate a multi-layer structure consisting of electrodes, substrate, and integrated circuit chip. The second stage is encapsulation, and the final stage is leakage current testing of prototype devices. For the leakage current testing, the main problem has to do with the continuous moisture environment within the living body. The use of an integrated circuit at the array site allows for a minimal number of wires connecting the AFMA with external equipment, either through head connectors, or subcuntaneous wireless packages. Our first generation ASIC designs provide neural signal buffering, time-domain multiplexing, and constant current stimulation for all ASIC designs only 4 wires are needed in the connecting cable in order to power, command, and extract data from the AFMA. Although our current designs are focused upon wired arrays, we are already working towards the design of wireless systems magnetic file transcutaneous inductive coupling [1].

II. RESEARCH DESIGN AND METHODS

The basic design of our prototype AFMA uses individual fine wire electrodes mounted in a superstructure that maintains their relative position. Typically, they are comprised of 18 electrodes; 16 electrodes (length≈1mm) are for recording or stimulation, and 2 additional long electrodes (≈1.5 mm), called anchors, are for mechanical stability. The electrodes can be fabricated from a range of metals including Pt, Pt/Ir, or Ir. A mixture of electrodes specifically suited for stimulation or recording and be used, and the lengths, tip exposures, and tip geometry can vary as needed by the user. The AFMA is desired to be of small size so that it can be implanted with minimal disruption of the underlying neural substrate. Fig 1 shows a prototype design for the AFMA ceramic substrate (3.115×2.57mm and 125μm thickness). There are two sets of pads on the ceramic substrate that is connected to the electrodes. The inner set provides connection directly to the electrode shaft via a short welded wire as shown in Fig 2 (b). The outer

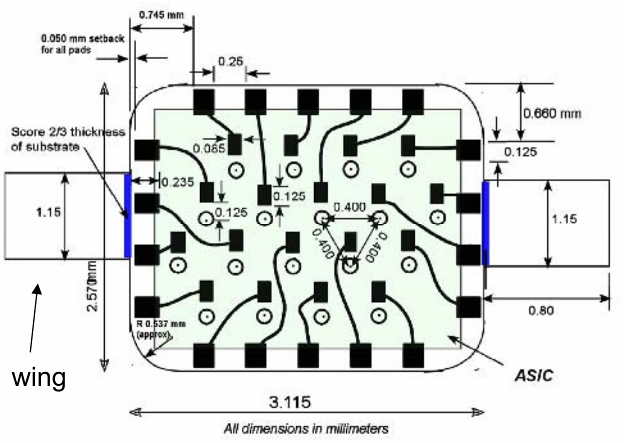

Figure 1. Drawing of the AFMA ceramic substrate

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sets provide connection to the ASIC that is placed directly on top of the electrodes. The connections from the electrodes to the inner pad set and connections from the ASIC to the outer pad set will be by gold-ball wire bonding. Fig 2 shows the concept of the AFMA. The ceramic substrate used to align and connect to the electrodes serves as a platform for electrical connections from the electrodes to the ASIC. Wire bonding of the electrodes and ASIC to the ceramic substrate will be accomplished using a gold-ball wire bonder. One problem that we expect to encounter is how to adequately hold down the extremely small ceramic substrate during the wire bonding process. For ultrasonic bonding, the substrate must be firmly clamped against a rigid, typically metal, surface. To accomplish this, we have designed substrate "wing" as shown in Fig 1. The wings are attached to the main substrate with a 2/3 score through the ceramic so that once all wire bonding operations are completed; the wings may be broken off. We have evaluated prototype substrates, fabricated by *American Technical Ceramics* (ATC), and the scoring does permit the wing breakage without residue or damage to the main substrate. It is our goal that fabrication of AFMA should be performed within the normal technical tolerance of equipment like a gold-ball wire bonder.

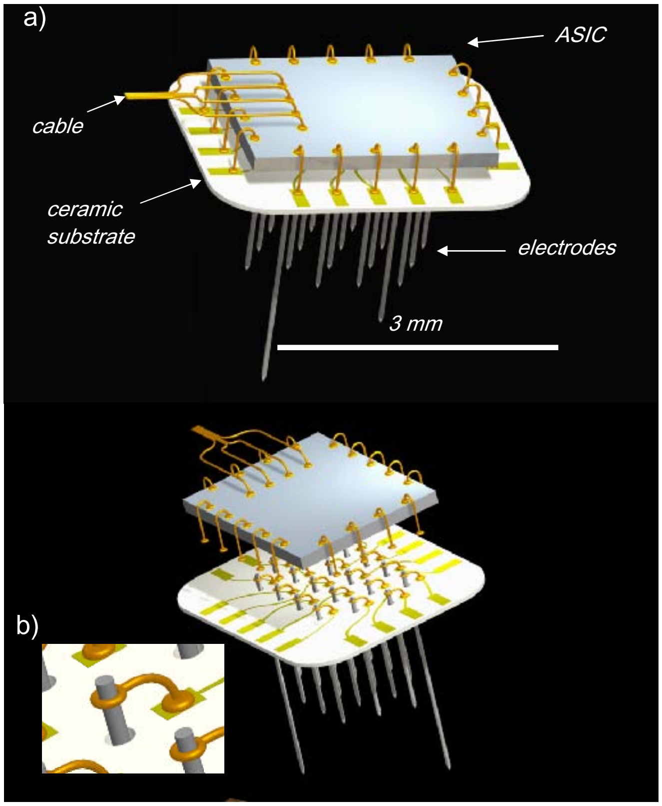

Figure 2. (a) 3D rendering of AFMA assembly showing ASIC and electrode wire bond connections to the ceramic substrate
(b) magnified image of direct connected wire bond between inner pad and electrodes

III. ENCAPSULATION AFMA

The next step of assembly after building initial structure will be the placement of the AFMA assembly into a micro-sized mold, as shown in Fig 3. Prior to encapsulation the AFMA assembly will be cleaned by a combination of solvent, Oxygen plasma, Argon plasma, UV-Ozone, and ionograph washing, as determined to be effective by the Impedance Spectroscopy leakage current testing. Prior to final encapsulation the electrodes will be held aligned within the ceramic substrate using cyanoactylate adhesive. Surface cleaning combined with adhesion of the polymer will provide the low electrical leakage needed for implanted survival. Encapsulation will be done in a class-100 clean room to prevent particulate matter from entering the encapsulants. The expected candidates of the encapsulate material are silicon adhesives with an integrated silane coupling agent. We have numerous experiments to investigate the mixing ratio and curing time for several candidate silicone encapsulants, and we are now developing a prototype encapsulation procedure.

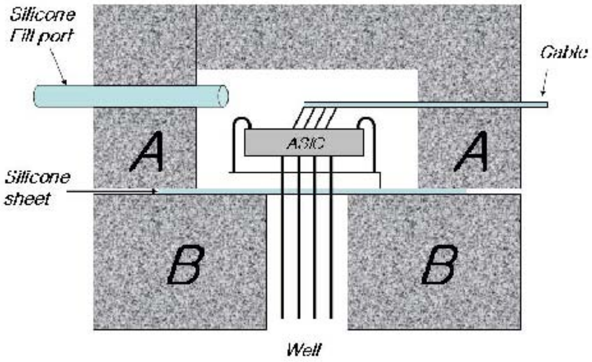

Figure 3. Molding concept for AFMA

During encapsulation state, the electrodes will be physically protected by inserting them, using a perpendicular fixture, through a thin silicone sheet that covers a protective well. The silicone sheet will seal around the electrode shafts. Then the upper portion of the Teflon mold (A) will be clamped to (B), and the silicone will be injected through a fill port while the mold is under vacuum. The silicone adhesive material will bond to the internal AFMA components, the cable, and to the silicone sheet. Excess flashing will be removed after extracting from the mold. Anticipated thickness of the AFMA will be ~2.5mm, which is enough small size of AFMA purpose.

IV. LEAKAGE CURRENT MEASUREMENTS

Electrochemical failure of microelectronics is related to surface impurity levels, temperature, and relative humidity (RH). In case of the AFMA, RH is one of the critical issues because AFMA will be exposed to 100% RH environment once implanted. The RH effect can easily be demonstrated by low-level leakage current measurements. Leakage current measurements have been used widely as test of IC reliability and encapsulation. Some research papers from this laboratory have shown relevant results the conclusion from these studies are "Under dry conditions (0 % RH), leakage currents are small (~1-10 pA) and insensitive to surface contamination levels. This implies that electrochemical IC failure becomes vanishingly small under dry conditions. At 100% RH, steady-state leakage currents are large (~10-100 μA) and roughly proportional to surface loadings of contaminants. Individual chemical compounds exhibit step increases of leakage current at critical RH values corresponding to solid-to-saturated solution transitions."[2]. The leakage is one of the critical issues for implanted chips; therefore we will use impedance spectroscopy (IS) experiments to understand mechanisms of protection and failure. Leakage between the bonding pads has significance from two perspectives. First, presence of DC potentials, such as might be used for anodic or cathodic biasing of stimulation electrodes, as well as DC power for the ASIC can be the electrochemical driving force for corrosion reactions. Second, even in the absence of DC potentials, leakage between bonding pads can reduce the magnitude of recorded neural signals due to the fact that these shunt pathways act in a voltage dividing manner in conjunction with the electrode impedance. Setting hard limits for both of these cases is difficult. Using IS leakage measurements, the significance of DC leakage can be easily quantified by examining changes in the IS frequency plot while the specimen is under representative DC biasing. Often, DC bias will induce an increase in the measured IS impedance plot, and this is a desirable stable situation. Commonly called the "sweepout" effect, the mechanism is debatable, but the consequence is undeniable: an increase in the impedance causes a decrease in the bonding pad leakage, and a movement away from electrochemical corrosion reactions. In contrast, a decrease in the IS impedance, while under bias, is a movement towards increased electrochemical corrosion reactions. The absolute magnitude of leakage currents or impedance plots is not as important as the changes that occur with, and without, bias. For the case of non-DC shunting leakage, a reasonable limit is that the magnitude of the impedance plot, measured in the neurologically significant range (10Hz-10kHz) should be at least a factor of ten larger than the impedance of the electrodes themselves. We will use both lateral and vertical impedance spectroscopy to quantify the magnitude of leakages along pads on the substrate, and from the internal connections to the external fluid.

V. DISCUSSION & CONCLUSION

In order to design AFMA fabrication, we plan to design it in different stages. To date, most of our design concepts are based upon earlier work in our laboratory, but we feel the methodology for the AFMA development is sound. After fabrication of wired AFMA prototypes, we will move to wireless system AFMA as shown in Fig 4. The wireless link is via a transcutaneous inductive coupling coil. The coil is directly connected to AISC. The pads on the ASIC will be individually gold-bumped, using a ball-bumping setting of the wire bonder, in combination with a coining tool in the bonder head. With the ends of the wires being previously stripped by a micro-heating tool, the gold wires will be attached to the ASIC pads by placing a gold ball bond on top of the wire, thus sandwiching the wire between the ball and the gold bump on the die.

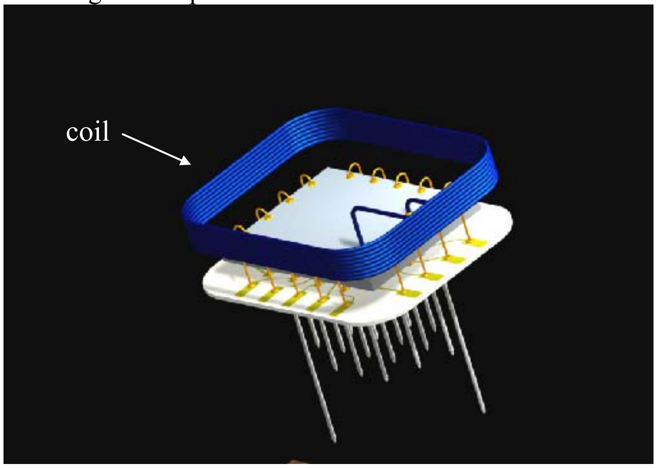

Figure 4. 3-D concept mechanical drawing of wireless array system. Wireless link is via the transcutaneous inductive coupling

Fig 5 shows how the AFMA will be a component in a totally wireless system. In one example, the FMA is wired to a *subcutaneous module* (SM). The SM communicates across the skin to the *external module* (EM) via a magnetic link – power, data, and commands are sent across this same short-range link. The EM will can be connected to remote external equipment via a 2-way wideband radio transmitter link. In a similar manner, the AFMA itself could communicate over the transcutaneous magnetic link, without the need for the SM, or the AFMA connecting cable. We emphasize that our long-term goal remains totally wireless systems. However, our assessment is that this goal needs to be reached through a series of steps, which provides the platform for developing the AFMA.

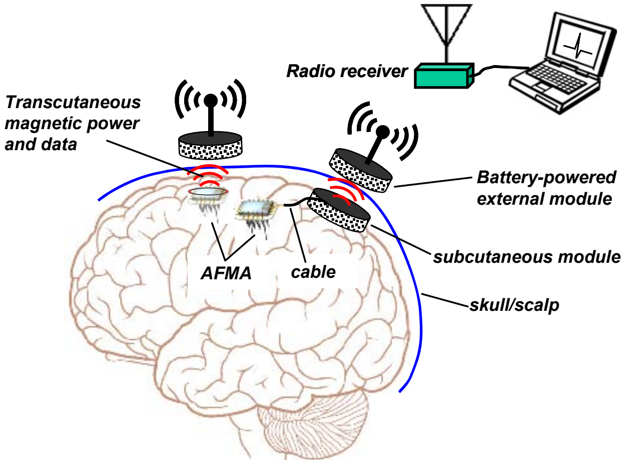

Figure 5. Concept of wireless system using AFMAs

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