Accelerated-Stress Reliability Evaluation for an Encapsulated Wireless Cortical Stimulator*

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***Abstract*— In preparing a wireless cortical stimulator for use in the Intracortical Visual Prosthesis (ICVP) project at the Illinois Institute of Technology (IIT), an accelerated environmental stress test is being performed on prototype stimulator modules. Stimulator devices, containing a custom application specific integrated circuit (ASIC), and encapsulated with PDMS, were soaked in an autoclave chamber at 121°C and 100% relative humidity for more than 2200 hours with and without power supplied to the ASIC. Experimental results showed no physical degradation of the stimulator devices after soaking. Reverse telemetry that measures the stimulator internal power supply, recorded periodically over the entire test time, verified that the devices were electrically functioning, as designed, without deterioration. Taking into consideration other standard reliability test environments, the accelerated moisture resistance-biased autoclave testing duration of 2200 hours, as conducted in this study, overwhelms other less-severe test conditions and demonstrates long term stability of the proposed vision prosthesis device with proven thermo-mechanical and electrical robustness.**

I. INTRODUCTION

The long-term reliability of implantable neural prosthesis devices is recognized as one of the essential characteristics defining acceptable performance. In particular, for the devices implanted inside human brain, safety and functional stability are basic prerequisites for the intended application. Such requirements can be verified by a series of reliability testing designed to accelerate failure in IC devices and packages. Normal driving forces leading to physical and electrical degradation of implantable devices are temperature, moisture and voltage. Typical failure mechanisms associated with these driving forces may include corrosion, electro-migration and inter-metallic junction degradation.

The ICVP vision prosthesis devices developed in the Laboratory of Neural Prosthesis Research at IIT consist of a ceramic substrate superstructure, over 18 intracortical electrodes, a wireless stimulator ASIC and an inductor coil reside on top of the ceramic substrate. The assembly is encapsulated with Poly-Di-Methyl-Siloxane (PDMS) that incorporates a silane adhesion promoter. Figure 1 shows the stimulator device, commonly called a Wireless Floating Microelectrode Array (WFMA) as recently fabricated in our laboratory.

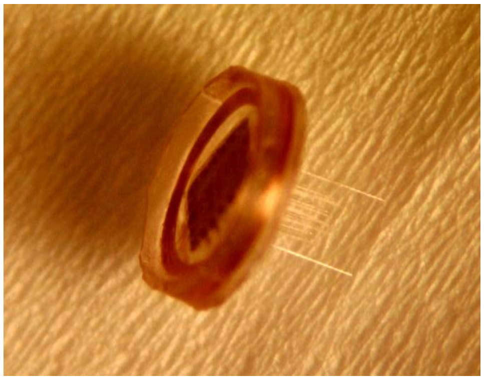

Figure 1. WFMA device for vision prosthesis

Some of the industry-standard methods to evaluate thermo-mechanical and electrical robustness of such non-hermetic devices include: temperature-cycling test, highly-accelerated-stress-test (HAST), temperature-humidity bias (THB) test and accelerated-moisture-resistance autoclave (pressure pot) test.

Various examples of environmental testing for commercial IC devices and passive components can be referred to for assessing the reliability of implantable devices. One of the investigations for the physical and electrical degradation of plastic encapsulated power transistor demonstrated that following environmental tests, (temperature cycling, HAST, THB) delamination failures were seen between the molding compound and die/lead frame, as well as elevated electrical leakage currents [1]. Such degradation was considered to be critical because it might cause bond wire breakage and facilitate moisture penetration on to the die resulting in contamination and possible corrosion in a humid environment.

Another study on electronics reliability was conducted on DIP and SOIC packages to see the effect of preconditioning, voltage bias and humidity [2]. Preconditioning consisted of 30 temperature cycling, moisture soak and solder reflow cycle followed by HAST with bias. This study showed device failure after test, mainly corrosion of aluminum pad and demonstrated effect of voltage and temperature accelerating failure.

For the reliability evaluation of the ICVP device, we selected accelerated moisture resistance-biased autoclave test. Similar to THB, failures during the autoclave test (normally conducted at 121ºC and 100% relative humidity) with the devices in storage, and under electrical bias, might be caused

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by moisture-induced swelling of encapsulation polymer, leakage currents and corrosion of metallization.

Here we present reliability testing results for the vision prosthesis stimulator device during 2200hrs of environmental testing with, and without, bias.

II. MATERIALS AND METHODS

A. *Stimulator Device and Coil*

For each sample, an ICVP Stimulator ASIC chip was attached to the ceramic substrate (without electrodes) and wire-bonded to the gold pads on the substrate. An inductor coil with 50uH inductance, fabricated using 25-micron polyimide insulated gold wire, was connected directly to the bonding pads on the ASIC chip. The stimulator assembly was encapsulated with Dow 96-083 PDMS using open-top mold, and cured in a convection oven at 150°C for 30min. Reverse telemetry that measured the internal ASIC power supply was tested on each device after assembly. Four devices were randomly selected for environmental testing.

For the autoclave test with bias, a power transmission coil with an inductance of 8.4uH was fabricated using AWG14 stranded copper wire insulated with thin Teflon. The wire was wound using a Teflon bobbin of 3 inches in diameter to form a power coil that was driven by a 5 MHz Class E converter.

B. Experimental Setup and Instrumentation

A NAPCO 8100TD autoclave chamber was used for the accelerated moisture resistance test. Typical pressure pot conditions of 121°C and 100% relative humidity were selected for both tests with and without bias. For the test with bias, a feed through connector designed for seamless connection of the coil through the chamber door to the test instruments outside was installed. The power coil was placed onto a platform inside chamber and the stimulator IC devices contained in a small beaker were placed in the middle of power coil. The 5HMz carrier in the power coil provided wireless powering of the devices under test. A SOAR DC power supply 7402, a custom-designed Class E telemetry controller circuit board, and a Tektronix TDS3034B oscilloscope were used to provide and monitor wireless power transmission to the devices under test. Periodically, each device was removed from the chamber and tested for reverse telemetry operation. Figure 2 shows schematic diagram for power transmission and reverse telemetry. Overall experimental setup is shown in Figure 3.

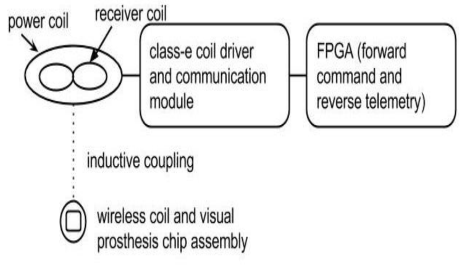

Figure 2. Schematic diagram of power transmission and reverse telemetry

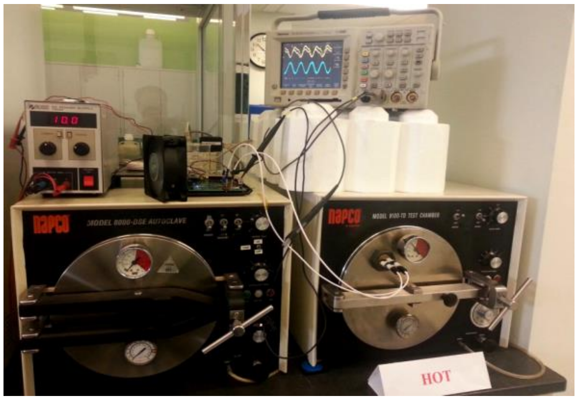

Figure 3. Overall experimental setup showing autoclave chambers, oscilloscope, class E board and DC power supply

III. EXPERIMENTAL METHODS

Three devices were initially soaked, without being powered, in the chamber to determine if any electrical degradation or physical deterioration would occur due to physical stress alone. Following each 24 hours of soaking, the devices were taken out of the chamber for reverse telemetry test and visual inspection under the light microscope. Later, the test interval increased to every two days, and later to four days, based on the previous test results. After 1500 hours of soaking without bias, and no indication of physical or electrical deterioration, an additional accelerated moisture resistance test under wireless powering, was performed on these three pre-stressed devices. For comparison, a new stimulator device package, not previously stressed under storage alone, was added to the autoclave testing with bias.

The magnitude of power transmission and actual current inside the power coil, was monitored to ensure correct powering of the ASICs. Every 24 hours, the four devices were taken out for visual inspection and the reverse telemetry test. The power coil assembly was inspected whenever reduced current was seen in the power coil. The harsh autoclave environment proved highly damaging to the 5MHz power coil, significantly more so than the devices under test. It was challenging to maintain proper Class E tuning under conditions of water infiltration into the power coil [3]. In some cases it was necessary to pause the test while the power coil assembly was dried in an oven for couple of hours or replaced with new coil. The pressure pot test with bias was continued for eleven days, as of this writing and is on-going.

IV. RESULTS

A. *Visual inspection*

As shown in Figure 4, all four devices have indications slight surface contaminations that were present at the time of encapsulation. Polymer degradation or component failure in the package such as delamination, trapped water, discoloration, die lifting, bond wire breakage and coil wire de-bonding was not observed. Sample 2 shows a bubble in the package which was trapped during encapsulation process. The bottom side is shown in sample 4.

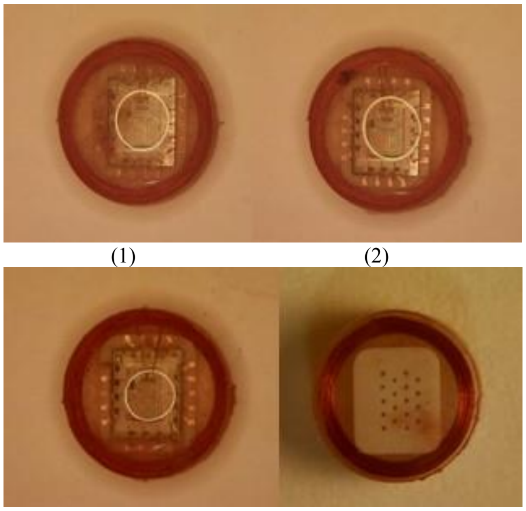
(1) (2)
(3) (4)

Figure 4. Devices after 2200 hrs of soaking

B. *Reverse telemetry*

Measurements of the ASIC internal power supply, by the reverse telemetry, of the devices tested without bias, for approximately 1500hrs (63days), are summarized in Figure 5. The same type of reverse telemetry data the devices tested with bias, for 720hrs (30days), are shown in Figure 6. The data from each device were normalized based on the stimulator ASIC power supply voltage of 5Volts.

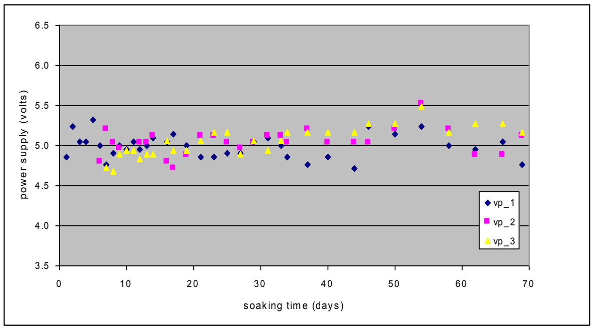

Figure 5. Variation in voltage of the devices with soaking time: without power transmission

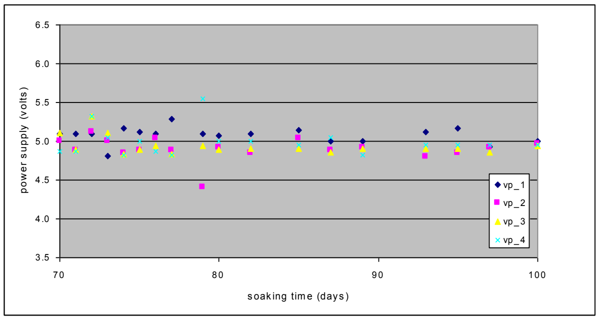

Figure 6. Variation in voltage of the devices with soaking time: with power transmission

V. DISCUSSION

The autoclave test is a brutal stress for the encapsulated assemblies. All four samples in this experiment showed no physical deterioration, such as delamination or bond wire breakage caused by moisture penetration, which has been observed in other studies [1, 2].

To some extent, the autoclave test may also be viewed as a low-cycle thermal fatigue test because normally samples are taken out of the chamber while they are at 100°C for the electrical measurement. Alternating thermal stress over more than a month can be another type of environmental attack affecting deterioration of the components in the prosthesis device assembly.

The visual prosthesis ASIC chip is powered wirelessly via the inductive coupling between the power coil (of the external hardware) and its wireless coil. The forward command, from the external hardware to the chip, is also transmitted by FSK modulation of the magnetic field of the power coil. The reverse-telemetry signal, from the chip to the external hardware, is handled by amplitude modulating the load within the ASIC at a 130 kHz rate, thus placing the reverse telemetry on a low-frequency carrier that is sensed by the telemetry controller. All of the ASIC functions rely upon highly sensitive circuitry that would be undoubtedly disrupted by electrical malfunction of numerous portions of the circuitry. In many cases, sub-microampere current sources control the operation of the ASIC. The ability of the tested devices to maintain both forward and reverse telemetry operation provides us with high confidence about the polymeric packaging method.

Figure 5 and Figure 6 show the bias (power supply) voltage data measured from each device under test. In practice, the data are transmitted by modulating the width of the reverse telemetry carrier envelope, with the duration of transmission encoding the voltage value. In the telemetry control board, an FPGA decodes the carrier pulse duration into the bias voltage. The variation in bias voltage from each device measured less than 1 volt over 2200 hours of testing without any specific trend. Such scatter in data in Figure 5 and 6 is substantially due to the variation in the position of the device with respect to the power/receiver coils causing expected power supply variations and subtle reverse telemetry shifts, along with the board decoding jitter. The variation is not representative of deterioration of the devices. To the contrary, the very fact that the reverse telemetry was maintained over the duration of the stress test is, alone, verification of the lack of device deterioration, since sensitive ASIC circuitry would undoubtedly cause cessation of reverse telemetry operation.

The Autoclave test specified by JESD22-A102C describes a maximum duration of 336 hours [4]. THB condition shows longer soaking at 85°C/85% RH for 1000 hours [5]. Similarly, HAST specifies tests at 110°C and 85% RH for 264 hours [6]. The Accelerated moisture resistance test-biased used in this study was conducted under even more harsh environment of 121°C, 100% RH and 20psig for 2200 hours (and the test is currently on-going). As shown in Figure 5 and 6, all of four devices are electrically functioning without any distinct or significant degradation, implying physical and electrical robustness of vision prosthesis device designed in the lab.

Normally reliability assessment for commercial electronic devices involves sample size such as 45 or 77 pieces in order to have statistical significance of the data [7]. In contrast, only four pieces were tested in this study mainly because of limitation in fabrication of the device. However the data obtained from the experiment can be a reference to predict device stability since they were environmentally stressed for a longer time.

Lastly, the issue of what acceleration factor this stress test represents remains unresolved. Normally, one determines an activation energy for computing acceleration factors (first-order exponential model) by observing time-to-failure for two different temperatures. Since we have currently seen no failures, using the harshest conditions that we currently can practically impose, other methods may be needed to estimate the acceleration factor for this autoclave test. None-the-less, the maintenance of operation for these devices tested (albeit with limited quantity) gives us high confidence for the integrity of the encapsulated assembly design relative to expected survival once implanted and maintained at biological body temperatures.

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