A Miniaturized Hermetic Package for Neuroprosthetic Implants

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Abstract

This paper reports development and characterisation of a novel hermetic packaging method for neuroprosthetic implants based on a ceramic hybrid onto which a metal cap is electroplated. In an automated accelerated lifetime test the packages are immersed in saline solution, while encapsulated humidity sensors measure intrusion of vapour. Assuming an Arrhenius relationship, a time of 66 days within the human body before onset of vapour intrusion can be predicted. The hermeticity of the packaging concept is further investigated by helium leak tests. The results demonstrate that the choice of glob-top material and process parameters is very critical.

1 Introduction

In order to ensure reliable operation of active electronic implants over decades within the human body, it is crucial to protect the circuitry from moisture. Since polymers are no hermetic barriers, a lot of research is done in the field of hermetic biopackaging, using wafer-level technologies, like anodic bonding [1] or thin film packaging [2]. Both technologies have in common that the circuitry has to tolerate at least 350 °C during the process flow. Another method using ceramic hybrids is demonstrated by [3]. There, the final sealing is done by soldering. Here, a new packaging concept is investigated which also uses a hybrid substrate but allows for much smaller package sizes.

2 Materials and Methods

2.1 Design and Fabrication

According to **Figure 1**, a multilayer thick film hybrid circuit is fabricated in a 5-mask screen printing process on an Al_2O_3 substrate (Rubalit 708S, CeramTec, Marktredwitz, Germany) with pastes by ESL Europe (Reading, UK). The first metallic layer (5837-G paste) takes on the function of electric feedthroughs for the implant to which electrodes can be connected (a). A dielectric layer (4913-G paste) isolates it from a second ring-shaped metallic layer (b - d). A moisture resistant overglaze layer (4771-P1 paste) covers the tracks and all layer transitions outside the hermetic seal (e). The pastes are fired at 850 °C for 10 min except the overglaze that is fired at 525 °C-555 °C for 5 min. For accelerated aging tests the electric circuit (f) of the implant is represented by a SHT15 humidity sensor (Sensirion, Staefa, Switzerland). The circuit is encapsulated by either RTV3140 silicone adhesive (Dow Corning, Midland, MI, USA) or MONOPOX GE790 epoxy (Delo, Landsberg, Germany) as glob-top material (g). These materials differ in their thermal expansion coefficient (315 and 17 ppm/K, respectively). Next, a 100 nm TiW / 100 nm Pt conductive layer is sputtered on the surface area (h). After this, a 100 μm thick Cu film is electroplated at a rate of 30 mA/cm² from a sulphuric-based solution to realize the hermetic seal (i). The implant is encapsulated with RTV3140 to insulate the wires soldered to the pads and to prevent the copper from being exposed to saline.

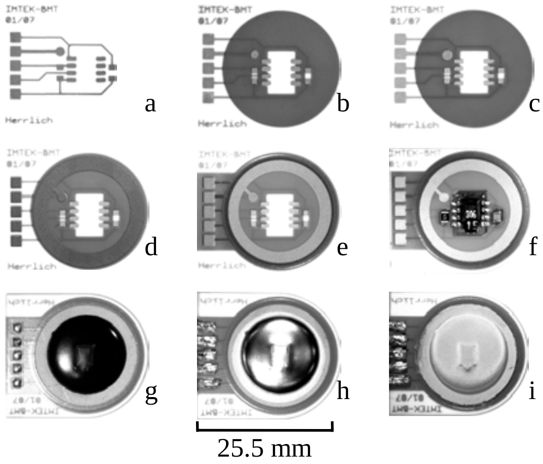

Figure 1: Process flow for package fabrication

2.2 Lifetime Tests

For accelerated aging 3 epoxy-encapsulated packages were immersed in saline solution at 60 °C and 85 °C. Additionally, 2 silicone-encapsulated packages were tested at 85 °C as reference. In a long-term test at 37 °C, one epoxy-encapsulated package and one package without metal cap for each encapsulation material was tested, the later two in order to investigate vapour diffusion. The relative humidity inside each package was read out automatically by a custom-built multiplexer system.

2.3 Helium Leak Detection

The helium (He) leak detection was carried out using a SmartTest HLT570 (Pfeiffer Vacuum, Asslar, Germany) on 11 packages with both encapsulation materials, respectively, according to [4]. For this test, the packages contained a cavity of 0.05 cm³ instead of the humidity sensor. The packages were pressurized in a He atmosphere for 4 hours at 5.17 bar (absolute), before measuring their leak rate successively.

3 Results

3.1 Lifetime Tests

During accelerated aging, the relative humidity inside the packages changed. **Table 1** lists the times when vapour intrusion was detected.

Table 1: Results of the accelerated tests

Temperature	**60 °C**	**85 °C**
sample 1 (epoxy)	7 days 2 hours	3 days 9 hours
sample 2 (epoxy)	14 days 7 hours	5 days 7 hours
sample 3 (silicone)	-	2 hours
sample 4 (silicone)	-	2 hours

According to the results of 85 °C, silicone encapsulated packages failed more than one order of magnitude earlier than epoxy packages. Assuming an Arrhenius relationship, failure rates increase exponentially with temperature, the predicted onset of vapour intrusion at body temperature was calculated to 66 days with an activation energy $E_a = 0.59$ eV according to equation $K = exp\{E_a/k\cdot(1/T_1-1/T_2)\}$ where K is the acceleration multiplier, k the Boltzmann constant, T_1 = 60 °C, and T_2 = 85 °C. In long-term tests at 37 °C, the relative humidity rose by 0.4 %/h for epoxy and got saturated after weeks. In silicone the relative humidity increased by more than 15.7 % within the first hour and saturation occurred after a few hours. After 28 days no vapour intrusion into the metal sealed epoxy package was observed (**Figure 2**).

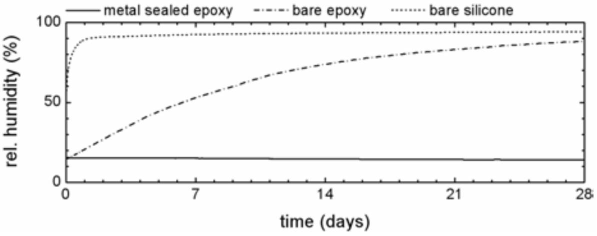

Figure 2: Long-term monitoring of humidity at 37 °C

3.2 Helium Leak Detection

The silicone packages showed leak rates, which are in average more than one order of magnitude higher than that of epoxy samples (**Figure 3**).

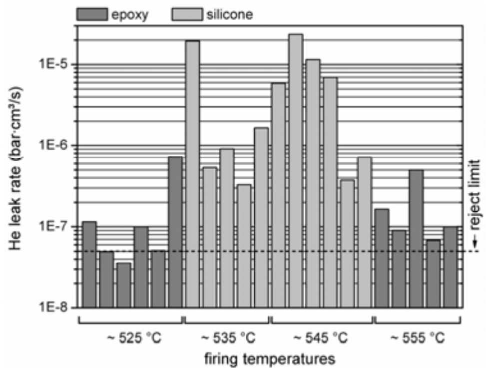

Figure 3: He leak rates of all implant samples

The firing temperature of the overglaze layer also plays a major role, so that only three packages had leak rates under the reject limit of $5.07\cdot10^{-8}$ bar·cm^3/s. These were fired at 525 °C and were made of epoxy.

4 Discussion and Conclusion

Epoxy-encapsulated packages are more than one order of magnitude better than silicone ones in the test specific characteristics, but not yet reliable enough for implantable applications. Process parameters strongly influence hermeticity and have to be further optimized, especially the firing temperatures. The major performance difference of the two encapsulants might be explained by the mismatch to the thermal expansion coefficient of Al_2O_3 (6.8 ppm/K), which is ca. 18 times larger for silicone than for epoxy. Future investigations will focus on epoxy as glob-top material and will employ a larger number of samples.

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6 References

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