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EXPERIMENTAL INVESTIGATION ON CORROSION PROPERTIES OF LDS MID FOR HEARING AID APPLICATIONS

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Abstract

The trend towards miniaturization is ever going in the hearing aid industry. The Moulded Interconnect Device (MID) technology can offer the unique possibility to reduce the size of the hearing aids by combining electrical and mechanical functions in the same components. On the other hand, one of the main concerns for MIDs in hearing aids is the corrosion of metal tracks. This paper investigates the corrosion of the MID parts based on different base materials, layer thickness and mechanical wear of the MIDs. The results presented in the paper will be useful for designing MIDs in hearing aids and other electro-mechanical applications.

Introduction

Moulded interconnect devices (MID) are defined as plastic substrates that incorporate hybrid electro-mechanical functions on the same device. By the integration of electrical and mechanical functions on a single device, MID reduce the number of components in the final assembly, save space, reduce process steps and assembly time [1]. It can produce three dimensional circuit patterns onto a complex and intricate surface giving the design extreme flexibility and making it robust.

Use of MID in hearing aids is not widespread until now. But the technology has the potential to find an exciting application area in hearing aid industries. One of the few examples of the use of MID in hearing aids is the Siemens Acuris P hearing aid where a MID system is used (as shown in Figure 1) to make multi-channel, directional hearing aid system containing up to three microphones. Some of the connector systems in hearing aids like RIC connector, electro-acoustic connector, programming connector etc. and many other electromechanical components can be benefitted by MID technology. With time, more and more hearing aid components will be redesigned based on MID concepts due to its unprecedented process and cost advantages.

Figure 1. Example of MID components used in hearing aids [2].

For the MIDs in hearing instruments, corrosion can be a big challenge. Corrosion is defined as a physical-chemical reaction of metal with its environment [3] which causes changes in the properties of the metal and can lead to damages of the metal. Detrimental effects of corrosion also includes higher contact resistance, short-circuit and nasty apperance. Historically MID is widely used for automotive application especially for dash board components where the environment is less corrosive compared with hearing aid’s working environment. For hearing aid’s MID components, effects of corrosive environment should be thoroughly tested. The current paper investigates on different substrate materials in combination of different metal layer thickness to find their corrosion resistance. A novel process has been presented in the paper to simulate the effect of working condition for hearing aid MIDs where some friction is involved. The results and discussion presented in the paper will be useful for designing MID components for hearing aids and for other electro-mechanical micro components.

Experimental plan and sample preparation

The objective of the test was to investigate the corrosion of the MID parts based on different base materials, layer thickness and mechanical wear of the MID paths. The test geometry used in the experiment was 60×60 mm plates of 2 mm thickness. These plates were moulded by 3 different plastic materials - one LCP and two different PAs. The specifications of the materials are listed in Table 1. The reasons to choose LCP and PAs are
their use in hearing aid applications, suitability of MID productions and unique electromechanical characteristics.

Table 1. List of plastic materials used for the experiment.

<table>
<thead>
<tr>
<th>Material</th>
<th>Grade</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid Crystal</td>
<td>LCP Vectra LDS 840 i</td>
<td>Ticona</td>
</tr>
<tr>
<td>Polyamide (PA</td>
<td>Vestamid HT Plus TGP 3586</td>
<td>Evonik</td>
</tr>
<tr>
<td>6TX)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyamide (PA10T)</td>
<td>Vestamid HT Plus TGP 3587</td>
<td>Evonik</td>
</tr>
</tbody>
</table>

After moulding, the metal tracks were made by Laser Direct Structuring (LDS) process. According to this process a laser beam initially makes the intended line and then electroless metallization process is used to make the metal tracks [2]. The width of the metal lines is 300 µm and the length is 10 mm. The test plate used in the experiment is shown in Figure 2.

Figure 2. MID test plate used for the experiment (width of the metal line is 300 µm and length is 10 mm).

For MID metal lines (conductive paths), 4-6 µm copper (Cu) is deposited on the plastic surface. Then a 3-4 µm thick layer of nickel (Ni) is deposited which acts as a diffusion barrier between copper and gold (Au). Finally a thin film of Au (about 0.1 µm) is deposited to increase conductivity and to protect Cu and Ni layer from atmospheric corrosion. The stack of metal layer for MID track is schematically shown in Figure 3.

Figure 3. Metal layer thickness of MID conductive paths.

For the current investigation, two different specifications for metal layer thickness were used to investigate the effects of metal layer thickness on the corrosion. For one group of samples the metal layer thickness was as mentioned above and for the second group a thicker Cu (8-10 µm) and Ni (6-8 µm) layer was used whereas the Au layer thickness was the same as before (0.1 µm). So the initial configurations of 4 different types of samples were as described below:

1. LCP Vectra 840i LDS, Metallization 4-6 µm Cu; 3-4 µm Ni; 0.1 µm Au (Samples described as: LCP- thin)
2. LCP Vectra 840i LDS, Metallization 8-10 µm Cu; 6-8 m Ni; 0.1 µm Au (Samples described as: LCP- thick)
3. PA6T/x Vestamid HTplus TGP 3586, Metallization 8-10 µm Cu; 6-8 µm Ni; 0.1 µm Au ( Samples described as: PA6TX)
4. PA10T Vestamid HTplus TGP 3587, Metallization 8-10 µm Cu; 6-8 µm Ni; 0.1 µm Au ( Samples described as: PA10T)

The 4 groups have further been subdivided into a reference group where the samples were not exposed to any mechanical wear and a group where the samples were exposed to mechanical wear. The mechanical wear was designed to simulate the actual working condition of hearing aid MID components for connector applications. The connector for hearing aids - for example the RIC (Receiver in the canal) connector undergoes a significant amount of mechanical wear during the plugging and unplugging of components like plugs and sockets. Hearing aid switches and buttons also undergo contact friction during switching on and off operation. So it is important for hearing aid MIDs that they can withstand contact friction and due to the wear no significant corrosion is occurred. For the current experiment, the mechanical wear was artificially made on a group of samples according to the process schematically presented in Figure 4. The wear was made in two different steps and in two different orientations. In the first steps, a specially designed holder loaded with contact springs (connector terminals) was moved back and forth for 15 cycles making sure that the wire ends were in contact with the MID tracks. In the second step, a spring loaded probe able to apply 100 g axial load was translated back and forth over one of the metallic tracks for 30 cycles.
30 cycles forward/back along a single MID-path loaded with a flat ended test probe

100 gram axial load

30 cycles forward/back with terminal loaded to make friction at the contact points

Movement of 15 cycles across with terminal loaded to make friction at the contact points

Contact springs- wire is bended to apply contact force on the mating surface by the spring action

Figure 4. Schematic representation of the process for making mechanical wear- it simulates the frictional wear of hearing aid components in actual applications.

After the sample preparation, the reference samples and mechanically treated samples of 4 different configurations were exposed to salt-mist test. Details about the test are described in the next section.

Salt-mist test

Salt-mist tests are usually designed for testing the metal parts and the device cases for simulating maritime and coastal conditions [4]. The test is not commonly performed on conventional electrical & electronic components since the salt mist sprayed onto the test parts is too harsh. But as mentioned before, the working environment of hearing aid is extreme where it is exposed to humidity, sweat, oil, ear wax, dirt and many other corrosive agents. For this reason, the salt-mist test was chosen to test the MID samples. The assumption was, if the MID could survive the salt-mist condition, it would survive any other corrosive environment during the operation of the hearing aids.

The salt-mist solution used was composed of 5g of Sodium chloride (NaCl), 5g of disodium hydrogen phosphate dehydrate (Na₂HPO₄·2H₂O) and 1 litre of demineralized water. The pH of the solution was adjusted to 4.7 by using concentrated acetic acid (CH₃COOH). The samples were exposed to salt mist for one hour in the chamber (spray activated at 0, 20, and 40 minutes), then the parts were dried for 1 hr 20 mins at room temperature. The samples were exposed again for 1 hour to salt-mist; finally they were dried at room temperature for 24 hours. The cycle was repeated for 3 days. Then the samples were stored at 40°C with about 95% relative humidity for 7 days.

Results and discussion

The samples after corrosion exposure were analyzed by optical methods- by the use of Alicona Infinite Focus and Leica MZ 125 microscopes. Optical images show that the line and border sharpness of metallized tracks on LCP substrate were more sharp and straight compared to the PA parts (as shown in Figure 5). The line sharpness affects the corrosion properties as sharp and well-defined lines are less likely to make edge corrosion. Edge corrosion occurs when the gold layer is not deposited following the exact edge of the line keeping underlying Cu and Ni exposed. Another point is smooth and well-defined lines will induce less friction with the mating surface resulting in less wear of the metal tracks and less corrosion.

Figure 5. Line sharpness of the metal tracks on LCP, PA 6TX and PA 10T (line on LCP is more sharp and straight compared of PAs).

Figure 6 shows the result from the corrosion test. Pictures in the first column are the pre-test samples means the pictures were taken before the corrosion exposure. Pictures in the second column are the reference samples - the parts that were exposed to corrosion environment without any mechanical damage. Finally the pictures in the third column were taken on the samples that have been exposed to mechanical wear before the sweat test.
The reference samples show almost no corrosion. But in few cases, pin hole corrosion was observed on some lines. The reason of pin hole corrosion was the remaining holes in the top Au layer that open the surface of underlying metal layer to the corrosion environment. A full coverage of Au layer over the Ni layer would prevent this type of pin hole corrosion. But it is technically challenging for LDS metallization processes to produce parts 100% free from pin holes. A thicker Au layer can help in the prevention of pin holes, but again there is process and cost limitation about how thick the Au layer can be.

Some pin whole corrosion was observed in all four configurations of samples. Besides this pin whole corrosion, the samples without mechanical wear performed well under salt-mist test. On the other hand, the samples that were mechanically scratched showed significant corrosion in all three materials—especially on the lines that were treated with 100 g axial load (shown on the right most lines of column 3 in Figure 6). The wear made by contact spring was less vulnerable to salt-mist. But it is clear from the experiments that if the metal tracks are designed for applications where there is contact friction, corrosion issues will be a concern.

A comparison among LCP, PA6TX and PA10T reveals that LCP substrates get relatively less corrosion. The reason is the less absorption of humidity. LCP absorbs less humidity compared to PA materials. The humidity absorption for PA can reach up to 5% of the weight of the plastic part; on the contrary LCP has a water absorption which is less than 0.04% (w/w). Moisture vapor transmission rate is also extremely low with LCP compared with PA [5]. So, LCP can create near-hermetic substrate and provoke less corrosion which is not the case with PA. Considering this fact, LCP is a better material for MID that may undergo moisture exposure.

Another important finding of the current investigation is having thicker Cu and Ni layer does not improve the corrosion properties. Less corrosion was observed with the thin metal on LCP compared to the thick metal on LCP as shown by top two pictures of column 3 in Figure 6. Amount to corrosion was even higher with the same lines of PA6TX and PA10T. The reason can be explained by the surface roughness of the metal tracks. Surface roughness was measured by Alicona and SPIP image processing software. The results are shown in Figure 8. From the measurement and also from the picture it is clear that thicker Cu and Ni layer makes the surface more rough. For the roughness measurement, among different
roughness parameters, the $S_a$ value was considered. $S_a$ is a 3D surface parameter that gives the arithmetical mean of roughness height and the average deviation of the surface from the nominal plane. For LCP with thin metal layer the average roughness ($S_a$) measured was 1.70 $\mu$m whereas on the same material with thicker metal layer the roughness measured was 3.33 $\mu$m. For PA materials the roughness was 5.30 $\mu$m and 4.92 $\mu$m respectively. The rougher surface makes higher friction during the mechanical contact and makes more wear of the surface. That contributes to the higher surface corrosion. The recommendation is MID component should have smooth surface with minimum possible surface roughness of the metal layers especially when friction is involved.

Figure 8. Surface roughness of the metal tracks (conductive metal paths) - thicker Cu and Ni layer makes the surface more rough.

Conclusion

This paper presents the investigation of corrosion properties for MIDs based on the metal layer thickness, different plastic materials and mechanical wear. The experimental conditions and materials were chosen based on the suitability of hearing aid applications. The experimental results clearly show that having thicker Cu and Ni layer doesn’t help in prevention of corrosion. Moreover a thicker Cu and Ni layer makes the surface rougher which increase corrosion by enhancing friction with mating components. Mechanical wear of the metallized surface is critical for corrosion of the hearing aid’s MID components. To prevent corrosion, the surface of the metal track should be as smooth as possible. Another aspect to remember for the MID plastics is the water absorption. Less water absorbing material will be the choice for less corrosion provocation.

Outlook

A thicker Au layer can improve the corrosion properties. This issue was not investigated in the current investigation and make a scope for future research. Generation of water layer on the metal surface enhance the corrosion. If it is possible to make a water repellant surface on the top of the metal layer, the susceptibility of corrosion can be reduced. Future investigation will focus on finding and testing of method that can make water repellant surface over the metal tracks. For example commercially available solutions like METASU HS-15P from Yuken Ind. Co. Ltd, Japan can be tested for this purpose [6].

References


