Nano Coating: Environmental Protection for Hearing Instruments
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Abstract:
Hearing instruments spend most of their service life in an environment which is quite hostile for electronics. The results of this exposure range from reduced performance and reliability to complete functional breakdowns. The search for methods and materials to protect hearing instruments from known aggressive substances, temperature changes and moist environments has been an ongoing activity since the inception of the first hearing instrument. The recent emergence of Nano Coating technologies has completely changed the way we think of and apply coatings to the modern hearing instrument. By applying a nanometer-thick layer of polymer on the entire device rather than a substantial layer of a conformal coating in selected areas, the protection of the hearing instrument is significantly improved. Nano Coating is an example of such a coating technology being applied to Interton hearing instruments.

Good product design takes into account the conditions under which the product will operate. Many devices that are used in punishing environments where they are exposed to dust, salt, moisture and extreme temperatures actually contain sensitive electronic components. In many cases, protection is built into the design. A well-known example of delicate equipment housed to survive hard conditions is a traffic surveillance camera, which spends its entire working life outdoors.

Why is the life of a hearing instrument so hard?

Temperature
The temperature to which hearing instruments are exposed is typically around 37 degrees Celsius (98 degrees F). The human body will to some degree stabilize the temperature in the hearing instrument, but some influence of ambient temperature variations (extreme cold or extreme hot weather) will still be exerted on the working temperature. Temperature or temperature change combined with humid ambient air are the main drivers of condensation. Also, chemical or electro-chemical processes that might take place in the hearing instrument are also affected by temperature.

Moisture and humidity
The presence of moisture in hearing instruments is the direct cause of condensation-related malfunctions. Obvious ways moisture can get into hearing instruments include wearing them in rainy or snowy weather, or wearing them while perspiring. Hearing instruments also regularly suffer through bathing, swimming and trips through the washing machine when users forget to take them off or remove them from shirt or pants pockets. Humidity in the environment also plays a role. Humidity measured in ITE shells being worn tends to be similar to that of the ambient environment (Bailey & Valente, 1996; Agnew 1999), which obviously can be an issue in tropical climates.

Moisture can also be the result of the humid conditions in the ear canal itself, which can be particularly problematic for in-the-ear styles. The range of normal relative humidity found in normal, open ear canals is around 40%, although it has been seen to be around 70% for those with history of middle ear pathology (Gray et al, 2005). Not surprisingly, individuals with a high relative humidity in the ear canal (>60%) report greater history of hearing instrument failures (Hall & Crouch, 2010).

The combination of a high humidity and changing temperatures will eventually lead to condensation in the hearing instrument. This basically means that the electronic components, battery and contact points get wet, ultimately leading to corrosion and device failures.

Cerumen
Cerumen is a mixture of apocrine sweat and oil secreted by glands in the ear canal. Dead skin cells from the ear canal and tympanic membrane and tiny hairs from the ear canal are caught up in this mixture. In unobstructed ear canals, cerumen migrates out of the ear canal as the ear canal sheds dead skin. This self-cleaning function of the ear canal is disrupted with hearing instrument use. With insertion, the hearing instrument, earmold or dome “acts as a bulldozer scraping and pushing ear wax, building a wall of debris, thereby forming a plug” (Courtois, 1991). Cerumen is also moist and contributes to the overall humidity in the ear canal.

Along with long-term exposure to body heat and humidity, the cerumen can react with hearing instrument materials to cause discoloring and brittleness.

Exposure to damaging agents
Solvents and other ingredients in hair sprays, hair gels, colognes and perfumes can also damage hearing instrument parts. In addition, oil, grease, particulates, or whatever the user has on their hands can end up on the hearing instrument receiver, causing serious degradation of the performance. Most hearing instruments have been fitted with some form of a wax protection system, a filter, a membrane or a trapping system. These systems are intended to protect the receiver from being contaminated with cerumen. To function properly, they will have to be cleaned occasionally.

Deposits of oil, grease and particulates during the handling of the hearing instrument can eventually lead to blockage of the acoustic output port of the hearing instrument receiver, causing serious degradation of the performance. Most hearing instruments have been fitted with some form of a wax protection system, a filter, a membrane or a trapping system. These systems are intended to protect the receiver from being contaminated with cerumen. To function properly, they will have to be cleaned occasionally.

Condensation on internal surfaces will form into liquids that, when in constant contact with conductive surfaces, can lead to such issues as short circuiting, leakage currents, formation of corrosion, and migration of conductive material. All of these issues can cause some form of non-functionality over time. In particular, liquids containing salts such as perspiration, introduced into the hearing instrument during various sports activities, will exacerbate the above mentioned detrimental effects. After evaporating, the perspiration also leaves behind a salt residue just waiting to be reactivated next time condensation of moisture takes place. Batteries, in particular Zinc-Air (ZnO2) batteries, have been known to leak. The leakage typically happens after usage if the battery is exposed to deep discharge. Leakage can happen if the discharged battery is not immediately removed from the hearing instrument, as air humidity influences the battery chemistry. The main effect is expansion and leakage of the alkaline electrolyte of the battery into the battery compartment of the hearing instrument. The electrolyte, an aqueous solution of potassium hydroxide, is a very good conductor which will wreak havoc once it comes into contact with a conductive surface such as the battery contacts. Another possibility is that the leakage may lead to a short circuiting of the battery with a complete loss of functionality. As with perspiration, once dried up, it will leave behind a residue that can be re-activated as a conductor by adding water.

The secretion of cerumen will most likely over time lead to blockage of the acoustic output port of the hearing instrument receiver, causing serious degradation of the performance. Most hearing instruments have been fitted with some form of a wax protection system, a filter, a membrane or a trapping system. These systems are intended to protect the receiver from being contaminated with cerumen. To function properly, they will have to be cleaned occasionally.

Consequences for the hearing instrument
When hearing instruments are exposed to these tortuous conditions, there will be short and long term effects that can lead to the malfunction of the hearing instrument.
Coating Technology of Yesterday

The classical way of trying to prevent hearing instrument problems that may arise from all the debilitating exposures has been to apply coating materials locally. The usage of conformal coatings for encapsulation of critical components, such as the integrated circuits, is critical and necessary for the functioning of these circuits. In addition to protecting from aggressive substances, the coating also shields the integrated circuit from light, an exposure that could disturb the functioning of the circuit.

Because these coating materials often are epoxy-based, they can potentially introduce other problems such as free ions, which can damage the delicate workings of the integrated circuit. In addition, such materials cannot be used on surfaces with which you want to establish electrical contact. Materials other than those that are epoxy-based are still in use for localized protection of components. These include an assortment of waxes, lacquers, and silicones. Yet like the epoxy-based materials, these coatings are not conducive and thus cannot be used in places where electrical contacts are necessary.

Metallic surfaces, such as contact points (battery contacts, DAI & programming contacts) have traditionally been protected against corrosion by applying a non-corrosive metallic protection layer, typically gold. A reasonably thick layer and the freedom from small openings called “pinholes” in the protective layer are necessary to obtain sustained protection.

Changing the Technological Mindset for Protective Coatings

The traditional approach to protecting hearing instruments from environmental exposure has been to seek out areas and/or spots where visible damage occurred and coat with a suitable material. The rationale for this approach is that by encapsulating the problem point, the area would be protected. Certain areas, such as all electrical contacts for the battery springs and contacts for audio or programming inputs, could not be encapsulated. As reviewed, these metallic surfaces had to be protected by depositing another less corrosive sensitive metal, such as gold, to protect from corrosion.

The search for methods and materials to make a global protection for the hearing instrument and all its components has been going on for years. The emergence of Nano Coating technology has completely changed the way we think of coating. By applying a coat that will act globally and enter every cavity and add to every surface—internally as well as externally—we obtain an added layer of protection.

Does Nano Coating make other forms of protection obsolete? The answer is that some degree of local and partial protective coatings will still be used, but only where the combined effect is beneficial or where there is a specialized need, such as protecting the integrated circuits.

The new kid on the block - Nano Coating

So what is this Nano Coating? “Nano” is derived from the Greek word for “dwarf” and is the standard metric prefix referring to 10^-9. It is used in conjunction with various technologies that deal with the study of controlling matter on an atomic and molecular scale.

Generally, nanotechnology deals with structures that are 100 nanometers or smaller in size in at least one dimension, and involves developing materials or devices within that size range.

Good examples of nanotechnologies are Integrated Circuits, which currently are on the order of 65 nanometers in feature size (smallest dimension of a transistor) and Nano Coatings. The thickness of the Nano Coating protecting layer used by Interton is typically in the range 60 - 80 nanometers. This corresponds to 1/1000 of the thickness of an average human hair. One nanometer equals 1x10^-9m or 1 billionth of a meter.

Nano coated microphone unit with beaded water droplet.

The contact angle is a result of the interface/surface tensions (surface free energies) between liquid and solid surrounded by vapor, and is measured according to Young’s equation:

\[ \gamma_{LV} = \gamma_{SL} + \gamma_{SV} \cos \theta \]

Where \( \theta \) is the contact angle, \( \gamma_{LV} \) is the solid/liquid interfacial free energy, \( \gamma_{SV} \) is the solid surface free energy, and \( \gamma_{LV} \) is the liquid surface free energy.

Contact angles obtained by Interton’s preferred method of Nano Coating typically run in the 120 - 130 degree range. This is considered to be highly hydrophobic. A hydrophobic surface is defined as a surface that will form a droplet with a contact angle greater than 100 degrees.

How does the contact angle from Interton’s Nano Coating process compare to other non-nano coated materials typically found in the electronics industry? Table 1 gives an overview of a few of these materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>Contact Angle, degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass</td>
<td>0</td>
</tr>
<tr>
<td>Cellulose acetate</td>
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</tr>
<tr>
<td>Nylon</td>
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<tr>
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<tr>
<td>PET</td>
<td>77</td>
</tr>
<tr>
<td>PVC</td>
<td>85</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>99</td>
</tr>
<tr>
<td>Paraffin wax</td>
<td>110</td>
</tr>
<tr>
<td>PTFE</td>
<td>112</td>
</tr>
</tbody>
</table>

Table 1

When hearing instruments - including all internal components - are nano coated, any liquid resulting from condensation or introduced from outside beads up and rolls away. Figure 3 illustrates this protection mechanism with a nano coated hearing instrument microphone.

The increased contact angle by the Nano Coating process also gives improved protection against other substances such oils and waxes, referred to as “oleophobicity.” This mechanism is important in relation to protecting a hearing instrument from the effects of cerumen as well as making it difficult for fingerprints and other particulates to adhere to the outer surfaces of a hearing instrument.

Figure 3. Nano coated microphone unit with beaded water droplet.
How is Nano Coating applied?

The Nano Coating coating process is done by applying a plasma (electrically charged monomer molecules) under vacuum conditions to finished hearing instruments. Doing this under vacuum conditions allows for the coating material to enter the hearing instrument, thereby coating every exterior as well as interior surface.

When the electrically charged monomer molecules attach to the surface of the various materials in the hearing instrument, they chemically combine with each other and form a polymer film. This polymer film is molecularly bound to the host surface making the coating inseparable from the host surface. The thickness of this polymer film is 60 - 80 nanometers.

Compared to prior art of coating, Nano Coating brings with it the advantage of coating areas of the hearing instrument that were not possible before. This is truly a process that brings coating from being local to global protection.

Specialized manufacturing equipment is used to provide hearing instruments with the Interton Nano Coating. The central component of the manufacturing equipment is the processing chamber (Figure 4) which will hold a number of hearing instruments in a custom designed fixture for simultaneous processing.

Checking the hearing instrument performance at regular intervals during the AST testing and inspecting for impact of the various exposure from the testing are important parts of quality assurance. As mentioned earlier, looking for signs of corrosion, migration, blockage of sound inlets (microphone ports) and build-up of debris, is a crucial part of the verification process.

The processing chamber has an integral electrical coil that will subject small organic molecules (the monomer gas) to an ionizing electrical field under low pressure conditions, thereby creating the plasma. The entire process is, in general, referred to as Plasma Deposition.

How do we test the nano coated hearing instruments?

To verify the protective properties of the Nano Coating process, Interton performs a number of environmental tests. In order to address the previously mentioned areas of concern, specific tests have been designed. Replicating the various exposures and whenever possible accelerating the impact of these is a primary goal. The ideal situation would be to carry out a time limited test that would emulate the exposures experienced by the hearing instrument over its useful lifetime. Such a test - the Interton AST (Accelerated Screen Testing) - is a 5-week test that yields results predicting long-term performance.

The following tests from the AST are of particular interest when evaluating the efficacy of the Nano Coating:

- Salt Mist and Humidity (IEC60068-2-11 & IEC60068-2-3)
- Temperature Cycling (IEC60068-2-4)
- Damp Heat, Cyclic (IEC60068-2-30)

Tests in which nano coated surfaces and hearing instrument housing materials are exposed to sunlight are carried out in order to investigate whether discoloration or brittleness occurs.

In all likelihood Nano Coating will play an important role in keeping the hearing instrument surface free from bacteria and viruses. The very nature of the technology will render the hearing instrument surface an unfriendly (non-hospitable) host for such microbes.
Summary

The introduction of Nano Coating brings with it significant benefits for the hearing instrument user. Known issues from present generations of hearing instruments are being addressed with the application of Nano Coating coating technology, thereby affording the hearing instrument user the greatest opportunity for improved reliability with minimal downtime. Maintaining and caring for the hearing instrument is easier and less time-consuming, ultimately contributing to increased end user satisfaction.

References


