Improve Reliability of Hearing Instruments using Nano Technology

Weili Lin, Ph.D.
Director, Emerging Hardware Technology Development
Starkey Hearing Technologies
Eden Prairie, MN, 55344 USA
Weili_lin@starkey.com

***Abstract*—*Historically, hearing aids have been prone to damages by foreign materials. Manufacturers have applied various techniques to address this issue, most recently by using hydrophobic nano coating. However, these methods have shown to be inadequate, especially in dealing with oily substances such as earwax. HydraShield2 nanotechnology has been developed to mitigate the ingress of both water and oily substances for hearing aids. This was accomplished by significantly modifying the surface's interaction with foreign materials. Through both lab tests and human subject studies, this technology has been found to be very effective in mitigating the ingress of foreign materials. As a result, the reliability of hearing instruments has been enhanced and the customers' satisfaction has been improved.*

***Keywords*—*The lotus effect; nano coating; superhydrophobic; oleophobic; omniphobic; HydraShield2; hearing instruments; hearing aids.*

I. Introduction

A. Problems to Be Solved

One of the recurring problems with hearing aids is the frequent exposure to moisture, earwax, body oil, and other foreign materials. As a result of these exposures, hearing aids often suffer from degraded performance and eventually cease to function due to: (a) blockage of acoustic paths (such as acoustic ports and pathways); (b) damage to transducers and mechanical components; (c) corrosion and leakage batteries; (d) malfunction of circuit.

Historically, damages caused by foreign material ingress have been the number one reason for hearing aid returns and repairs. In many cases, this issue also prevented the hearing impaired from adopting this life-changing technology. In addition, this problem will be exacerbated in the near future as the demographics of hearing aid users shifts to those with more active lifestyles (such as baby boomers and children).

B. Existing Solutions

Many techniques have been tried in order to protect hearing instruments from the ingress of foreign materials. For example, acoustically transparent but water repellent mesh/screen and foams were applied in front of the acoustic ports to protect the transducers. For certain products, O-ring type of seal was installed around the battery compartment and case seams to prevent moisture ingress.

However, these traditional protective methods have been proven to be ineffective and/or unfavorable. For instance, the openings of the mesh/screen can be clogged over time by foreign materials, which will adversely affect the acoustic performance of hearing instruments. As a result, these protective means need to be replaced quite frequently in the field. In addition, the incorporation of O-ring can make the case design more complicated and lead to undesirable size increases.

Consequently, the buildup of earwax, moisture and other foreign substances continues to be a challenge for hearing instruments. A different method needs to be developed to provide enhanced protection against foreign materials while addressing the limitations of the traditional techniques.

II. Our Solution: Omniphobic Nano Coating

A. The Lotus Effect

One potential solution to this issue lies in the application of thin repellent coatings to hearing instruments as an enhancement to the traditional approaches.

Water repellent phenomena can be found in many plants. The lotus, for example, has leaves with an exceptionally non-wetting surface as the basis of its self-cleaning mechanism, commonly referred to as the lotus effect. This phenomenon is in fact caused by both the hierarchical roughness of the leaf surface, and the intrinsic hydrophobicity of the waxy layer covering the surface roughness. As a result, water droplets tend to roll off the leaves and carry the dirt and mud with them.

How a solid surface repels a liquid, therefore, mainly depends upon two factors: surface energy and surface morphology.

a) The surface energy affects the liquid-solid surface interface by influencing the attractive forces between the liquid and solid at the molecular scale. The degree of water repellency of a surface, or hydrophobicity, can be characterized by measuring the contact angle of a small water droplet on a level surface (as shown in Fig. 1). The contact angle θ can be determined in simple cases by Young's equation [1][2].

$$\text{Cos}\theta = (\gamma SV - \gamma SL) / \gamma LV \quad (1)$$

Where, γSL, γSV, and γLV are the interfacial free energies per unit area of the solid-liquid, solid-gas, and liquid-gas interfaces, respectively.

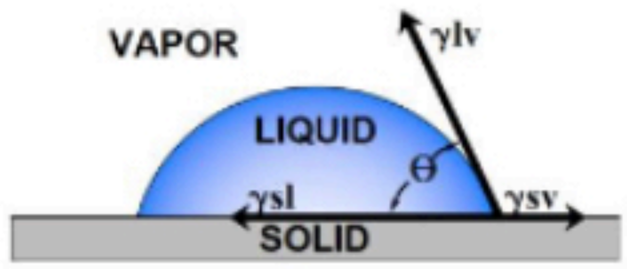
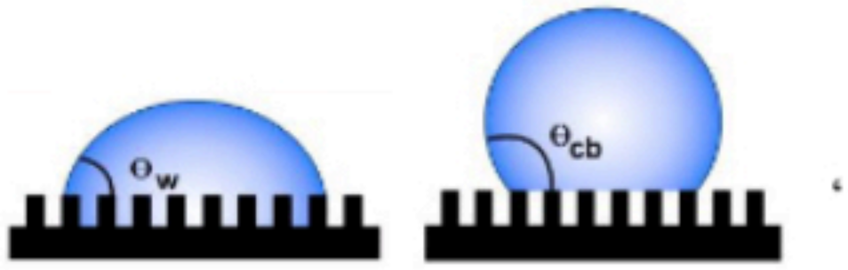


Fig. 1. Illustration of liquid contact angle on a solid substrate

A surface is deemed hydrophobic if the water contact angle θ (WCA) is between 90^0 and 150^0, and superhydrophobic if WCA is above 150^0.

b) Alteration of surface morphology at the micro- and/or nano-scale, on the other hand, can allow an air layer to be formed in the spaces between the surface texture features during liquid contact. This surface roughness/texture is crucial in producing superhydrophobic surface, which can be described by two distinct states as shown in Fig. 2 [3]. A liquid droplet that completely wets a textured surface is in the "Wenzel state". Conversely, a liquid droplet that rests on the layer of air within a textured surface is in the "Cassie state", which can have far less droplet adhesion and a far greater contact angle.



(a) Wenzel State (b) Cassie State

Fig. 2. Comparison of behaviors for a liquid droplet on a textured surface

This lotus effect, shown as the "Cassie state" above, can be achieved artificially by introducing textures on a surface of interest at the nano scale, such as a nano tube forest, nano particles, or etching, through photochemical or plasma treatment. As a result, several hearing aid manufacturers have applied this technique to their products in the past few years in order to improve product reliability [4]. However, this type of coating was only capable of repelling water, but not effective in reducing the ingress of earwax and other oily substances.

B. *Omniphobic Nano Coating*

A surface coating resistant to both water and oil wetting (a.k.a., omniphobic) would be ideal for preventing or minimizing ingress from a number of contaminants simultaneously. Recently, Starkey, in collaboration with its partner, has developed this type of coating technology called HydraShield2 [5]. In addition to being superhydrophobic, HydraShield2 is also oleophobic for certain material, which can effectively repel oily substances such as earwax.

HydraShield2 was delivered through supramolecular vapor deposition (SVD) process. In order to increase the surface roughness, nano particles were deposited onto the substrates first and were subsequently encapsulated. These nano structures were then covered by functional self-assembling monolayer, which was intrinsically hydrophobic. Altogether, the total thickness of the coating is on the order of 100nm.

In order to make this delivery system economically viable for our manufacturing, batch process has to be used to treat as many products as possible each time. To accomplish this, extensive work was carried out to fine tune the relevant parameters, such as vacuum level, deposition duration, number of devices, and desired locations within the deposition chamber. Fig. 3 shows the interior of a SVD chamber with hearing aid components placed strategically for experimental purpose.

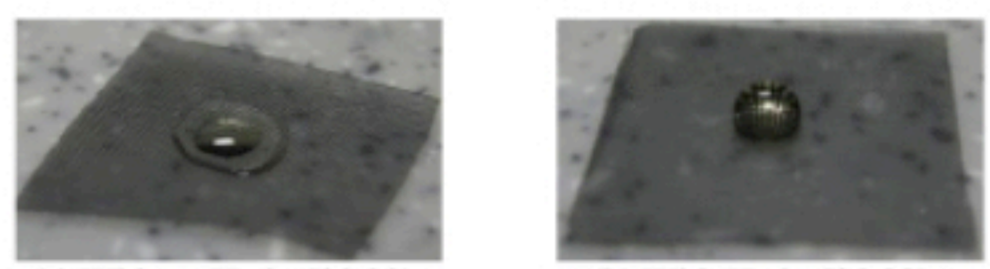
Fig. 3. Hearing aid components placed within a SVD chamber

C. *Targeted Areas*

In order to provide effective protection for our hearing instruments, we have focused on the following areas when HydraShield2 was applied:

a) *Case and Battery door:* Omniphobic coating deposited in these areas prevents liquid from seeping into small holes, seams, and crevices, As a result, it reduces damage to mechanical components, battery, and electrical circuit.

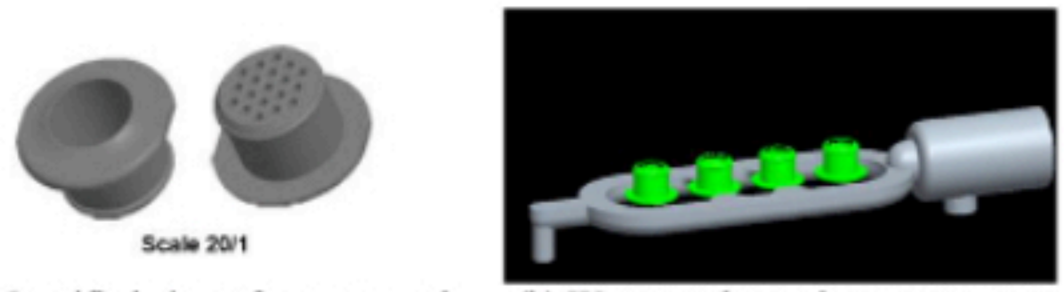
b) *Microphone Cover:* Replaceable covers, consisting of screens in front of microphones, have been used as microphones's first line of defense. By treating the cover with HydraShield2, body oils and earwax are prevented from penetrating the openings on the cover. Instead, these unwanted liquids form spheres on the cover and can easily roll off the surfaces (see Fig. 4). As a result, microphone covers last longer in the field and microphones are further protected.



(a) Without HydraShield2 (b) With HydraShield2

Fig. 4. The behavior of liquid droplet on a sheet of microphone screen

c) *Speaker:* Due to their position in the ear canal, speakers are heavily exposed to earwax. Similar to microphone covers, wax guards made of many small openings (see Fig. 5) have been installed in front of speakers for protection. By treating a newly designed wax guard with HydraShield2, earwax can be repelled and kept away from speaker due to oleophobic nature of the coating.



(a) Magnified view of a wax guard (b) Wax guard samples on a runner

Fig. 5. New wax guards that were treated with HydraShield2

III. Evaluation Methods

The following experiments were carried out to evaluate the effectiveness of HydraShield2 against the ingress of foreign materials.

A. Contact Angle Measurement

The contact angles were measured using both water and olive oil droplets on substrates that are made of commonly used plastics in hearing instruments. Untreated plastic parts (as control) and parts treated with hydrophobic coating and HydraShield2 technology were included in this evaluation.

B. Salt Fog

The salt fog test is an accelerated corrosion test in order to predict a product's long-term performance under humid and salty conditions. The protocol of MIL-STD-810G (method 509.5) has been adopted due to its well defined test cycles and clear acceptance in the consumer electronics industry.

During the test, a 5% salt solution concentration was used to create a salt atmosphere at a temperature of 35°C. The test consists of 48-hour salt atmospheric exposure followed by 48-hour drying under ambient conditions.

C. IP Rating and Immersion Test

Several methods have been used to measure the level of resistance to unwanted substances for a given product. For instance, in the watch industry, water resistance is usually accompanied by an indication of the static test pressure (such as the depth of water) that a watch was exposed to during a leakage test. On the other hand, the Ingress Protection (IP) rating, as defined in IEC 60529, has been widely used in other markets, including hearing aid industry, to classify the degree of protection against the intrusion of foreign objects.

There are two numbers in the IP code, with the first digit indicating the level of protection against solid objects, and the second digit representing the level of protection against the ingress of water. For our application, the measure for the level of water resistance is more relevant.

The water ingress levels consist of protection against dripping water, spraying/splashing water, water jets, and immersion. In terms of the degrees of protection against immersion, levels 7 and 8 correspond to a submersion of up to one meter and an immersion beyond one meter, respectively.

D. Simulated Earwax Test

Several approaches were used to simulate the behavior of earwax on wax guard in order to assess the effectiveness of HydraShield2. In order to maintain test consistency, olive oil has been used to simulate ear wax during these tests.

. Fig. 6 shows one particular test setup in which the wax guards, with olive oil deposited on top of them, were mounted on a rotational system. By spinning the wax guard at a certain speed, olive oil could be pushed through the openings on the wax guard by centrifugal force. As a result, the level of resistance to oil provided by the wax guard can be assessed.

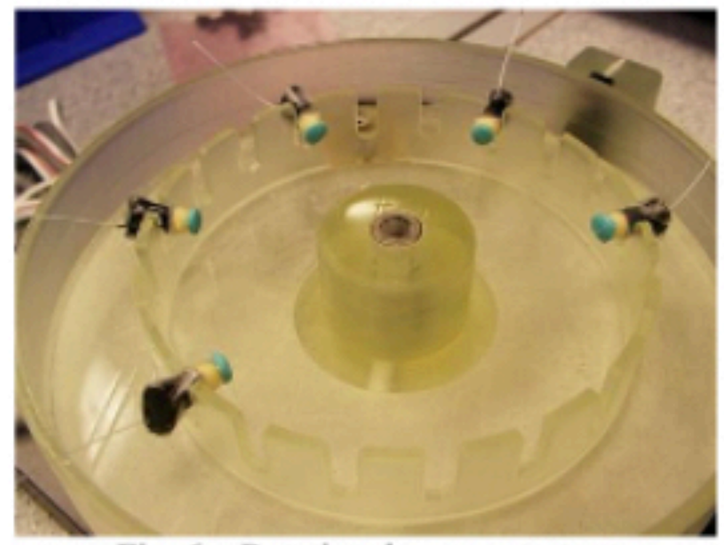


Fig. 6. Rotational earwax test setup

E. Human Subject Test

In order to assess the effectiveness of HydraShield2 in actual applications, more than one thousand hearing aids and wax guard units treated with HydraShield2 were deployed to the field. The performance of these products was monitored and, in some cases, customers' feedbacks were gathered.

IV. Outcome

A. Lab Test

a) *Contact Angle:* The housings of most Starkey hearing instruments are made from Nylon variants. It has been shown previously that HydraShield2 technology was able to deliver both superhydrophicity and oleophobicity on Nylon based substrates [5], and was thus more advantageous over the traditional hydrophobic technology.

In addition, as shown in Fig. 7, ABS showed the biggest increase in olive oil contact angle after it was treated with HydraShield2. As a result, this could become the preferred material for developing future earwax mitigation schemes.

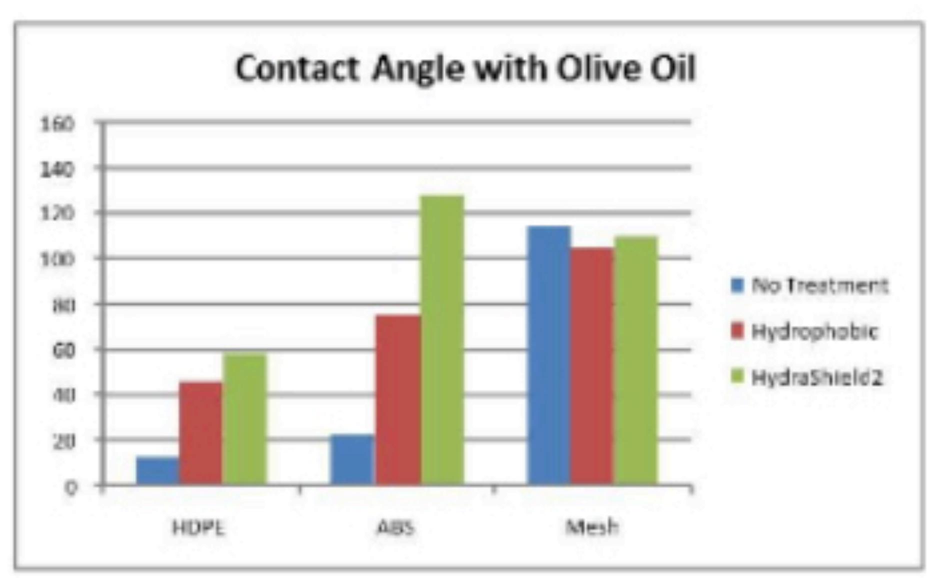


Fig. 7. Contact angles for several different substrate material using olive oil

b) *Salt Fog Test:* It was found that devices treated with HydraShield2 performed extremely well through Salt Fog tests. They not only retained electro-acoustic performance after the exposure, they also did not show any sign of corrosion on their batteries. In contrast, most of un-treated devices showed significant degradations in performance, and their batteries were also corroded quite severely.

c) *IP Rating:* An independent lab evaluated all three sizes (10, 312, and 13) of Starkey hearing aids that were treated with HydraShield2 nano coating. After being immersed in one meter of water for 30 minutes, the devices showed no evidence of moisture intrusion. As a result, they were clasified as IPX7, which is a significant improvement over previous products in terms of water resistance.

d) *Earwax Test:* Table 1 shows the results of simulated earwax test using the rotational method. Under the speed of 215 revolutions per minute (RPM), failures were already observed for untreated wax guard; wheras treated wax guard performed flawlessly untill the rotational speed was nearly doubled. This clearly demonstrates that HyrdraShield2 were more superior in reducing the ingress of earwax (in liquid form) than the traditional method.

Table 1 Results of simulated earwax test under several rotational speed

Sample	Type	215 RPM	300 RPM	425 RPM
1	HydraShield2	Pass	Pass	Pass
2	HydraShield2	Pass	Pass	Pass
3	HydraShield2	Pass	Pass	Pass
4	HydraShield2	Pass	Pass	Pass
5	HydraShield2	Pass	Pass	Fail
1	control	Pass	Fail	Fail
2	control	Pass	Fail	Fail
3	control	Pass	Fail	Fail
4	control	Fail	Fail	Fail
5	control	Fail	Fail	Fail

B. *Human Subject Test and Actual Return Rate*

During the field study, many patients reported that the treated wax guards lasted much longer than their previous wax protection schemes. In some cases, this replacement cycle was improved by a factor of 2 to 3 times.

Furthermore, after HydraShield2 was deployed in the field, the warranty return rate on hearing instruments was reduced by nearly 5%, which was a significant improvement over the previous methods.

V. CONCLUSIONS AND FUTURE WORK

Through extensive laboratory testing and actual patient study, we were able to demonstrate that HydraShield2 nanotechnology offers a more effective and comprehensive solution to moisture and earwax resistance than traditional techniques.

This represents a paradigm shift in improving the durability and longevity of hearing instruments in the field. HydraShield2 not only brought the moisture protection to a new level through superhydrophobicity, but it also significantly improved resistance to oily substances through oleophobicity. Furthermore, this technology is invisible and compatible with manufacturing process.

HydraShield2 has already helped thousands of hearing professionals and patients experience the comfort of knowing that their hearing instruments are more reliable and will maintain their performance for much longer than ever before. Through this work, it was evident that nano technology is not just a scientific wonder in laboratories; it can actually improve people's life.

In order to improve the reliability of hearing instruments further, future work will be focused on improving the durability and effectiveness of HydraShield2. One possibility is to increase the surface roughness more significantly. In addition, this type of nanotechnology can potentially be applied to transducers directly.

ACKNOWLEDGMENT

The author would like to express acknowledgement to several co-workers and our industrial partner, especially Molly Young and Steve Hanke. This work will not be possible without their contributions.

REFERENCES

[1] Young, T., "An Essay on the Cohesion of Fluids," Phil. Trans. R. Soc. Lond., 95, 1805, pp. 65–87.

[2] T. S. Chow, "Wetting of rough surfaces," Journal of Physics: Condensed Matter, 10 (27), 1998, L445.

[3] J. Bico, C. Tordeux, and D. Quéré., "Rough Wetting," Europhysics Letters, vol. 55, no. 2, 2003, pp. 214–220.

[4] Lin, W., "Improving Water Resistance for Hearing Instruments," Canadian Hearing Report, Vol.4 (Suppl. 1), 2009, pp. 9-15.

[5] Lin, W., "Improving Resistance to Foreign Material for Hearing Instruments," Nanotech 2012, Vol.1, pp. 726-278.