Effect of Hybrid Alumina/Aluminium Foil Dome Diaphragms on Sound Performance of Loudspeaker

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Abstract. Plasma electrolytic oxidation (PEO) technology enables to fabricate a nanostructured ceramic top layer on an aluminium foil, called hybrid alumina/aluminium material, which has the enhanced properties like hardness, stiffness, wear resistance and corrosion resistance. In this work, PEO nanostructured coatings were applied to aluminium speaker domes to study what effects PEO coatings could offer. A set of treated domes were processed to have a thin coating and the other processed to have a thicker coating. Afterwards, the speaker domes were conducted with several tests and measurements. From the frequency range of a low frequency (200 Hz to 5 kHz) there was very little downside to adding the coating, only at middle frequencies (5 kHz to 12 kHz) a slight decrease in sensitivity can be found. In high range frequencies (12 kHz to 14 kHz) the sensitivity in dampening and sound distortion resistance was increased. In general, these qualities should lead to a better, cleaner sound quality reproduction.

1. Introduction
Nowadays there is not much progress to improve the sound of the speaker. Very little new technology has been created that would allow for the progress and sound quality of the high-end speakers. The aim of this project was to test how the effects of plasma electrolytic oxidation (PEO) coatings could improve the sound quality of the speakers and maybe provide new technology to revolutionize what distinguishes a subpar speaker from a superb speaker. Simply put, the speaker has a dome that is connected to an electromagnetic coil and is held in place by dome suspensions. The speaker begins to work when the coil applies a forth to the dome. To create a desired sound, the coil changes its poles by changing the direction of the current, which in turn moves the dome diaphragm in different directions. This creates modulations in the air which then will create the desired sound. [1,2] Overall, the speaker’s goal is to accurately represent the sound of what it is producing. People have been attempting to do this through increasing the decay rate (dampening)[3], to avoid extra noise and produce a cleaner sound quality, to increase sensitivity to more accurately vibrate and lastly to increase stiffness to avoid distortion in the shape of the dome, which would lead to sound distortion. Therefore, in this experiment Sound Pressure Level (SPL) was measured and CSD measurements were taken which translates to sensitivity and sound cleanness to improve sound quality most properly. The results were compared to the results of a beryllium dome since at the moment beryllium is the optimum material to make high frequency speaker domes, however it is too expensive to manufacture...
on a large scale. Another way to improve the effectiveness of the speaker would be to increase the adhesion between the coil to the dome and between the dome suspension and the dome.

Plasma electrolysis oxidation is a process that enables the surface modification of metals to give it a lot of beneficial properties.\[4,5,6,7\] For a long time, PEO coatings have been studied and applied for its mechanical properties in mechanical and medical fields. PEO simply put is a way to deposit an oxide film layer on the surface of the sample. PEO is mainly based on the principle that when an aqueous solution is electrolyzed, it will create an oxygen gas layer upon the sample. This oxygen gas layer can eventually result in surface dissolution or under the right conditions, the oxide film layer. To begin the PEO process the sample is put at the anode of a high current circuit inside an aqueous solution, when the current begins and the electrolyte solution starts to electrolyze oxygen gas is released and creates a thin protective layer around the surface. However, as time goes on the current density continues to rise and it begins to break down the oxygen layer, the electric field around this time should be between $10^6$ and $10^8$ V/m.\[5\] This electric field is sufficient to being the ionization process which will then turn the oxygen into plasma. Once the plasma has been ionized it is capable of reacting with the aluminium surface to turn into meta-stable $\text{Al}_2\text{O}_3$. As time goes on the longer the surface continues to be oxidized and the thicker the coating is.\[6\] This oxide film layer, or coating, is known to have many outstanding properties. This includes thermal stability, high bond strength, and corrosion resistance and wear resistance; these properties are some great attributes that the coating can immediately give the speaker. \[4,5,6,7,8\] These would result in longer lifetime, as well as enable the speaker to last in harsher environments. It is important to study the other effects that the PEO coating can give the speaker dome. This could be achieved by having a better wear resistance of the dome so that it can last longer.

2. Experiment Methods

In this experiment, the PEO technique was used to coat the surface of six aluminium domes which would normally have been used in speakers. The first three domes were designated to be processed to have a thinner coating and the last three to have a thicker coating that was twice the thickness. To accomplish this, both sample underwent mainly all of the same parameters; an electrolyte solution consisting of certain concentrations of $\text{Na}_2\text{SiO}_3$, $\text{Na}_3\text{PO}_4$ and KOH was used inside the tank where the PEO coating had taken place, Figure 1. The other parameters were a current density of 0.1 A/cm$^2$. The current ratio between the positive current and negative current was 0.7:1, respectively. While coating, to prop the sample in the electrolyte solution we used a clamp that would grasp and suspend the dome in the solution while the coating process occurred. To get a coating that had twice the thickness the coating time process was changed, since the coating deposits at a consistent rate.\[6\]

The coating thickness of the speaker dome was measured using a PosiTector 6000 coating thickness gauge. This was used to measure 9 evenly distributed points on the speaker dome edge in attempt to get a proper image of the speaker dome thickness, Figure 2. Most notably, however, is that samples one, two and three had been coated with an average thickness of 10.4, 10.1 16.4 microns, respectively, and samples four, five and six having an average thickness of 28.3, 26.4, and 34.7 microns respectively.

It is important to notice that while going around the perimeter of the dome, a wide range of coating thicknesses was observed for each dome sample. This was most likely because the clasp was not distributing the high charge evenly across the surface of the domes. This most likely was because the areas near the clasp were exposed to higher voltage, resulting in a higher distribution of plasma and therefore a thicker coating. Even though the overall average between the coatings were distinct and consistent, this uneven distribution could have distorted the sound since the rigidity of some areas of the speaker dome would be different due to the coating discrepancies. This could be prevented by designing a clasp that would complete the circuit by making contact evenly with all edges of the speaker dome, and thereby ensuring an even coating distribution. Further work could be done in this area.

To test the effects of the coatings upon the speaker dome, the domes were sent to Radian Audio Engineering where several tests were performed. The first being a two-part test where the driver was tested by putting the dome in front of a microphone, while having a horn attached to the driver. This is
demonstrated in Figure 3a. The second version of the test had all the same parameters, however the horn was removed as demonstrated in Figure 3b. While normally the compression drivers are used with horns, it was removed to avoid horn effects imparting on the dome vibrations. This allowed more readily to identify the effects of PEO coating on compression driver performance. The microphone was one meter away from the driver and a 2.83V sine wave sweep was as a test signal. Sound Pressure Level (SPL) frequency response was measured using the Linear X LMS measurement system. Clio measurement system was used for impulse response and cumulative response measurements.

Figure 1. Setup of the PEO coating facility

Figure 2. The aluminum speaker domes with a PEO coating

Impulse response and cumulative response comparison. Impulse response is essential to the quality of the sound since the higher and more detailed the impulse response, then the more sensitive to the input signal changes, thereby having a potential for a more accurate sound representation.

Figure 3. The setup of the first test (a) with the horn and (b) without the horn

3. Results and Discussion

One of the most important objective parameters defining quality of a speaker is frequency response of reproduced sound pressure level (SPL). The higher and smoother is SPL response, the better the performance. The other important parameter is level of distortion at a given SPL. SPL response has a direct correlation to the intensity of speaker dome vibration in response to input signal. [9] The SPL response data resulting from the first test, where there was a horn attached to the driver in a loudspeaker is displayed in Figure 4(a), which compares output sensitivity vs. frequency. The same compression driver was used with a beryllium dome was also tested and its SPL is displayed in Figure 4 to compare with the aluminium dome as well as the coated dome. Beryllium was chosen because it is one of the lightest metals with the highest modulus of elasticity, and thereby the ideal choice for speaker dome material. [1,2] However, it is not commonly used in speaker domes because of the extremely high price domes and manufacturing difficulties related to health hazards during certain stages of its processing.

In the test, the higher the sound level is at the same frequency would be better. To achieve this, it would be better to have a lighter dome to increase the SPL. For the majority, as can be seen in the graph, the coating on the aluminium sample had very little effect on the SPL. There was a very little to no improvement from the frequency range of 200 Hz to 30 kHz, despite the extra mass. This would be because while there was a mass change of 2.1 g, the minimal vibrations that would have been required...
to reproduce such low frequencies was not impeded by the slight mass change. When at such low speeds of the vibrations, the force created would be little since \( f = ma \). Therefore, it still takes just about the same amount of force to stop and change the direction of the dome, which results in little change in sensitivity.

The rest however when reaching towards the higher ends of the frequency range, from around 5 kHz to 12 kHz the coating seems to impede and reduce the SPL of the dome when being compared to just the normal Al dome. This is clearly because of the increase in mass, which would require more mass to change the direction and also vibrate more quickly. Lastly, from the range of 12 kHz to 14 kHz and 28 kHz to 30 kHz there is a clear improvement in sensitivity. This may happen because at these high frequencies the dampening characteristics play a larger role in the sensitivity and sound quality. When this happens the coating of the speaker dome actually has dampening characteristics that overcome the adverse effects of the added mass.

![Figure 4. Sound pressure level vs frequency with (a) the horn attached and (b) without the horn attached](image)

The results of the second part of the first SPL experiment without the horn is displayed in the Figure 4(b). The beryllium dome was not tested, instead the thinly coated speaker dome was added to the test. The graph demonstrates nearly all of the same data showing not much change to the SPL except for a slight decrease from 5 to 12 kHz and a slight increase from 12 to 14 kHz and 28 kHz to 30 kHz. However, at the range of 12 to 14 kHz was more favourable to the thick coating whereas at the 28 kHz to 30 kHz range a thinner coating was favoured.

During the second test impulse response and cumulative response were also measured as shown in Figures 5-8. In the first test impulse response and cumulative spectral decay (CSD) were measured. The cumulative spectral decay (CSD) essentially shows how the diaphragm vibrations decay after very short impulse excitation. The faster the decay the better since it leads to prevention of delayed resonances and indicates better dampening. A cleaner, faster decay rate would result in a better sound quality. In the graph, a faster decay rate would show less vibrations along the time axis.

When comparing these graphs, it seems that there is very little impact of the coating on the impulse response (Figure 5) or the CSD (Figures 6). However, when checking the early impulse response in Figure 5, the coated dome appears to have higher pulse magnitudes to some degree. This may indicate that the coated dome can have a higher efficiency and provide a louder sound. When looking at the CSD graphs in Figure 6, the graphs do differ in some areas. In the CSD graph the shorter and thinner the results are the better the sound decay is, since it will be quicker. When comparing the two graphs the graph for the coated dome does show a slight improvement in the HF decay, since in the uncoated dome there does appear to be some vibrations remaining whereas in the coated dome there is the resonance ridges are narrower and have less energy overall. This effect could be explained if the coating had given the speaker dome a higher stiffness, since with a higher stiffness the dome would be more resistant to strain and therefore would stop excitations in the dome more quickly. From previous experiments done on the effect of PEO coatings toward the aluminum alloy, it was discovered that there was a direct correlation between coating thickness and stiffness. As seen in, Figure 7, the longer
coatings times would have resulted in thicker coatings which then resulted in a higher ratio of stress to strain. [6]

![Figure 5. Impulse responses of (a) uncoated dome and (b) the coated dome](image)

![Figure 6. Graph of CSD for (a) the uncoated Dome and (b) the coated Dome](image)

Another measurement taken by the Clio measurement system is multitoned distortion. These tests use a wide range of single tones, spaced at third octave intervals. The set of tones is visible in Figure 8 at third octave frequencies starting from 500Hz up to 20 kHz at levels around 110 dB. Total SPL registered by the microphone was 126 dB. The result shows that coated dome has very similar level of distortion as the original uncoated dome. Marginally higher distortion from 400Hz to 1.2 kHz for the coated dome could be due to uneven coating. However slightly lower distortion for the coated dome above 6 kHz is due to slightly better damping. From previous experiments pertaining to PEO coatings on aluminum metal, we know that the coatings provide wear resistance resulting in lower mechanical fatigue and higher reliability under operating conditions involving high temperature and extensive wide band vibrations. Also, the coatings provide corrosion resistance to help the speaker dome last longer in harsher environments. [4,5,6,7]
4. Conclusion
From these experiments at the range of 12 kHz to 14 kHz the PEO coating provides a lot of benefits to the speaker dome that could improve sound quality. From the SPL (sound pressure level) test whether the horn was attached or not the coated speaker domes had demonstrated mostly the same effects. When dealing with low frequencies from 200 Hz to 5k Hz the coatings had shown no adverse effects to the sensitivity of the speaker domes. However, when reaching frequencies between 5 kHz to 12 kHz the sensitivity of the coated domes shows a notable decrease in sensitivity. The last result from SPL test showed that at the high frequency from 12 kHz to 14 kHz the dome actually had improved in sensitivity. It also is important to notice that at this high frequency range the thicker coating of DPH #5 had actually performed better. From the impulse response test, there was very little to no change showing that the PEO coating neither impedes nor improves its response to input signal. From the CSD (cumulative spectral decay) graph the decay is mainly the same till once again we reach frequencies of 12 kHz to 14 kHz due to the stiffness of the coating. Lastly, from the multitoned distortion test there was little to no change. Thus, the PEO coating has very few adverse effects besides the decreased sensitivity at the mid frequency range. On the other hand, however, the PEO coating has many beneficial effects from increased wear resistance, increased sensitivity and increased dampening effects to the speaker dome. Overall, the hybrid alumina/aluminium foil (i.e., with the PEO coating) would be very beneficial when applying this process to low frequencies as well as high frequencies so as to help get better sound quality and also increase lifetime. More work should be done to get higher statistical confidence on the effects of PEO coatings as well as on other potentials the PEO coating could apply to other materials to make hybrid alumina/metallic foils for other industrial applications.

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