Advantages of Combining Ultrasonic Atomization with Electrostatic Fields

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The field of atomization to obtain coatings is well established, as is that of electrostatic support for the spray plume. However, by combining the benefits of ultrasonic atomization with electrostatic support, we can realize to a higher degree the advantages of both and add a new advantage. Very high potential is commonly used on industrial electrostatic coaters for various reasons. The flow rates are very high, the droplets initially have high kinetic energy and those droplets can be many different sizes. However, in ultrasonic atomization, since the droplets that are created are all the same size and with almost no kinetic energy, the amount of potential required to entrain the droplets and attract them to the substrate can be surprisingly low. Initial theories proposed in the 10 KV range[1]. Testing has shown efficacy in controlling the plume as low as 3 KV. With these low voltages, the following has proven true: It is possible to have 100% transfer efficiency in a spray coating. The stability of the spray plume can be maintained significantly better allowing a higher standard of coating uniformity. The droplets repel each other and maintain their size as predicted by the math that governs ultrasonic atomization. The droplets are attracted to the substrate. Suspended particles in the droplets repel each other in the droplets and when they land on the substrate, allowing for a uniform coating of suspensions. And finally, nano-materials have been shown to self-align in the final coating.

This technology is covered under Patent Application EP 3 275 559 A1[1]

The advantages of ultrasonic atomization have been presented on before. In summary, when a film is wetted out onto a surface vibrating at a fixed frequency, capillary waves are created. These capillary waves were first defined by John William Strutt (Baron Rayleigh) in the 1890's.[2] As the amplitude of vibration under the film is increased, the momentum of the waves created can overcome the surface tension of the liquid and each wave produces a droplet. Since the capillary wavelength is defined mathematically, therefore so can the size of each of the droplets. This was first demonstrated and published by Robert Lang in 1963.[3] As a secondary benefit, the droplets basically "fall off" the tip of each wave and in doing so, do not begin their lives with any significant kinetic energy. Lab tests have shown initial droplet velocities of < 1.0 m/sec compared to that of more common atomizers where the droplets are often going 100 times faster. And as a final and profound benefit, since the atomizer is vibrating at a very high frequency (25-250 kHz), the nozzle becomes its own ultrasonic cleaner. To this end, the atomizer basically cannot clog. And when a nozzle cannot clog, this also means it will not change its behavior throughout the coating process. As a final added advantage, when atomizing solid materials in a liquid suspension, if those materials have a tendency to agglomerate in suspension and maybe fall out of suspension, the last exposure to high frequency vibration will generally break up these agglomerations and provide a vehicle for more uniform particle distribution in the coating.

Rayleigh's Equation for Capillary waves: $\lambda_L=((8*\pi*\theta)/(\rho*f^2))^{1/3}$
Where: λ_L= wavelength of the liquid
π = pi
θ = Surface Tension
ρ =Density
F = Frequency of Vibration

Lang's Constant: $D_{N,\,0.5}$=.34*λ_L
Where: $D_{N,\,0.5}$= Median Diameter of droplets

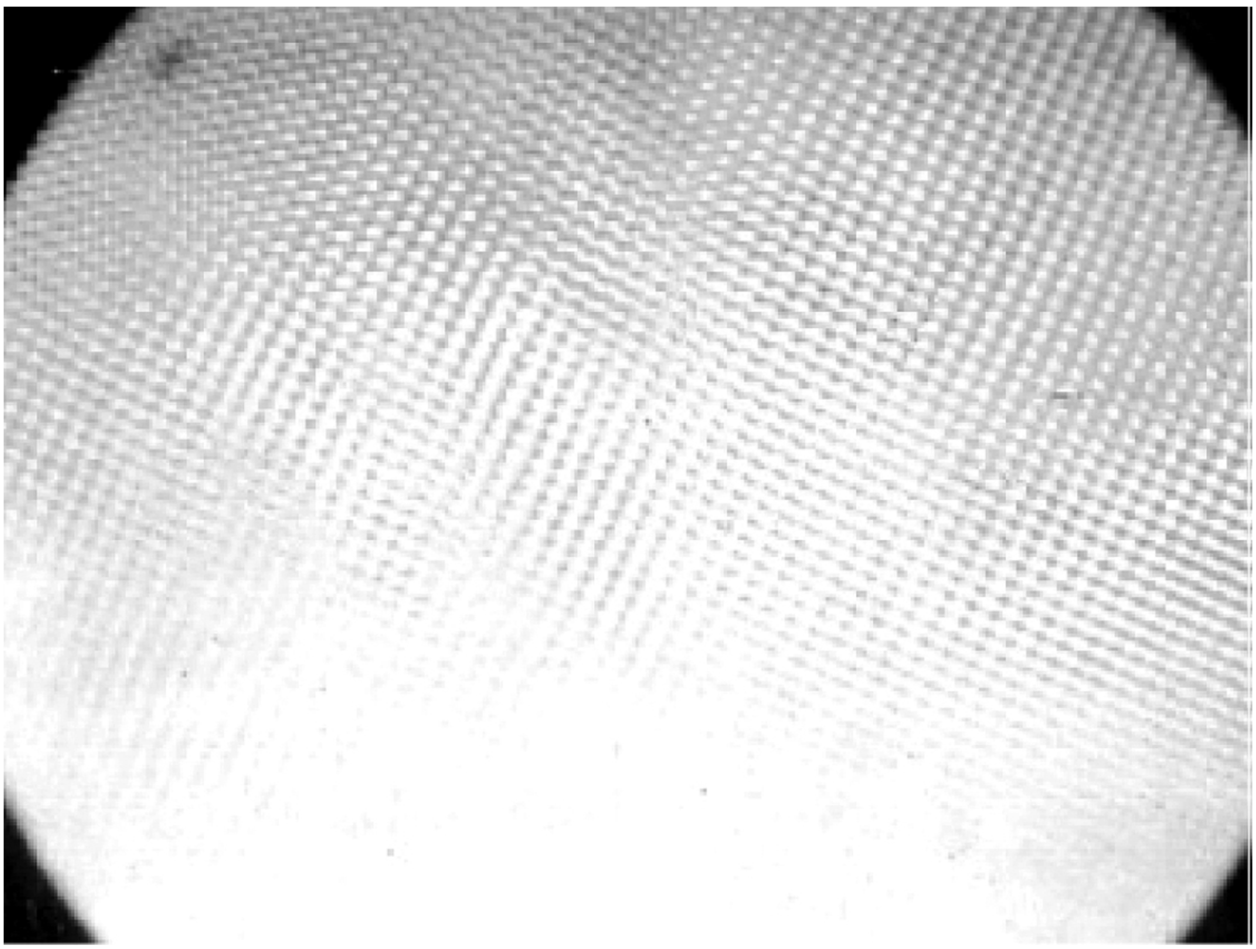

Figure 1 Capillary Waves, image courtesy of Sono-Tek Corp

Electrostatic entrainment of spray plumes has been occurring for many years. This has traditionally be the best way to minimize overspray in the industrial paint arena which saves the manufacturers money in materials and minimizes damage to the environment by limiting the use of VOC's. The objective is to charge the spray droplets to a state opposite of the spray target substrate. It is typically done where the atomizer itself is raised to a high DC potential and where the substrate is grounded. This creates electrostatic field lines between the atomizer and the substrate which then define the shape of the spray plume. Further, this also charges the droplets to a high DC charge state, which in turn causes the droplets to repel each other. Next this droplet charge is now opposite that of the substrate, therefore the droplets are attracted to the substrate.[4] Finally, depending on the coating material and substrate material, the site where an individual droplet lands may remain charged long enough to still repel more droplets from hitting the same site. This encourages uniform coatings to occur. In typical industrial electrostatic coating applications, the potential that the atomizer is raised is typically above 50 KV, as high as 90 KV. Also typical is not to charge the substrate relative to a neutral or grounded atomizer as a charged substrate may attract dirt particles in the spray area and ruin the net finish.

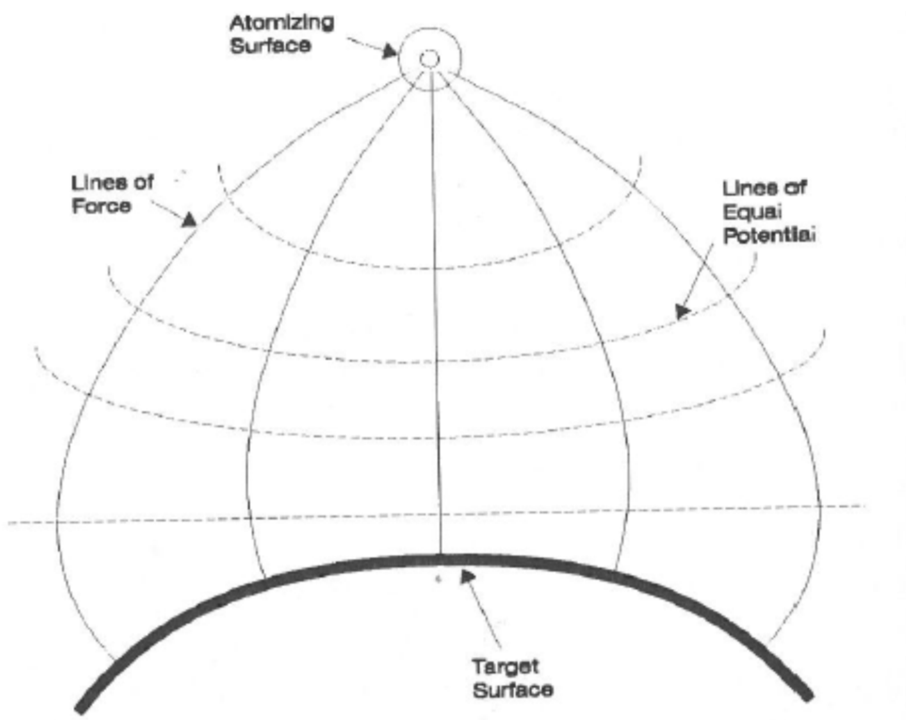

Figure 2 Berger, H., 1998, Ultrasonic Liquid Atomization, p 138

When the two technologies were first combined under lab conditions, the first test to run was to prove if it was feasible to expect 100% transfer efficiency. To prove this, simple salts in aqueous solutions were prepared in controlled concentrations and then sprayed under various conditions with varying power levels between 1 KV and 30 KV. The amount of material atomized was closely controlled by a precise syringe pump in volume control mode. The spray targets were aluminum foil strips that were carefully cleaned, dried, weighed, sprayed, dried and weighed again. The tests showed that all combinations above 3 KV measured a weight gain that exactly matched that required for 100% efficiency to be proven. The same test was repeated with a nonconductive polymer in an aqueous solution with the same net result. This was relative to previous studies where the very highest efficiencies that could be done with ultrasonic atomization alone was 95-98%, but using methods that did not support obtaining coatings in a time efficient manner. This also compares to other more conventional methods of atomization where efficiencies can fall below 40%.

One of the surprising effects of adding the electrostatic spray shaping method was the shape of the plume and its clear definition. Because the electrostatic field lines that are created are based on the size and shape of the electrode and of the size and shape of the grounded atomizer, it is possible to manipulate this shape. Ultrasonic spray typically uses low velocity gas flows to shape the spray. This lends itself to a profound center spray plume and an area of diminishment to zero. Often referred to as "overspray" this sometimes lends itself to blending adjacent plumes or adjacent passes of a plume, similar to painting. The edge definition of a spray plume shaped electrostatically is profound compared to those shaped by gas. The percentage of the whole plume as it changes from full density to zero density has shown to be less than 5% of the plume width.

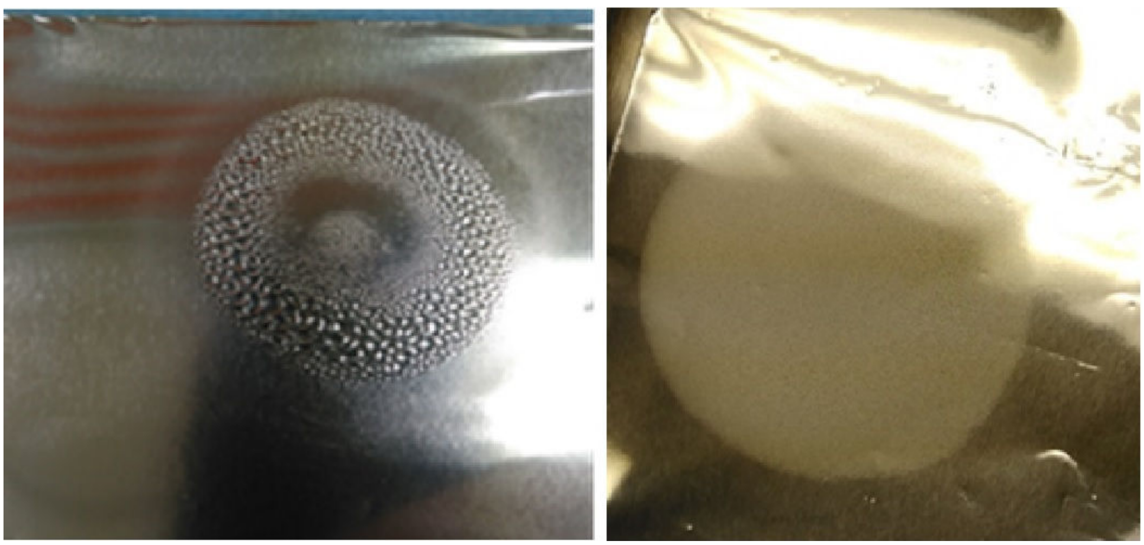

Figure 3 Plume (pattern comparison) (L) no electrostatics (R) with electrostatics (Images courtesy of Sono-Tek Corp)

As previously stated, the size of droplets created via ultrasonic vibration is defined by the math previously shared. However, whether due to the method of gas shaping employed to carry the droplets to the substrate, or simply due to high droplet density in a confined space, there is a natural tendency for the droplets in flight to re-agglomerate, creating larger droplets and taking away some of the advantages of ultrasonic atomization at the final coating. However, with this technology the droplets all become charged to the same state. This prevents re-agglomeration and allows the process to take full advantage of the core technology of ultrasonic atomization.

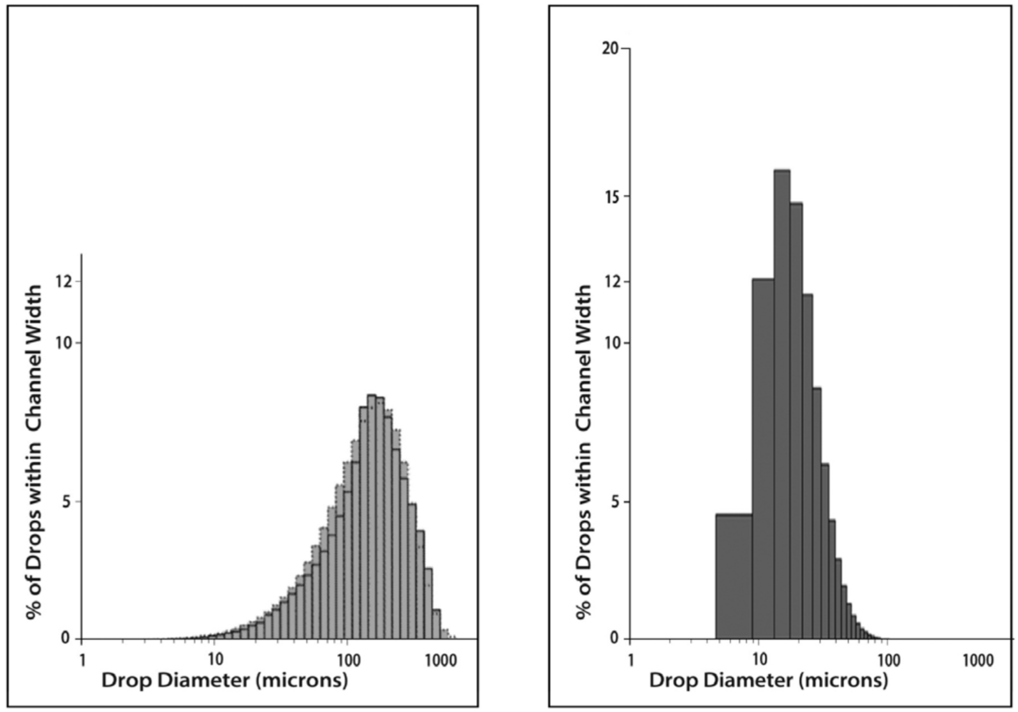

Figure 4 Droplet Distribution of (L) hydraulic nozzle (R) Ultrasonic atomizer (Image courtesy of Sono-Tek Corp)

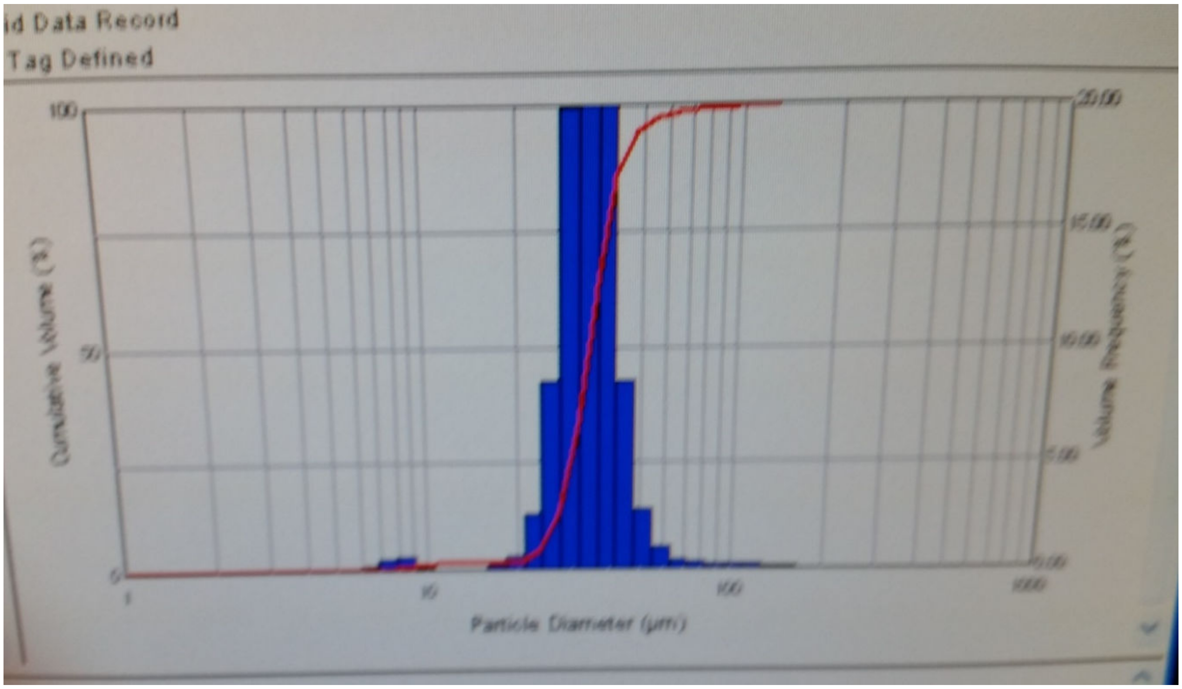

Figure 5 Image of Drop Size Distribution of Ultrasonic Atomizer with Electrostatics Applied (Image courtesy of Sono-Tek Corp)

One of the advanced uses of the combination of technologies is in its application to the spraying of suspended solids. What we observed was that not only do the droplets repel each other in flight to the substrate, but the material in suspension in the droplets also repels itself from the other particles in suspension. Furthermore, our observations were that not only were the solid particles dispersed on the coating in a more uniform manner, but that each droplet also seemed to contain a near equal number of particles in each droplet. This would support the theory that in the liquid film with the capillary waves, the particles are already charged and repelling each other to a uniform dispersion before they flowed into the tips of the capillary waves and became droplets. The photo evidence is below. This should have profound implications on achieving new plateaus in dispersion uniformity.

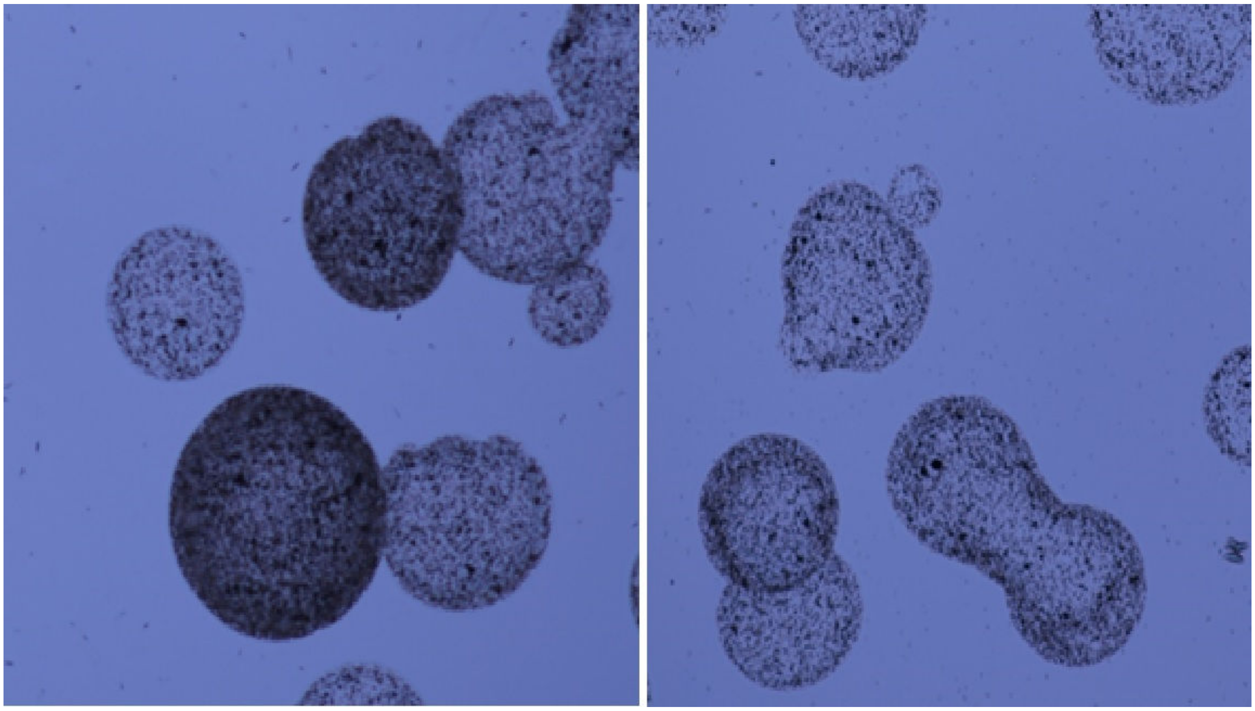

Figure 6 Nano-Carbon is dispersed droplets (L) no electrostatics (R) with electrostatics (Image courtesy of Sono-Tek Corp)

Later in our testing of the combined technologies, we found another key advantage. In applications where it is possible to obtain anisotropic electrostatic fields in subsequent multiple coating layers, we have demonstrated it is possible to create highly organized structures of nanomaterials. Prediction of the manner in which different nano-materials may organize has proven to be difficult and more needs to be understood about this phenomenon.

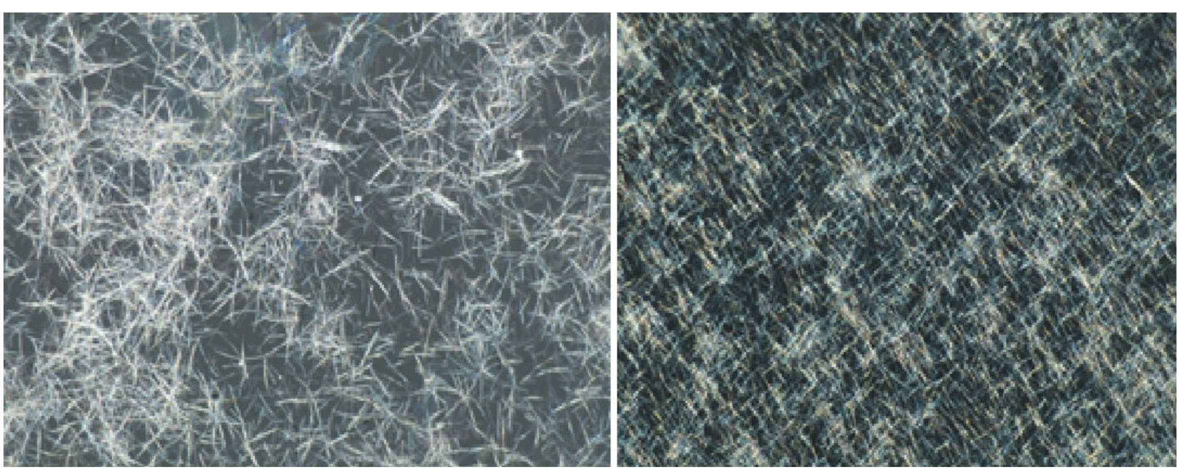

Figure 7 Silver nano-wire organization (L) no electrostatics (R) with electrostatics (Image courtesy of Sono-Tek Corp)

1. https://data.epo.org/publication-server/rest/v1.0/publication-dates/20180131/patents/EP3275559NWA1/document.pdf
2. Rayleigh, 1896, “Theory of Sound” VOL II
3. Lang, 1962, “Journal of the Acoustic Society of America” vol. 34,6
4. *Manufacturing Processes Reference Guide*, 1st ed. , Robert H. Todd, Dell K. Allen, and Leo Alting, 1994