Sep/Dec 2017 • No. 243

ESA Newsletter

Electrostatics Society of America - The Friendly Society

President's Message

This December I had the opportunity to visit two world class academic institutions in India: the Indian Institute of Technology (IIT) Kharagpur, and the Indian Institute of Science (IISc) Bangalore, under the Global Initiative for Academic Networks (GIAN) program sponsored by the Government of India. On a personal note, Christmas in my home town of Bangalore, with beautiful lights and colorful decorations, made this year's holiday warm and cozy with friends and family. I hope you all had a great and enjoyable holiday (Christmas, Hanukkah, Kwanzaa, …). Before I forget, I want to thank you all for making the year 2017 so wonderful for the ESA. Wish you all a very Happy New Year and looking forward to seeing you in Boston.

Under the GIAN program, I was invited to teach a short course for one week on high voltage engineering applications at IIT Kharagpur, along with Prof. N. K. Kishore, a faculty member from the host institute. Thanks to Prof. Kishore for his wonderful efforts in organizing the course, and thanks to IIT Kharagpur and the Government of India for their support. I was also invited by Prof. J. Thomas to give a talk at IISc Bangalore on the "Impact of renewable energy sources on windfarm connected transformers".

During my visit, I also had the opportunity to visit many research centers and labs at both IIT and IISc campuses; here I could interact with scientists and engineers, and visualize the depth of electrostatic principles in their applied researches. Below is a brief summary that I would love to share with all of you.

The Central Research Facility at IIT Kharagpur has Materials Science and Life Science divisions. The research focus is on various types of characterization including the study of structure and chemical composition of surfaces and bulk materials at different length scales (sub-nanometer to millimeter), phase transitions, as well as evaluation of mechanical, electrical, magnetic, and optical properties. The available facilities include state-of-the art field emission scanning and transmission electron microscopes, dual beam microscopes, X-ray diffractometers, Nano-triboindenter, and Raman Spectrometer. Another unique center that I visited was the Rubber Technology Department housing advanced rubber processing and testing equipment. Some of the projects undertaken include development of conductive nanocomposites for sensor and EMI shielding applications, polymer nanocomposites for food packaging, and conductive smart textiles for space application. We were also lucky to see a demo of electrospinning used in bio-materials and tissue engineering. Their research emphasizes the fundamental understanding of cell–material interactions. In regards to regenerative medicine, the group is developing biodegradable/bioactive materials with nano-micro architecture for skin and bone tissue engineering.

At IISc Bangalore, I had very little time, really only two hours, in which I could visit Prof. S. Bose, and Prof. Praveen Ramamurthy's labs in the Materials Engineering Department. Prof. Praveen's group focuses on interdisciplinary research of organic/polymer based devices, ranging from the synthesis of high performance conducting polymers, nanocomposites and nanostructured materials and the study of their fundamental properties for application in organic electronics, sensors and actuators. Prof. Bose's group is interested in developing multiphase polymer microstructures using melt flow processes and directed self-assembly of nanoparticles using phase separation in polymer blends as a template. One common technique used in almost all the above research is electrospinning in material synthesis. Does this imply we need to extend our society's interaction with material science research groups? Although we have had many (cont'd. p. 2)

President's Message (cont'd.)

researchers from such groups in the recent years as keynote or invited speakers, it would be nice to continue this culture for the benefit of ESA members.

Talking about our meetings, it is time to visit the ESA web site http://www.electrostatics.org/annualmeeting.html to know more about the organizational details of our 2018 Electrostatics Joint Conference, in Boston. Abstract submission is now open. Both Prof. Mark Horenstein and Prof. Shubho Banerjee have been working very hard to make the conference a great success. Your support in this endeavour is highly critical and appreciated. Please lend your continued support to ESA by your participation as a presenter, exhibitor, or simply as an observer, maybe even as a mentor.

For the Friendly Society
Shesha Jayaram, *shesha.jayaram@uwaterloo.ca*
President, Electrostatics Society of America

Current Events

Acoustic levitation widens the study of droplet jetting

Thunderclouds, combustion chambers, and inkjet nozzles are among the many settings where droplets break up in an electric field. More than half a century ago G. I. Taylor identified the mechanism behind the fission. Above some field strength known as the Taylor limit, the coulombic repulsion of charges on a droplet's surface overcomes the attractive intermolecular forces that hold it together. As a result, the droplet ruptures and spews a fine jet of tiny daughter droplets.

Despite the natural and technological relevance of the phenomenon, some details remain murky. Macroscopic properties such as solute concentration, pH, and charge density are not uniform along a parent droplet's radius, and its surface and bulk compositions can differ dramatically. No one precisely understands the fluid dynamics that determine what molecular and ionic solutes the daughter droplets inherit from their parent. The dynamics of the rupture are complex, and the mathematical singularity of the electric field at the sharp point that forms at the moment of breakup complicates numerical simulations.

Most research on droplet jetting is conducted with a 15-year-old technique known as field-induced droplet ionization, in which a series of parent droplets are dripped in air between the parallel plates of a charged

(cont'd. p. 4)

ESA Officers

President:
Shesha Jayaram, Univ. of Waterloo
Vice President and Awards Chair:
Maciej Noras, Univ. of North Carolina
Executive Council:
David Go, Univ. of Notre Dame
Poupak Mehrani, Univ. of Ottawa
Rajeswari Sundararajan, Purdue Univ.

Calendar

- 36th Electrical Insulation Conference June 17-20, 2018, Hyatt Regency, San Antonio, TX, *http://electricalinsulationconference.com.,* Contacts: Diego Robalino, *diego_robalino@ieee.org* and David McKinnon, *davmckin@gmail.com, (Abstract deadline: Oct. 15)*
- 2018 Electrostatics Joint Conference, June 18-20, 2018, Boston University, Boston, MA, *http://www.electrostatics.org/annualmeeting.html* Contact: Mark Horenstein *mnh@bu.edu*

Electrostatic Demo Session

At the upcoming ESA Meeting scheduled for June 2018 in Boston, MA, we are planning to hold a special session devoted to electrostatics demonstrations. The goal is to provide demonstrations on a variety of topics including electrostatic fundamentals, educational experiments, safety topics, and research projects. Our session will build upon the demonstration sessions held during our 2012, 2014 and 2016 ESA Annual Meetings.

We are currently looking for volunteers to present demonstrations. If you have a favorite demonstration to share or have an idea for a new one, this event is for you. Please let me know if you need to borrow equipment for your demonstration (fieldmeter, electrostatic voltmeter, Van de Graaff generator, electrophorus, power supply, … whatever you need) and I will do my best to support your demo.

If you have any questions about our session, please contact Kelly Robinson, who is coordinating the demonstration session.

Kelly Robinson, PE, PhD
Owner, Electrostatic Answers
kelly.robinson@electrostaticanswers.com

2018 Electrostatics Joint Conference

Boston University
Boston, Massachusetts, USA
June 18 - 20, 2018

The Electrostatic Society of America (ESA), Institute of Electrostatics Japan (IESJ), Industry Applications Society (IEEE-IAS) Electrostatic Processes Committee, and La Societé Francaise d'Electrostatique (SFE) invite papers in all scientific and technical areas involving electrostatics. The scope of the conference ranges from the fundamental physics underlying electrostatics to applications in industry, atmospheric and space sciences, medicine, energy, and other fields. The meeting will bring together experts across the diverse field to present the latest developments in electrostatics.

Anticipated Technical Session Topics

- Atmospheric and space applications
- Biological and medical applications
- Breakdown phenomena
- Contact charging and triboelectric effects
- Electrically-induced flows and electrokinetics
- Flows, forces and fields
- Gas discharges and microplasmas
- Electrospinning
- Material processing
- Measurements and instrumentation
- Particle control and charging
- Safety and hazards


Photonics Center Boston University

Conference information, including abstract submission, registration, student travel grants and lodging, will be updated and available at http://www.electrostatics.org.

Student paper competition: Presentations by students (undergraduate and graduate) are eligible; please indicate participation when submitting abstract.

Important dates:

March 1, 2018 Abstract submission deadline (submit on-line at http://www.electrostatics.org)
March 17, 2018 Notification of paper acceptance
May 16, 2018 Final manuscripts due
June 17, 2018 Reception (6-9PM)
June 18, 2018 Conference begins (8AM)
June 20, 2018 Conference ends after evening banquet (7 PM – 10 PM)

Contact information:

For questions regarding the technical program and abstract submission, contact
Technical Chair: Dr. Shubho Banerjee, Rhodes College, Memphis, banerjees@rhodes.edu , (901) 843-3585
For questions about local arrangements and conference hosting, contact
General Chair: Dr. Mark Horenstein, Boston University, mnh@bu.edu, (617) 353-9052

About Boston University: Boston University is a private research university located in Boston, Massachusetts. The university has over 33,000 undergraduate and graduate students from more than 130 countries, nearly 10,000 faculty and staff, 17 schools and colleges, and 250 fields of study. The conference venue is the Photonics Center which houses the Dept. of Electrical and Computer Engineering

ESA Award Nominations

Dear Friends,

The ESA is accepting nominations for the following awards:

The **ESA Distinguished Service Award** recognizes outstanding service to the ESA over an extended period of time, with a demonstrated long-term commitment to the growth and continued well-being of the Society (requirement: 10 years as ESA member).

The **ESA Lifetime Achievement Award** recognizes outstanding contributions to the field of Electrostatics, as shown by the pervasiveness of the contributions in understanding certain problems or important practical benefits resulting from the work (requirement: 10 years working in field of Electrostatics).

The **ESA Honorary Life Member Award** recognizes exceptional contributions to both the ESA and to the field of Electrostatics, sustained over much of a career (requirements: 10 years as ESA member, 20 years working in field of Electrostatics).

The **ESA Rising Star Award** recognizes significant contributions at an early stage of a career to the field of Electrostatics, Requirements: age of 40 or younger, but cannot be a student).

The **ESA Entrepreneur Award** recognizes companies and/or individuals that implement electrostatics-related technologies and are recognized as having a meaningful impact in the industry and/or academia.

The **Teacher of the Year Award** recognizes outstanding teachers who use Electrostatics to stimulate learning, inspire students, or otherwise encourage and energize the learning process in a formal educational setting in grades K-12 (requirement: 3 years teaching Electrostatics).

The **Student of the Year Award** recognizes middle or high school students who demonstrate outstanding achievement in Electrostatics, as showcased in laboratory projects, papers or presentations.

The ESA is also accepting nominations for induction to the Electrostatic Hall of Fame. This honor recognizes and records for posterity those individuals who have made extraordinary contributions to the field of Electrostatics. Nominees do not need to be still living. The Hall of Fame has three categories: (1) advancement of the fundamental knowledge of Electrostatics; (2) promotion of interest in the field of Electrostatics; (3) innovations using Electrostatics technology in industry.

The list of the award recipients is available at *http://electrostatics.org/esaawardwinners.html*

Nominations should be submitted electronically to the ESA Award Chair, Prof. Maciej Noras at *mnoras@uncc.edu*, by **March 1, 2018**. The nomination should be in the form of a letter from an ESA member that includes a description of how the accomplishments of the nominee satisfy the award requirements (including citations of publications or patents when relevant), the contact information of the nominator and nominee, and the names and contact information of 3 other ESA members who endorse the nomination. For the Teacher and Student awards, endorsements from two faculty members of the nominee's institution should substitute for the ESA member endorsements.

Thank you in advance for all the submissions,

Sincerely,

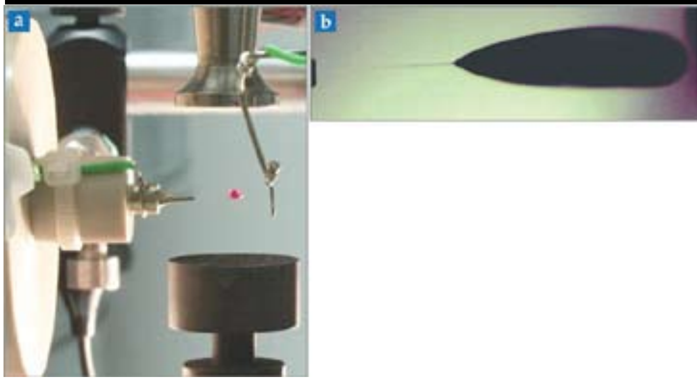
Maciej Noras

Current Events (cont'd.)

capacitor. As they fall, the droplets become polarized in the capacitor's electric field, take on a lemon-like shape, and, depending on the droplets' net charge, squirt jets from one or both pointed ends toward the electrodes. But although the field strength and the net charge can be freely adjusted, experimenters can probe the droplets' dynamics only within the few milliseconds they remain in free fall.

Carsten Warschat and Jens Riedel from Germany's Federal Institute for Materials Research and Testing (BAM) have developed an acoustic technique that can probe those dynamics on the same droplet for as long as it lives—levitated in electrified midair.1 As illustrated in the figure, their setup consists of a home-built levitator whose 40 kHz ultrasonic field produces a vertical standing pressure wave between two horizontal electrodes. A droplet placed at a pressure antinode can remain there for seconds to hours, limited only by its evaporation rate. What's more, the setup allows easy access to a nearby mass spectrometer that can capture the daughter droplets and analyze their composition.

Other researchers have studied jets from electrodynamically held droplets, but in that approach the electric field has to both rupture the droplet and hold it up, so neither role could be controlled independently. Optical levitation is another option, but the energy to hold the droplet aloft risks overheating it. Acoustic levitation doesn't suffer either problem. More- (cont'd. p. 5)



Acoustic levitation. (a) A 5 μL droplet of methanol (red) sits in the antinode of an ultrasonic standing wave produced by a vibrating plate, or sonotrobe, above it and a reflector below it. A pointed electrode, or skimmer, to the left and a ring electrode, seen edge-on to the right, are held at a 9 kV potential. (b) As the droplet ruptures in the strong electric field, it emits a jet of charged daughter droplets into the skimmer, which doubles as the inlet to a mass spectrometer.

over, whereas free-falling, electrodynamic, and optical methods are restricted to droplets with diameters on the scale of tens of microns, an acoustic wave can levitate droplets two orders of magnitude larger—up to 5 mm using a 40 kHz field. (See also Physics Today, March 2015, page 17.)

That freedom may come in handy in efforts to chemically synthesize relatively large amounts of material using a single droplet as a microreactor or to produce daughter droplets at low electric-field strengths. The Taylor limit depends inversely on the square root of the droplet radius r. That dependence offers experimental flexibility in cases where the dielectric breakdown of air occurs at field strengths close to the Taylor limit. With their lower surface-to-volume ratio and slower evaporation, larger droplets also live longer.

In their demonstration, the BAM chemists used high-speed photography and mass spectrometry to image the rupture and chemically analyze the progeny of a methanol droplet roughly 2 mm in diameter. They found that the $r{-}1/2$ dependence on the critical threshold field at which fission occurs is still valid at the millimeter scale, says Riedel. More importantly, the demonstration sets the stage for studies on the effects of a droplet's size, charge, and pH on the jet it emits. In preparation, Riedel and Warschat are currently building a controlled humidity chamber. Inside, a droplet's size will be an easily tunable knob and its lifetime effectively infinite.

(from *http://physicstoday.scitation.org/doi/10.1063/PT.3.3754*)

Study Shows Electric Bandages Can Fight Biofilm Infection, Antimicrobial Resistance

Researchers at The Ohio State University Wexner Medical Center have shown – for the first time – that special bandages using weak electric fields to disrupt bacterial biofilm infection can prevent infections, combat antibiotic resistance and enable healing in infected burn wounds. The dressing becomes electrically active upon contact with bodily fluids. Results of the regenerative medicine study published in the journal Annals of Surgery.

"Drug resistance in bacteria is a major threat, and antibiotic-resistant biofilm infections are estimated to account for at least 75 percent of bacterial infections in the United States," said Chandan Sen, director of Ohio State's Center for Regenerative Medicine & Cell Based Therapies, who led the study with colleagues at the Medical Center's Comprehensive Wound Center and Center for Microbial Interface Technology. "This is the first pre-clinical long-term porcine study to recognize the potential of 'electroceuticals' as an effective platform technology to combat wound biofilm infection."

Bacterial biofilms represent a major wound complication. Resistance of biofilm towards drug interventions calls for alternative strategies. Bacteria rely on electrostatic interactions to adhere to surfaces, an important aspect of biofilm formation. The concept that weak electric fields may have anti-biofilm property was first reported in 1992.

This study builds on Sen's 2014 research with a wireless electroceutical dressing (WED) using silver and zinc printed on fabric. When moistened, WED generates a weak electric field without any external power supply and can be used like any other disposable dressing.

"The fact that wireless electric dressing is FDA-cleared and already in clinical use heightens the need to understand underlying mechanisms to enable optimal use," Sen said. "Since it relies on electrical principles, it's not subject to the mechanisms that may promote drug resistance. Understanding how this novel dressing may influence microbial, host and host-microbe interactions will determine the optimal use of this simple technology platform."

During the study, WED dressing was applied within two hours of wound infection in pigs to test its ability to prevent biofilm formation. In addition, WED was applied after seven days of infection to study disruption of established biofilm. Wounds were treated with placebo dressing or WED twice a week for 56 days. Both proved successful, Sen said.

During burn injury, barrier function of the skin is breached, leaving the body vulnerable. Patients with burn injuries risk dehydration, along with the potential of foreign agents such as bacteria and allergen entering into the body and causing potential health complications.

Our study shows that WED may be viewed as a first generation electroceutical wound care dressing, and it also accelerated functional wound closure by restoring skin barrier function," Sen said. "Both from bacterial biofilm structure as well as host response perspectives, WED was consistently effective. No batteries or wires are needed because we harness the power of electrochemistry."

Ohio State researchers are teaming up with burn care team within the Department of Defense to start a clinical trial within the next month to test this technology on burn wounds in humans, Sen said.

(excerpted from *https://wexnermedical.osu.edu/mediaroom/pressreleaselisting/study-shows-electric-bandages-can-fight-biofilm-infection-antimicrobial-resistance)*

Electrostatic force takes charge in bioinspired polymers

Lois Yoksoulian

Researchers at the University of Illinois and the University of Massachusetts, Amherst have taken the first steps toward gaining control over the self-assembly of synthetic materials in the same way that biology forms natural polymers. This advance could prove useful in designing new bioinspired, smart materials for applications ranging from drug delivery to sensing to remediation of environmental contaminants.

Proteins, which are natural polymers, use amino acid building blocks to link together long molecular chains. The specific location of these building blocks, called monomers, within these chains creates sequences that dictate a polymer's structure and function. In the journal Nature Communications, the researchers describe how to utilize the concept of monomer sequencing to control polymer structure and function by taking advantage of a property present in both natural and synthetic polymers – electrostatic charge.

"Proteins encode information through a precise sequence of monomers. However, this precise control over sequence is much harder to control in synthetic polymers, so there has been a limit to the quality and amount of information that can be stored," said Charles Sing, a professor of chemical and biomolecular engineering at Illinois and a study co-author. "Instead, we can control the charge placement along the synthetic polymer chains to drive self-assembly processes."

"Our study focuses on a class of polymers, called coacervates, that separate like oil and water and form a gel-like substance," said Sarah Perry, a study co-author and University of Massachusetts, Amherst chemical engineering professor, as well as an Illinois alumna.

Through a series of experiments and computer simulations, the researchers found that the properties of the resulting charged gels can be tuned by changing the sequence of charges along the polymer chain.

"Manufacturers commonly use coacervates in cosmetics and food products to encapsulate flavors and additives, and as a way of controlling the 'feel' of the product," Sing said. "The challenge has been if they need to change the texture or the thickness, they would have to change the material being used."

Sing and Perry demonstrate that they can rearrange the structure of the polymer chains by tuning their charge to engineer the desired properties. "This is how biology makes the endless diversity of life with only a small number of molecular building blocks," Perry said. "We envision bringing this bioinspiration concept full circle by using coacervates in biomedical and environmental applications.

The results of this research open a tremendous number of opportunities to expand the diversity of polymers used and the scale of applications, the researchers said. "Currently, we are working with materials on the macro scale – things that we can see and touch," Sing said. "We hope to expand this concept into the realm of nanotechnology, as well.".

(excerpted from *https://news.illinois.edu/view/6367/573960*)

Ship exhaust makes oceanic thunderstorms more intense

Thunderstorms directly above two of the world's busiest shipping lanes are significantly more powerful than storms in areas of the ocean where ships don't travel, according to new research. A new study mapping lightning around the globe finds lightning strokes occur nearly twice as often directly above heavily-trafficked shipping lanes in the Indian Ocean and the South China Sea than they do in areas of the ocean adjacent to shipping lanes that have similar climates.

The difference in lightning activity can't be explained by changes in the weather, according to the study's authors, who conclude that aerosol particles emitted

Current Events (cont'd.)

Lightning behind an aircraft carrier in the Strait of Malacca. New research finds lightning strokes occurred nearly twice as often directly above heavily-trafficked shipping lanes in the Indian Ocean and the South China Sea year-round from 2005 through 2016. Credit: public domain.

in ship exhaust are changing how storm clouds form over the ocean. The new study is the first to show ship exhaust can alter thunderstorm intensity. The researchers conclude that particles from ship exhaust make cloud droplets smaller, lifting them higher in the atmosphere. This creates more ice particles and leads to more lightning.

The results provide some of the first evidence that humans are changing cloud formation on a nearly continual basis, rather than after a specific incident like a wildfire, according to the authors. Cloud formation can affect rainfall patterns and alter climate by changing how much sunlight clouds reflect to space.

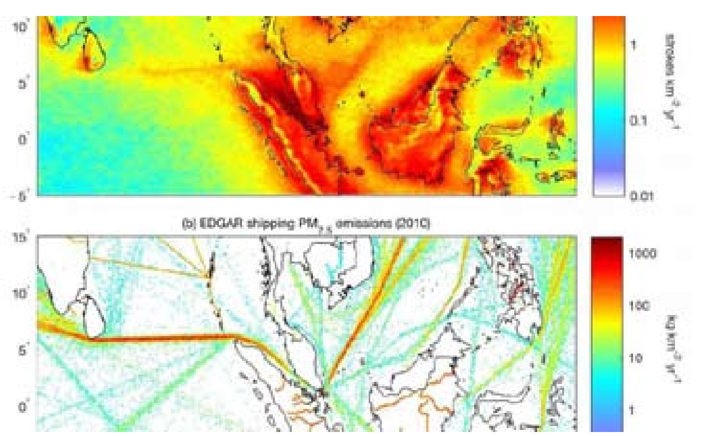
"It's one of the clearest examples of how humans are actually changing the intensity of storm processes on Earth through the emission of particulates from combustion," said Joel Thornton, an atmospheric scientist at the University of Washington in Seattle and lead author of the new study in Geophysical Research Letters, a journal of the American Geophysical Union. "It is the first time we have, literally, a smoking gun, showing over pristine ocean areas that the lightning amount is more than doubling," said Daniel Rosenfeld, an atmospheric scientist at the Hebrew University of Jerusalem who was not connected to the study. "The study shows, highly unambiguously, the relationship between anthropogenic emissions - in this case, from diesel engines - on deep convective clouds."

All combustion engines emit exhaust, which contains microscopic particles of soot and compounds of nitrogen and sulfur. These particles, known as aerosols, form the smog and haze typical of large cities. They also act as cloud condensation nuclei - the seeds on which clouds form. Water vapor condenses around aerosols in the atmosphere, creating droplets that make up clouds. Cargo ships crossing oceans emit exhaust continuously and scientists can use ship exhaust to better understand how aerosols affect cloud formation.

In the new study, co-author Katrina Virts, an atmospheric scientist at NASA Marshall Space Flight Center in Huntsville, Alabama, was analyzing data from the World Wide Lightning Location Network, a network of sensors that locates lightning strokes all over the globe, when she noticed a nearly straight line of lightning strokes across the Indian Ocean.

Virts and her colleagues compared the lightning location data to maps of ships' exhaust plumes from a global database of ship emissions. Looking at the locations of 1.5 billion lightning strokes from 2005 to 2016, the team found nearly twice as many lightning strokes on average over major routes ships take across the northern Indian Ocean, through the Strait of Malacca and into the South China Sea, compared to adjacent areas of the ocean that have similar climates.

More than $5 trillion of world trade passes through



The top map shows annual average lightning density at a resolution of about 10 kilometers (6 miles), as recorded by the WWLLN, from 2005 to 2016. The bottom map shows aerosol emissions from ships crossing routes in the Indian Ocean and South China sea from 2010. Credit: Thornton et al/Geophysical Research Letters/AGU.

the South China Sea every year and nearly 100,000 ships pass through the Strait of Malacca alone. Lightning is a measure of storm intensity, and the researchers detected the uptick in lightning at least as far back as 2005. "All we had to do was make a map of where the lightning was enhanced and a map of where the ships are travelling and it was pretty obvious just from the co-location of both of those that the ships were somehow involved in enhancing lightning," Thornton said.

Water molecules need aerosols to condense into clouds. Where the atmosphere has few aerosol particles - over the ocean, for instance - water molecules have fewer particles to condense around, so cloud droplets are large.

When more aerosols are added to the air, like from ship exhaust, water molecules have more particles to collect around. More cloud droplets form, but they are smaller. Being lighter, these smaller droplets travel higher into the atmosphere and more of them reach the freezing line, creating more ice, which creates more lightning. Storm clouds become electrified when ice particles collide with each other and with unfrozen droplets in the cloud. Lightning is the atmosphere's way of neutralizing that built-up electric charge. Ships burn dirtier fuels in the open ocean away from port, spewing more aerosols and creating even more lightning, Thornton said.

"I think it's a really exciting study because it's the most solid evidence I've seen that aerosol emissions can affect deep convective clouds and intensify them and increase their electrification," said Steven Sherwood, an atmospheric scientist at the University of New South Wales in Sydney who was not connected to the study.

"We're emitting a lot of stuff into the atmosphere, including a lot of air pollution, particulate matter, and we don't know what it's doing to clouds," Sherwood said. "That's been a huge uncertainty for a long time. This study doesn't resolve that, but it gives us a foot in the door to be able to test our understanding in a way that will move us a step closer to resolving some of those bigger questions about what some of the general impacts are of our emissions on clouds."

(excerpted from *https://phys.org/news/2017-09-ship-exhaust-oceanic-thunderstorms-intense.html*)

Music to Your Ears: New Transducers Meet Electrostatic Headphones

Jennifer Hand

Serious hi-fi enthusiasts get excited about the musical experience delivered by electrostatic headphones. Producing a natural, airy sound, they provide greater clarity, less distortion, and extended bandwidth when compared to other types of headphones where high resolution audio sources are involved. Most electrostatic speakers apply an electric charge on a thin elastic membrane situated between two conductive plates. The charged membrane moves in direct response to the electrical input, generating the sound waves that our ears and brain interpret as music, and moving us to joy and tears.

Despite their high quality and accurate audio reproduction, electrostatic speakers can be prohibitively expensive, sometimes fragile, and until recently, were handmade because of mechanical precision requirements. Seeing a need for affordable, high-quality headphones that could be manufactured more easily, Warwick Audio Technologies Limited (WAT) designed the High-Precision Electrostatic Laminate (HPEL) transducer, a patented technology based on an ultra-thin diaphragm and a single conductive plate instead of a pair. With its origins at Warwick University in the UK, WAT has developed a lightweight laminate membrane only 0.7 mm thick that is perfectly suited for electrostatic headphones.

The new HPELs are lightweight thin-film structures manufactured through a continuous roll process. "The technology we've developed is unique," explains Martin Roberts, CEO of WAT. "The HPEL transducer is made up of a metallized polypropylene film, a polymer spacer with hexagonal cells, and a conductive mesh" (Figure 1).

In the typical setup, direct current (DC) bias voltage is applied to the elastic membrane and alternating current (AC) drive signal to the surrounding plates. WAT's one-sided speaker involves both the DC bias and the AC drive signal applied to the elastic membrane, with a

Figure 1. Left to right: WAT's HPEL transducers; single laminate, assembled, and exploded views of a finished HPEL transducer. All laminates are made in the UK.

single wire mesh (plate) positioned opposite the membrane as a ground plane.

The fabrication method makes it possible to reproduce the transducers at a significantly lower cost than traditional electrostatic speakers. This means that for the first time, electrostatics may be considered a commercially viable high-res audio option across a wide range of device types and market segments.

The dynamics of the HPEL are dependent on the extremely complex interplay between membrane tension, AC signal level, speaker geometry, elastic and dielectric material properties, thermoacoustic losses, and the added mass effects of the air next to the open side of the membrane. The designers wanted to improve bass performance by reducing low-end roll-off, minimizing distortion, and maximizing the sound pressure level for a given electrical input. But they discovered that small changes to any component greatly affected the acoustic output.

In order to perform a virtual optimization of the HPEL transducer design they enlisted the help of Xi Engineering, a COMSOL Certified Consultant that specializes in computational modeling, design recommendations, and solving noise and vibration problems in machinery and other technology.

Because the transducer is one-sided, the electrostatic force varies with the position of the vibrating membrane, decreasing with the square of the distance between the membrane and the mesh. Once they understood the resulting nonlinear distortion and were able to predict its effects, the WAT engineers could then cancel any related distortions electrically.

In a more extensive simulation that involved a structural-MEMS-acoustic coupling, he examined the impact of adjusting parameters like the size of the hexagonal cells in the wire mesh, thickness of the wires, membrane tension, spacing between membrane and mesh, and material properties of each component. Marmo and his colleagues also studied the effects of different DC biases, which are often responsible for distortion at low frequencies, and looked at conductivity along the plate to discern whether voltages were higher in one area than another. They then used COMSOL to study the thermoacoustic losses and model the displacement of the membrane for different frequencies (Figure 2).

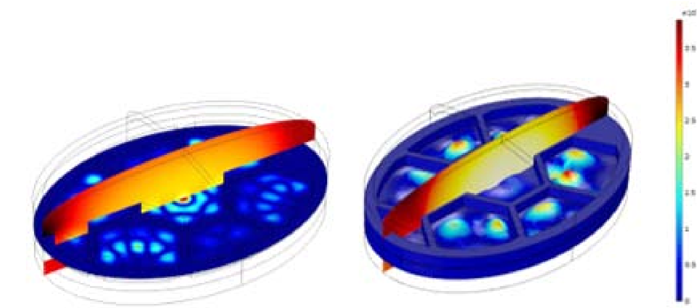


Figure 2. Simulation plot showing the sound pressure level (thermal color surface) in dB and the displacement of the membrane (rainbow color surface) in mm from a fully coupled acoustics-MEMS model solved in the frequency domain. Left: solution at 5,000 Hz. Right: solution at 5,250 Hz.

The simulations made it possible for the engineers at WAT to tweak design parameters in order to optimize overall performance. Ultimately, they were able to predict what was causing spikes in the frequency response and smooth out the signal for better fidelity. "This represented a huge cost and time benefit for us," says Roberts. "We went from making multiple prototypes by hand each week to simply dialing up a new one in the software. In addition to settling on a final design we're very happy with, it is now easy for us to customize our transducers for clients' individual requirements."

With simulation results verified and WAT satisfied with their design, the next step was for Xi Engineering to put WAT in control of further modeling. The Application Builder available in COMSOL software enabled Marmo's team to build an app from their simulation and host it online. The app's interface allows users to change certain inputs to test changes to a number of parameters, such as the DC bias, AC signal level, frequency range and resolution, material properties, speaker size, wire mesh shape and size, and spacer placement (Figure 3). The original model setup is not accessible from the app; instead, it allows users to run further tests without needing to learn the software.

"Providing WAT with a simulation app removed the need for them to purchase the software or appoint an experienced user," Marmo says. "Simulation apps put our customers in charge, so they don't have to come back to us for small changes and they can test exactly what they want. It also frees us to explore new challenges, rather than working on variations of the same problem." Xi Engineering expects to use computational apps more and more in the course of its work for other customers.

(excerpted from *https://spectrum.ieee.org/computing/software/music-to-your-ears-new-transducers-meet-electrostatic-headphones*)

Electrostatics
Society of America

30 Shalimar Drive
Rochester, NY 14618

ESA Information

ESA Home Page: *http://www.electrostatics.org*

Shesha Jayaram
ESA President
Dep't. of Elect. & Comp. Eng.
Univ. of Waterloo
Waterloo, Ontario
CANADA N2L 3G1
(519)888-4567, x35337
shesha.jayaram@uwaterloo.ca

Steve Cooper
Secretary/Treasurer
540 Morton Rd.
Athens, GA 30605
(706)255-5518
sandscooper1@gmail.com

Mark Zaretsky
Newsletter Editor
30 Shalimar Drive
Rochester, NY 14618
(585)588-6351
mark.zaretsky@kodak.com

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