



Mechanical Engineering

Momentum

Spring 2019

Piezoelectric renaissance
3D printing adds dimensional capabilities



COLLEGE OF ENGINEERING
MECHANICAL ENGINEERING
VIRGINIA TECH.

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INSIDE



An ME senior design team is working with '07 alum (CLAHS) Rob Jones who lost both his legs to an IED in Afghanistan. Listen to the story of how Hokies old and new are coming together to make a difference.

Professor Azim Eskandarian - Nicholas and Rebecca Des Champs Professor, ME Department Head
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ABOUT THE COVER

A scanning electron microscope image of the internal 3D architecture of the piezoelectric material reported on Cui et al., *Nature Materials* volume 18, pages 234 (2019)

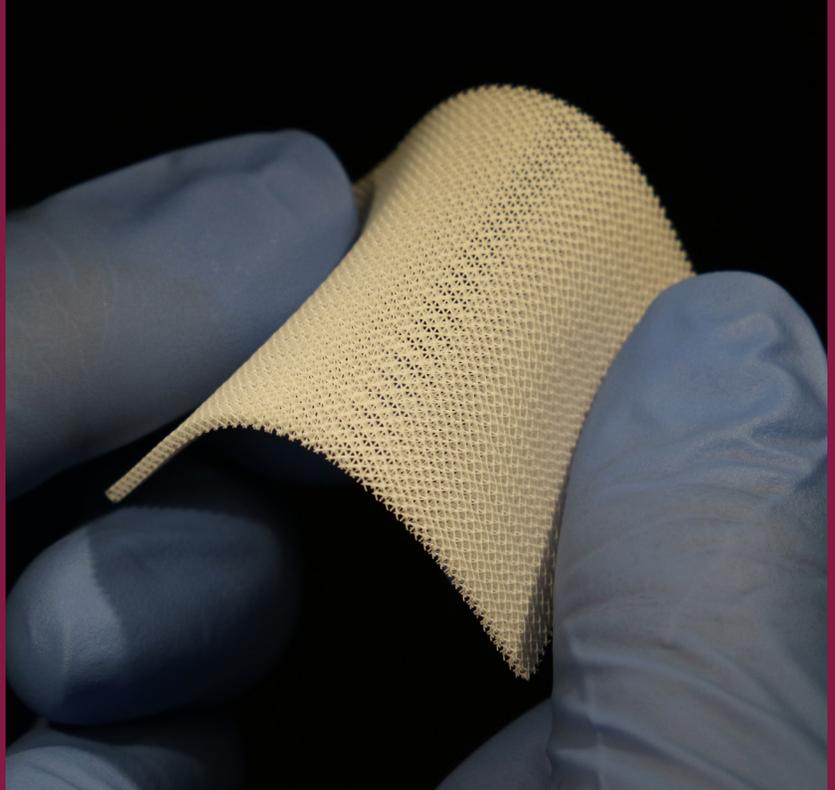
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**AZIMESKANDARIAN**

NICHOLAS AND REBECCA DES CHAMPS PROFESSOR
DEPARTMENT HEAD, MECHANICAL ENGINEERING

Welcome back to the most exciting part of the year! The point between the holidays and graduation is filled with excitement as our students prepare their senior design projects, their competition vehicles, and for the seniors, their resumes as they prepare to join the world as mechanical engineers and leaders in their field. These few months are often a tense, stay-up-late, around-the-clock work to the end of the semester.

Also exciting is watching our students and faculty win awards, get their research published, and work in the spirit of Ut Prosim to help others.

In this issue, our cover story looks at the work of one of our creative faculty, Dr. Xiaoyu 'Rayne' Zheng, who was recently published in one of the most influential journals in his field - Nature Materials. Rayne also received an award from the Journal of Materials Research.

A veteran faculty member, Dr. Wing Ng received great news to kick off the new year, being elected a Fellow of the American Institute of Aeronautics and Astronautics. He was joined by two other current faculty in Aerospace and Ocean Engineering, and by an ME graduate in this honor.

Not all of our students wait until their senior year to make a difference. Last year a new QL+ student group started, and they are making a difference in the lives of people in the New River Valley. These students aren't doing this to receive credit for their work - they are doing it because they love engineering challenges, and they love to help others. They are a great group of Hokies, and I hope you take a moment to learn about them.

This month, March 19-20, Virginia Tech will take part in the 2nd annual Giving Day. Despite the name, the goal of the day is to get people involved and so the goal is to encourage 5,500 Hokies to pledge as little as \$5. Last year more than 4,800 took part and through their gifts we raised some funds directly for Mechanical Engineering. Please see what we did with your donations in this issue. Also, click a link to become an Ambassador to giving day - it doesn't cost anything but a little time to reach out and encourage others to share their love of Virginia Tech.

The Lead



Click the logo to become a 2019 Giving Day Ambassador

To designate a gift to Mechanical Engineering on Giving Day: On the 'Give' page, select College of Engineering, and then use the dropdown menu to select ME. If you don't see your preferred gift designation, call 1-800-533-1144 to make your gift over the phone.



Chris Williams, John R. Jones III Faculty Fellow, has been selected to receive the Graduate Alumni Advising Award by the university. The award is presented annually by the Office of the Provost to a faculty member who has been particularly dedicated to and effective in the advising of graduate students. Recipients are selected by a committee of former award winners.



The Center for Tire Research will hold their semi-annual Industry Advisory Board April 2-3. The meeting is attended by representatives from the center's 20 member companies in the global tire, vehicle, materials and testing industries. In its eight years of operation, CenTiRe has funded research work of interest to industry and placed students into internships and employment. At left, graduate students present at an IAB meeting in 2018.



Professor Corina Sandu with 20 students of the students who visited mechanical engineering March 1 to take part in a graduate student open house put on by the department. In all 23 students from schools such as UC Berkeley, University of Illinois, Urbana-Champaign, Bangladesh University of Engineering, Carnegie-Mellon, and more came to get a close look at Virginia Tech.



Beth Howell, a mechanical engineering department program manager, received her Diversity Advocate certification from the University Office of Professional Development. The 58-hour course was offered to people who had successfully completed the Diversity Ally certification.

Department news

Eskandarian invited talks/Editorship

Azim Eskandarian, Nicholas and Rebecca Des Champs Professor and the Head of the Mechanical Engineering Department, delivered five invited talks nationally and internationally in Fall 2018 on the subject of Autonomous Vehicles Controls and Safety, including two keynote speeches in international conferences as follows:



Keynote speeches: **37th FISITA World Congress** (the International Federation of Automotive Engineering Societies) and Society of Automotive Engineers – India), Chennai, India, Oct. 2-5, 2018; and **Daegu International Future Auto Expo FORUM 2018** (DIFA 18), Korea, Oct. 29, 2018.

Invited Talks: **North Carolina State University**, Raleigh, North Carolina, Oct. 19, 2018; **Seoul National University**, Korea Oct. 28; and **Case Western Reserve University**, Cleveland, Ohio, ME Department, Nov. 15, 2018

In January 2019, Eskandarian became the **Editor-in-Chief** of [IEEE Transactions on Intelligent Transportation Systems](#) (ITS), one of the highest Impact Factor journals in Transportation Engineering and the top-ranked journal in Google ranking in this field.

Jiangtao Cheng publications/funding

Jiangtao Cheng's article, Resistant Energy Analysis of Self-Pulling

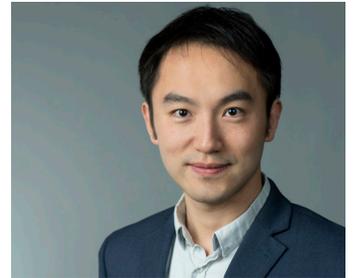


Process during Dropwise Condensation on Superhydrophobic Surfaces, was recently [published in Nanoscale Advances](#).

Cheng also received a **National Science Foundation award** of more than \$300,000 for a three year project on Electrowetting-Tuned Liquid Droplets on Lubricated Superhydrophobic Surfaces for Whispering-Gallery-Mode Sensing.

Zheng JMR Award

Assistant Professor Xiaoyu 'Rayne' Zheng has been recognized by the Journal of Materials Research as authoring the **JMR Paper of the Year**. The award



recognizes excellence in advancing materials knowledge through written scholarship. The paper receiving the award was titled, Additive Manufacturing and Size-Dependent Properties of High Temperature Ceramic. The lead student author on the paper was Huachen Cui. The award will be formally presented at the 2019 MRS Spring Meeting April 22.

Kochersberger outreach

Associate Professor Kevin Kochersberger has **initiated an outreach program** designed to motivate middle school students to pursue aviation sciences starting with flight basics found in sailplanes. The course will be offered in technical education classes at the middle-school level and students who complete the course will be eligible for introductory flight lessons at a glider club near their school.



Kochersberger has been a flight instructor in gliders since 1988. "As the managing director of a fund for scholarships, we weren't finding motivated students who would benefit from a flight instruction program," Kochersberger said. "IMFLY-N! will help find those interested students who will hopefully become the next generation of aviation pioneers. People are invited to learn more on the [IMFLY-N! web site](#).

Acar publications and talks

Assistant Professor Pinar Acar has published the following journal articles since December:



P. Acar, "Multi-Scale Computational Modeling of Lightweight Aluminum-Lithium Alloys" **Heliyon**, in press, 2019.

A. Paul, P. Acar, W. Liao, A. Choudhary, V. Sundararaghavan, A. Agrawal, "[Microstructure Optimization with Constrained Design Objectives using Machine Learning-Based Feedback-Aware Data-Generation](#)" **Computational Materials Science**.

P. Acar, "[Eliminating mesh sensitivities in microstructure design with an adjoint algorithm](#)" **Finite Elements in Analysis and Design**.

P. Acar and V. Sundararaghavan, "[Do Epistemic Uncertainties Allow for Replacing Microstructural Experiments with Reconstruction Algorithms?](#)" **AIAA Journal**.

P. Acar and V. Sundararaghavan, "[Stochastic Design Optimization of Microstructural Features using Linear Programming for Robust Material Design](#)" **AIAA Journal**.

In addition, Acar was elected to the AIAA Materials Technical Committee; and the

ASME Structures and Materials Technical Committee. She chaired "MDO-20: Metamodeling and Approximation Methods" in AIAA SciTech in January 2019, San Diego.

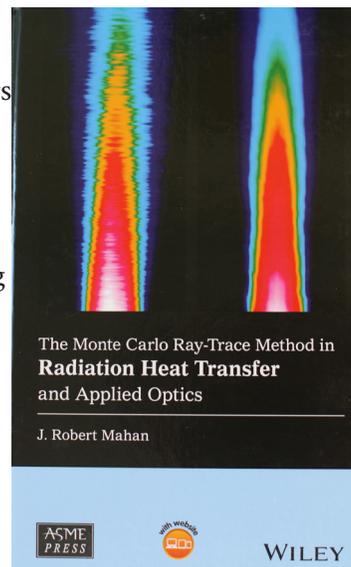
Acar has also given two talks:

"Uncertainty Quantification and Stochastic Optimization for Spatially Varying Composite Fiber Paths"; and A Transductive Learning Approach for Identification of Microstructure-Process Linkages" both at **AIAA SciTech 2019** in San Diego.

"Multi-Scale Computational Design of Materials: Current Challenges and Future Opportunities" at the Mechanical Engineering Department at **Carnegie Mellon University**, Pittsburgh, PA.

Mahan book released

Emeritus Professor Bob Mahan's second book on radiation heat transfer, the Monte Carlo Ray-Trace Method in Radiation Heat Transfer and Applied Optics, was released Feb. 1. The book offers the most modern and up-to-date approach to radiation heat transfer modeling and performance of optical instruments. The book was jointly released by John Wiley & Sons Ltd., and ASME Press.



Tarazaga and students at IMAC

Associate Professor and John R. Jones III Faculty Fellow Pablo Tarazaga took 14

students, including two undergraduates, to the **IMAC XXXVII Conference and Exposition on Structural Dynamics**. The group took part in 15 presentations.

Zuo presentations

Professor Lei Zuo, John R. Jones III Faculty Fellow, **delivered a keynote talk** at the 4th Asian Wave and Tidal Energy Conference in Taipei, "Mechanical Motion Rectifier: A High Efficient and Reliable WEC Power Takeoff."



Zuo gave an invited keynote at the First International Conference on Vibration and Energy Harvesting Application, in Shenzhen, China, "Energy Harvesting: From Wireless Sensors and Self-Powered Control to Blue Energy." The event was attended by more than 100 people from 38 institutions in Asia and Europe.

At a seminar at Columbia University, Zuo spoke on "Towards Blue Dream: The Design, Dynamics, and Control of an Innovative Power Take Off for Ocean Wave Energy Harvesting."

Zuo and graduate student Yu Pan won the **2018 Best Paper Award** on Vibration Applications the ASME 2018 Dynamics System and Control Conference for "Performance evaluation of train suspension energy harvesting shock absorber on railway vehicle dynamics."

Wu receives Chinese award

Doctoral student Yongjia Wu, who studies thermoelectric energy harvesting with Professor Lei Zuo, received the 2019 Chinese Government Award for Outstanding Self-Financed Students Abroad. Established by the China Scholarship Council, the award is presented to 500 of the more than half a million students who study abroad each year.

Ben-Tzvi publications, awards

Associate Professor Pinhas Ben-Tzvi was awarded the **IJCAS Academic Activity Award** in January. The International Journal of Control,

Automation, and Systems award was in recognition of outstanding service and dedicated work as an editorial board member of the IJCAS and for his exceptional contributions in the advancement of the journal.

Ben-Tzvi and his graduate students have published the following journal papers in 2019:

Sebastian, B., Ben-Tzvi, P., "Active Disturbance Rejection Control for Handling Slip in Tracked Vehicle Locomotion" *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 11, Issue 2, pp. 021003: 1-12, April 2019.

Ren, H., Kumar, A., Ben-Tzvi, P., "LOSA-X: Expandable 3D Motion Tracking System" *IEEE Sensors Journal*, Published online, January 2019. DOI: 10.1109/JSEN.2019.2893550

Rone, W., Liu, Y., Ben-Tzvi, P., "Maneuvering and Stabilization Control of a Bipedal Robot with a Universal-Spatial Robotic Tail" *Bioinspiration and Biomimetics Journal*, Vol. 14, Issue 1, pp. 016014: 1-16, January 2019.



Rone, W., Saab, W., Kumar, A., Ben-Tzvi, P., "Controller Design, Analysis and Experimental Validation of a Robotic Serpentine Tail to Maneuver and Stabilize a Quadrupedal Robot" *Journal of Dynamic Systems, Measurement and Control, Transactions of the ASME*, Published Online, February 2019. DOI: 10.1115/1.4042948

Saab, W., Rone, W., Kumar, A., Ben-Tzvi, P., "Design and Integration of a Novel Spatial Articulated Robotic Tail" *IEEE/ASME Transactions on Mechatronics*, Published online, February 2019. DOI: 10.1109/TMECH.2019.2897885

Williams, A., Sebastian, B., Ben-Tzvi, P., "Review and Analysis of Search, Extraction, Evacuation, and Medical Treatment Field Robots" *Journal of Intelligent and Robotic Systems*, Published online, February 2019. DOI: 10.1007/s10846-019-00991-6

Saab, W., Racioppo, P., Ben-Tzvi, P., "A Review of Coupling Mechanism Designs for Modular Reconfigurable Robots" *Robotica Journal*, Vol. 37, Issue 2, pp. 378-403, February 2019.

Saab, W., Racioppo, P., Kumar, A., Ben-Tzvi, P., "Design of a Miniature Modular Inchworm Robot with an Anisotropic Friction Skin" *Robotica Journal*, Vol. 37, Issue 3, pp.

521-538, March 2019.

Ben-Tzvi and his former Ph.D. student Anil Kumar, Senior System Integration Engineer at GM Cruise Automation, were issued the following US Patent: Ben-Tzvi, P., Kumar, A., "Linear Optical Sensor Arrays (LOSA) Tracking System for Active Marker Based 3D Motion Tracking."

Ben-Tzvi was elected and currently serves as the Co-Chair of the Technical Program Committee for the 43rd Mechanisms and Robotics Conference at the 2019 ASME International Design Engineering Technical Conferences (IDETC/CIE), August 2019, Anaheim, CA.

Ben-Tzvi is also serving as **Member of the Technical Program Committee** for the 2019 IEEE International Workshop on Robotic and Sensors Environments - ROSE 2019, Ottawa, Canada, 17-18 June 2019.

Ban organizes conference

Associate Professor Chunmei Ban is organizing the [Beyond Lithium-ion XII 2019 Conference](#) focusing on transformational advances in beyond-lithium energy storage technologies.



Correction

In the previous issue of *Momentum*, a photo incorrectly said that Professor Corina Sandu was receiving the SAE McFarland Award. The photo (reprinted at left) was taken at an ASME conference unrelated to the award. Sandu will receive the McFarland Award at the SAE Congress in April.

Wing Ng elected as AIAA Fellow

3 engineering faculty highlight Hokie presence on AIAA 2019 Fellow list

Twenty-nine members of the American Institute of Aeronautics and Astronautics were elected as Fellows for 2019 including three current Virginia Tech faculty: **Wing Ng, Christopher C. Kraft Endowed Professor of Mechanical Engineering, Rakesh Kapania, Mitchell Professor of Aerospace and Ocean Engineering, and Robert Canfield, professor and assistant department head in the Kevin T. Crofton Department of Aerospace and Ocean Engineering.**

Wing Ng on the work floor of the company he founded and continues to run, Techsburg

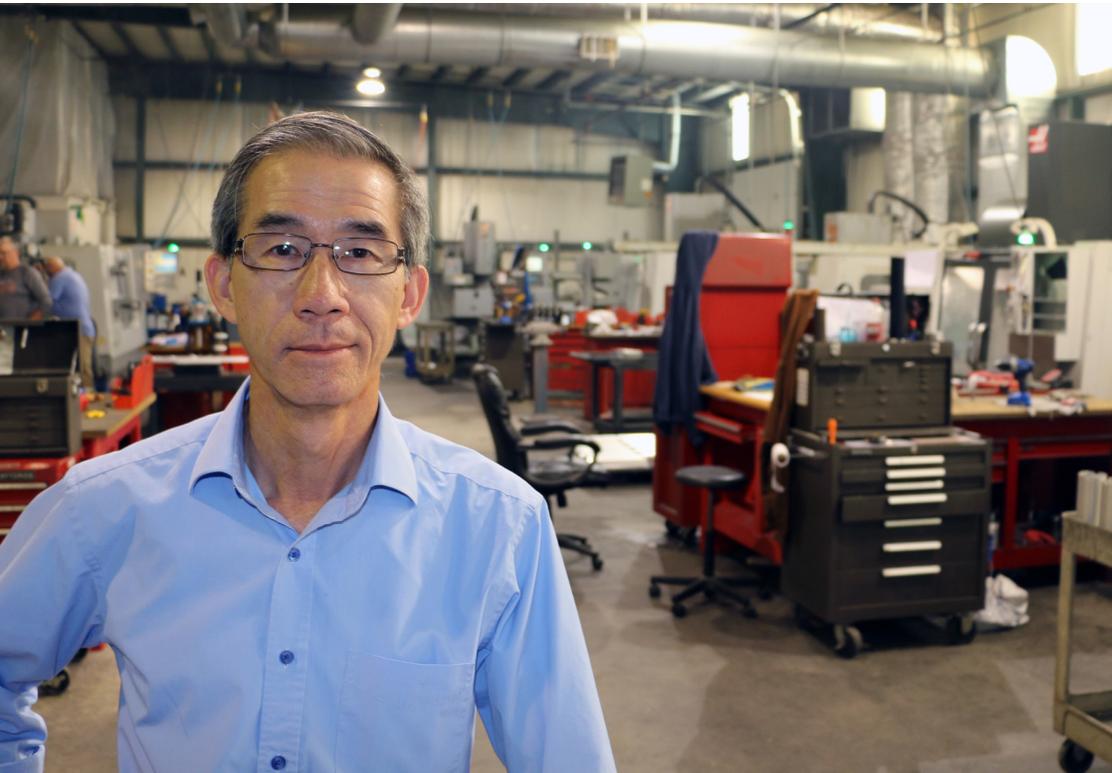
Others chosen for the honor this year include Virginia Tech alums **Fayette Collier** of the NASA Langley Research Center, who earned his BS, MS, and Ph.D.s in aerospace and ocean engineering in 1981, 1982, and 1988 respectively; and **Jaiwon Shin** of NASA Headquarters, who earned his Ph.D. in mechanical engineering in 1989. Additionally, new AIAA Fellow Hanspeter Schaub of the University of Colorado, was a faculty member in AOE in the early 2000s.

As the largest aerospace professional society in the world, AIAA fellows have made notable and valuable contributions to the arts,

sciences, and technology and fellowship is limited to one for every 125 associate fellows each year. The induction ceremony will be held May 14 in Crystal City, Virginia.

Wing Ng

Nominated for his work in industry as CEO and founder of Techsburg, Ng has conducted research in aero-propulsion and turbomachinery since 1984 and is a global expert in aerodynamic testing. His company, Techsburg, performs mostly proprietary and classified research and development work for aerospace companies, the gas turbine industry, and government laboratories. His use of innovative wind tunnel facilities allows for cost-effective critical data collection for aerospace companies to improve their products. Through his company and his university laboratory, he has helped develop quieter, more fuel efficient, and safer aerospace products. A member of AIAA since 1980 and an Associate Fellow since 1992, Ng has spent his professional career as a member of Virginia Tech, arriving in 1984 as an assistant professor. He received his Ph.D. in mechanical engineering from the Massachusetts Institute of Technology in 1984. He was elected to Virginia Tech's



Entrepreneur Hall of Fame in 2017.

Rakesh Kapania

Kapania was nominated for his significant contributions to teaching and research in computational structural mechanics, aeroelasticity, optimal design of unitized structures, multi-disciplinary design optimization, and composite structures. As a scholar-manager, Kapania has led two large programs toward the design of civilian and military future aerospace vehicles. He is part of a team selected by NASA to perform research on performance adaptive aeroelastic wings, and by the U.S. Navy on a program to bring machine learning to the analysis of submarine structures. His path-breaking work on curvilinearly stiffened panels and aeroelastic optimization of wings using curvilinear spar and ribs has spawned similar research world-wide. Kapania is a Fellow of the Royal Aeronautical Society (2016), and a recipient of the Platinum Jubilee Award from the Indian Institute of Science (2017). He has been with Virginia Tech since 1985 and the Mitchell Professor of Aerospace and Ocean Engineering since 2008. A former president of the EFO, he has won Dean's Awards for Research Excellence in 2000 and 2010. He holds a Ph.D. from the School of Aeronautics and

Aeronautics at Purdue University (1985). He has been a member of AIAA since 1982 and was elected an Associate Fellow in 1991.

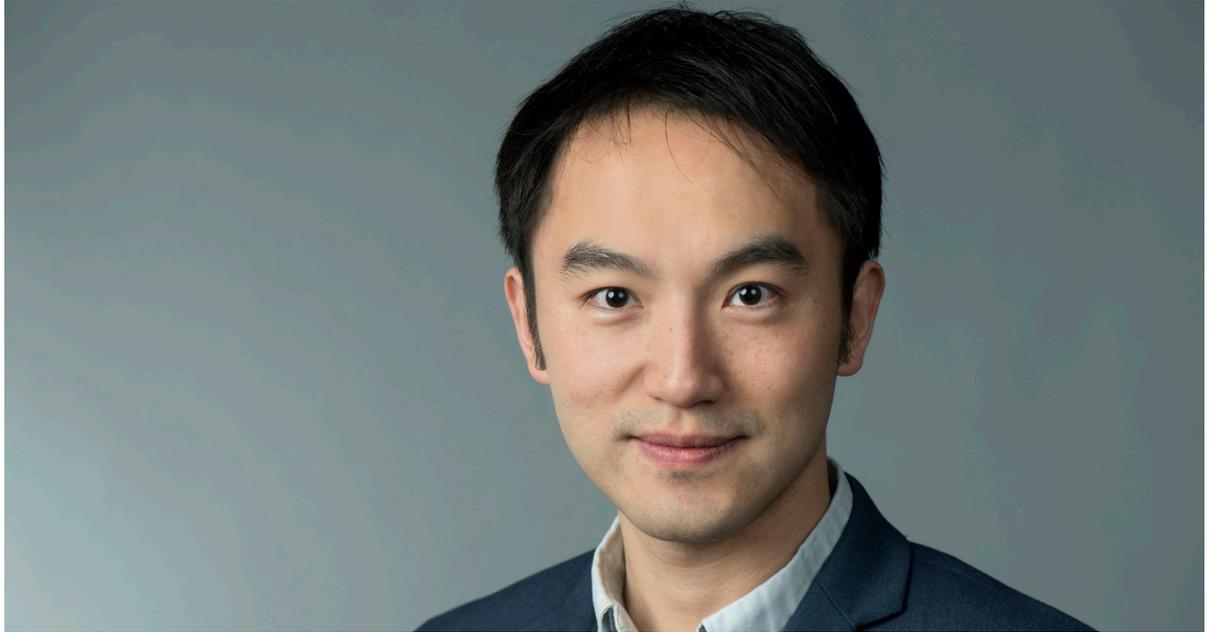
Robert Canfield

Canfield, Technical Director of the VT Airworthiness Center, is world-renown for his work to develop a methodology for automated structural design and optimization, recognized as the gold standard in the field. Users of software that incorporate this methodology include NASA, DoD, universities, Boeing, Northrop Grumman, Lockheed Martin and international corporations. The design methodology is also featured in a widely cited textbook on Reliability-Based Structural Design that he co-authored. His leadership as Chair of the AIAA Multidisciplinary Design Optimization (MDO) Technical Committee led to the growth of its premier MDO Conference. From 1984-2008 Canfield served in the U.S. Air Force, retiring

as a lieutenant colonel with tours at the Air Force Office of Scientific Research and the Air Force Institute of Technology. In 2009 he joined Virginia Tech, and during his tenure has been the Assistant Head for Academic Affairs and an interim Department Head. Canfield is a Hokie alum, earning his Ph.D. in Engineering Mechanics in 1992. He also holds an MS in Aeronautics and Astronautics from Stanford University, and a BS in Mechanical Engineering from Duke University. Canfield has been an AIAA member since 1985 and was elected an Associate Fellow in 2000.

Ng in 2014 receiving the William Wine Excellence in Teaching Award from university president Timothy Sands.





Zheng receives ONR Award

Xiaoyu 'Rayne' Zheng, assistant professor of mechanical engineering in the College of Engineering, has received an Office of Naval Research 2019 Young Investigator award to study rational design and additive manufacturing of 3D piezoelectrics with arbitrary anisotropy for maritime self-sensing structures. The work will be done as part of ONR's Maritime Sensing Program.

The ability to tailor energy transduction materials are critical to meet demanding operational environments where weight, robustness, and performance are equally important. The three-year, \$750,000 project aims to develop design and additive manufacturing techniques to advance the knowledge and capabilities for developing novel transducer and sensing platforms.

"Traditionally, you would have to deal with the existing properties within the materials you are given and distribute a large number of sensors onto your target of interests," said Zheng. "Our goal is to rationally design the structural-property relationships to enable a variety of customizable acoustic sensing and

transduction applications with only a fraction of their parent materials."

The Office of Naval Research Young Investigator Program is one of the nation's oldest and most selective science and technology basic research programs. Its purpose is to fund early-career academic researchers whose scientific pursuits show outstanding promise for supporting the Department of Defense, while also promoting their professional development.

Zheng is one of only 25 awardees this year, selected from more than 260 applicants, all of whom were college and university faculty and who obtained their doctoral degrees in the past seven years.

In addition to the ONR award, Zheng received the 2018 Air Force Young Investigator Award from the Air Force Office of Scientific Research for his work developing flexible inorganic metamaterials for future flight structures; and a Junior Faculty Award in 2017 from the Institute for Critical Technology and Applied Science.

Department welcomes four new faculty members in January



[Shima Shahab, Assistant Professor](#) - joins the department from the Dept. of Biomedical Engineering and Mechanics. Thrust area specialty: RADS. Research interests: Intersection of smart materials and dynamical systems for interdisciplinary applications including acoustic energy transfer.



[Changmin Son, Rolls-Royce Commonwealth Professor](#), comes to Virginia Tech via Pusan National University, South Korea. Thrust area specialty: EES. Research interests: Gas turbine heat transfer and aerodynamics - turbine internal cooling, secondary flow, turbine dynamics.



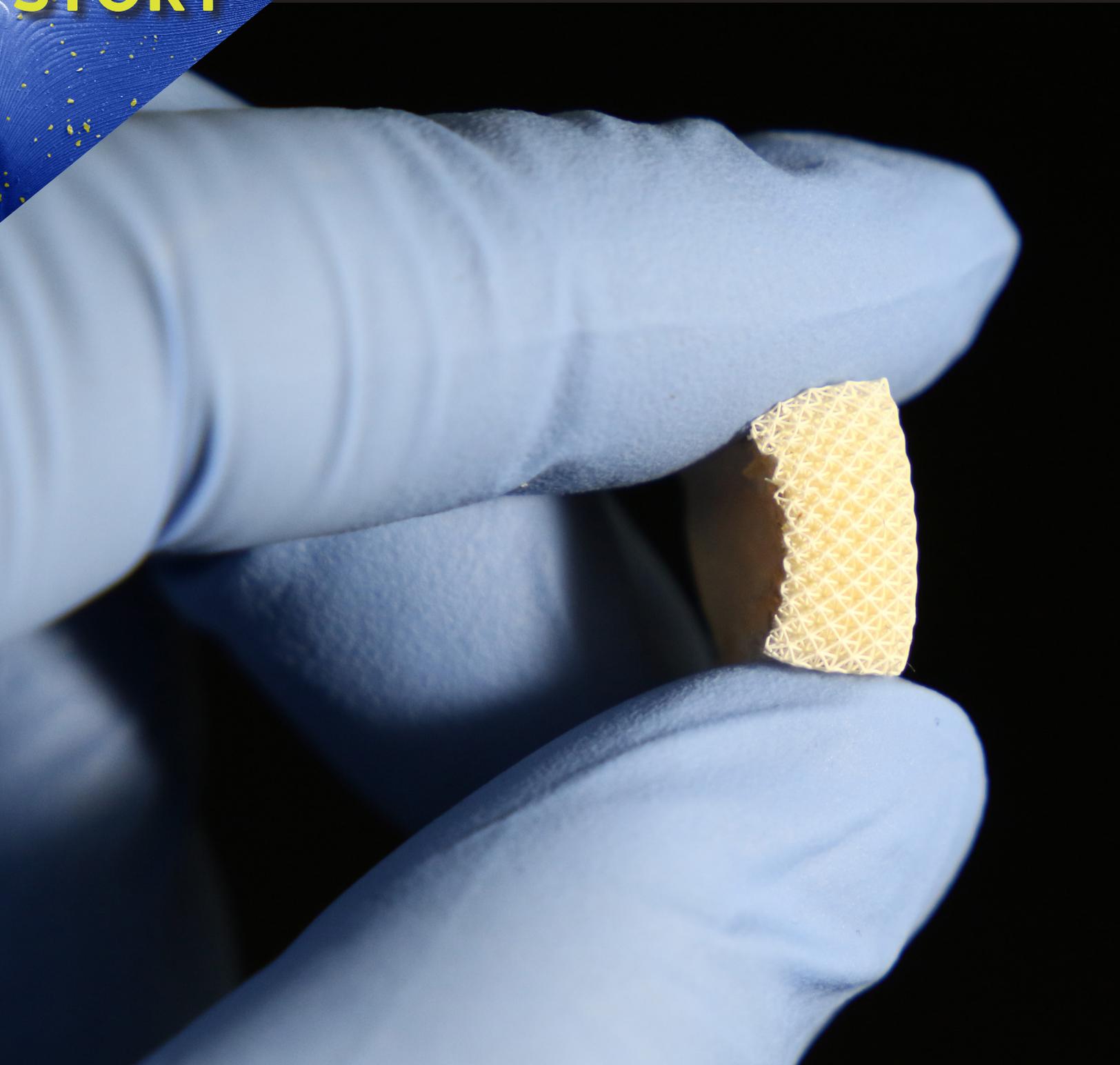
[Jonathan Boreyko, Assistant Professor](#) - joins the department from the Dept. of Biomedical Engineering and Mechanics. Thrust area specialty: BMNS. Research interests: Interfacial fluid mechanics, surface wettability of micro/nano-structured materials, phase-change heat transfer, biomimetic engineering.



[Chunmei Ban, Associate Professor](#) - comes to Virginia Tech from a position as senior scientist, National Renewable Energy Laboratory. Thrust area specialty: DMM. Research interests: Interfacial science and engineering for functional materials used in energy conversion and storage systems.



COVER STORY



3D printing of piezoelectrics an industry game-changer

The piezoelectric materials that inhabit everything from our cell phones to musical greeting cards may be getting an upgrade thanks to work discussed in the journal *Nature Materials* released online Jan 21.

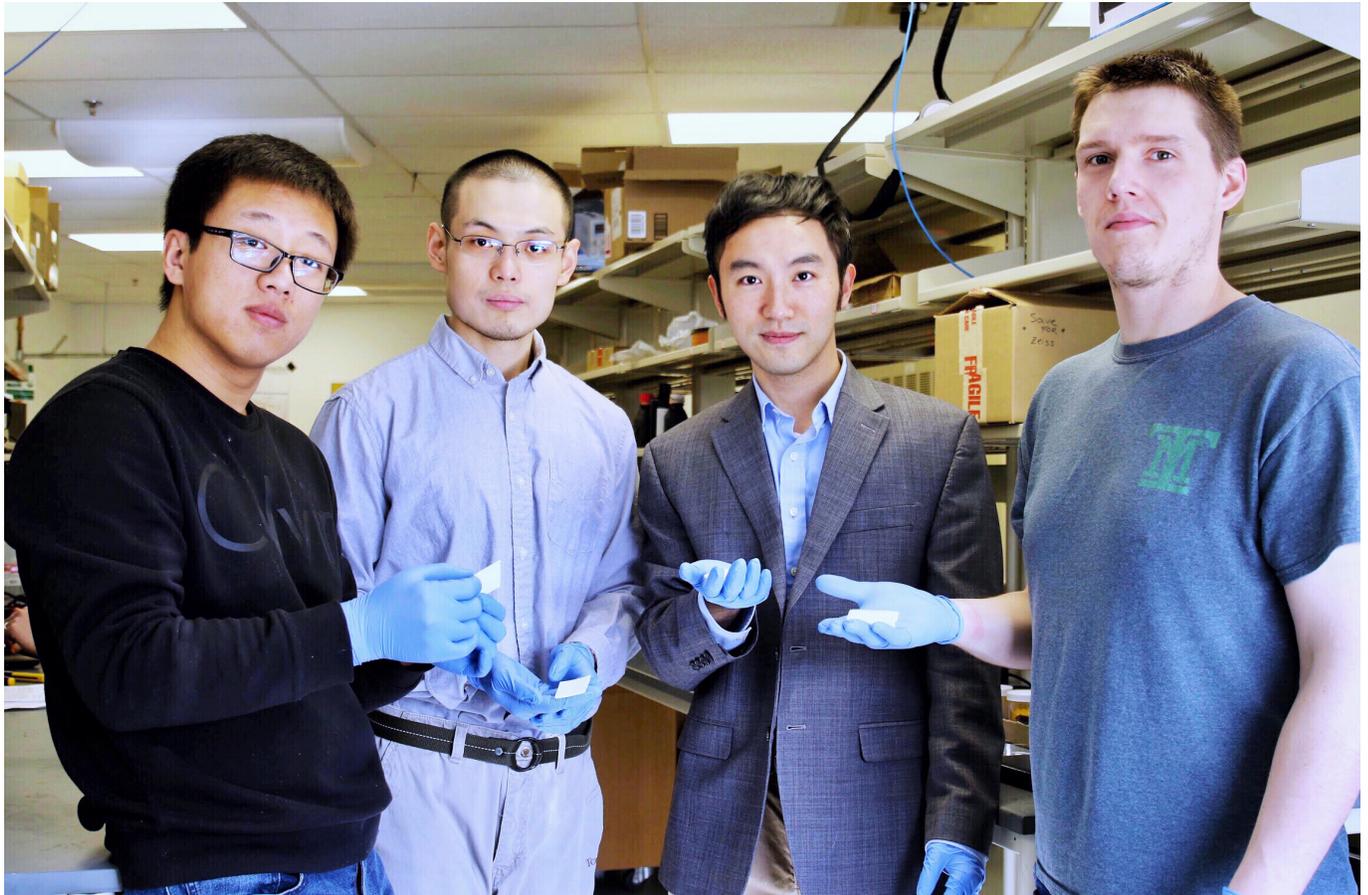
Xiaoyu 'Rayne' Zheng, assistant professor of mechanical engineering in the College of Engineering, and a member of the Macromolecules Innovation Institute, and his team have developed methods to 3D print piezoelectric materials that can be custom-designed to convert movement, impact and stress from any direction to electrical energy.

"Piezoelectric materials convert strain and stress into electric charges," Zheng explained.

The piezoelectric materials come in only a few defined shapes and are made of brittle crystal and ceramic – the kind that require a clean room to manufacture. Zheng's team has developed a technique to 3D print these materials so they are not restricted by shape or size. The material can also be activated – providing the next generation of intelligent infrastructures and smart materials for tactile sensing, impact and vibration monitoring, energy harvesting, and other applications.

Unleash the freedom to design piezoelectrics

Piezoelectric materials were originally discovered in the 19th century. Since then the

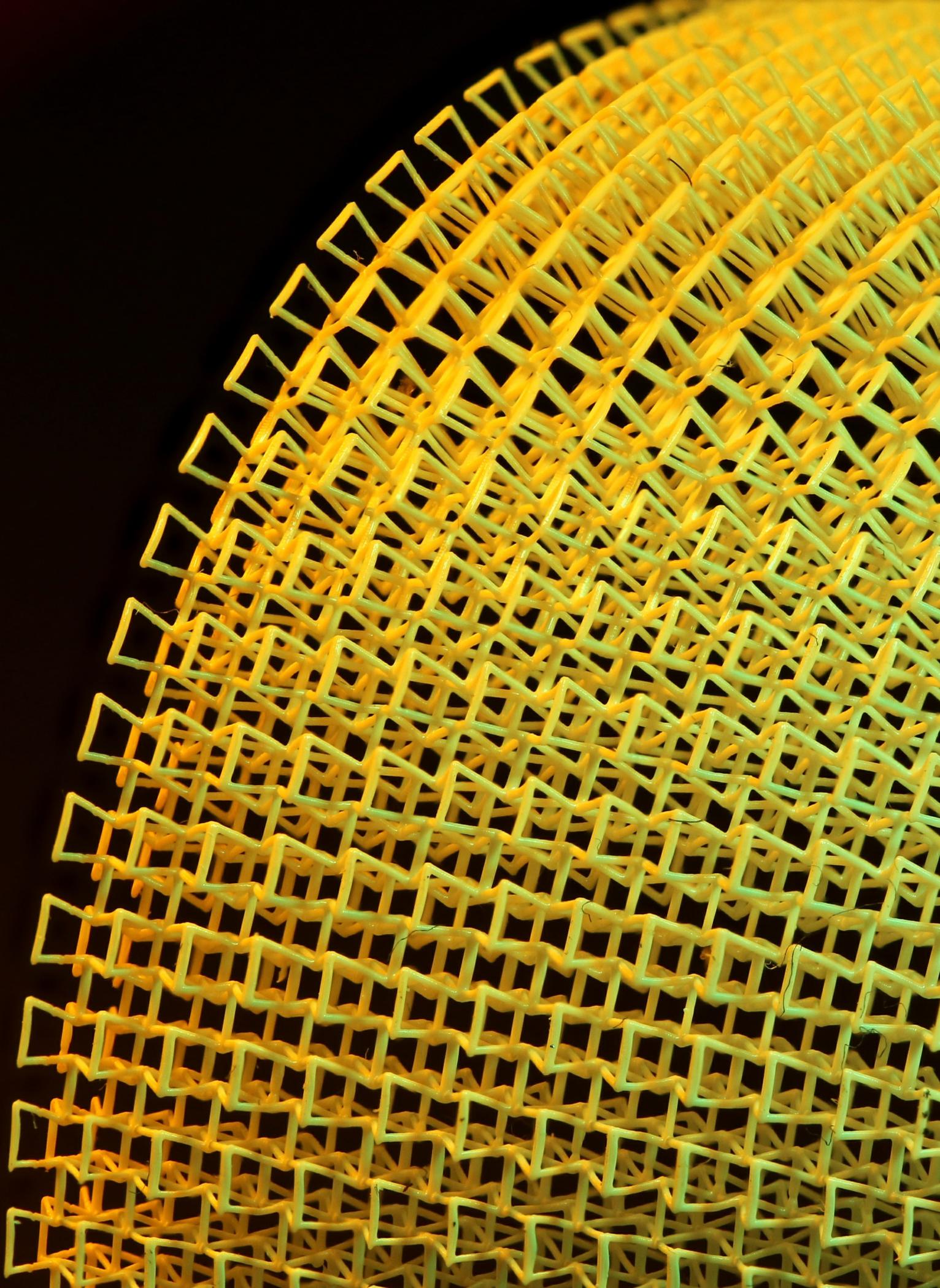


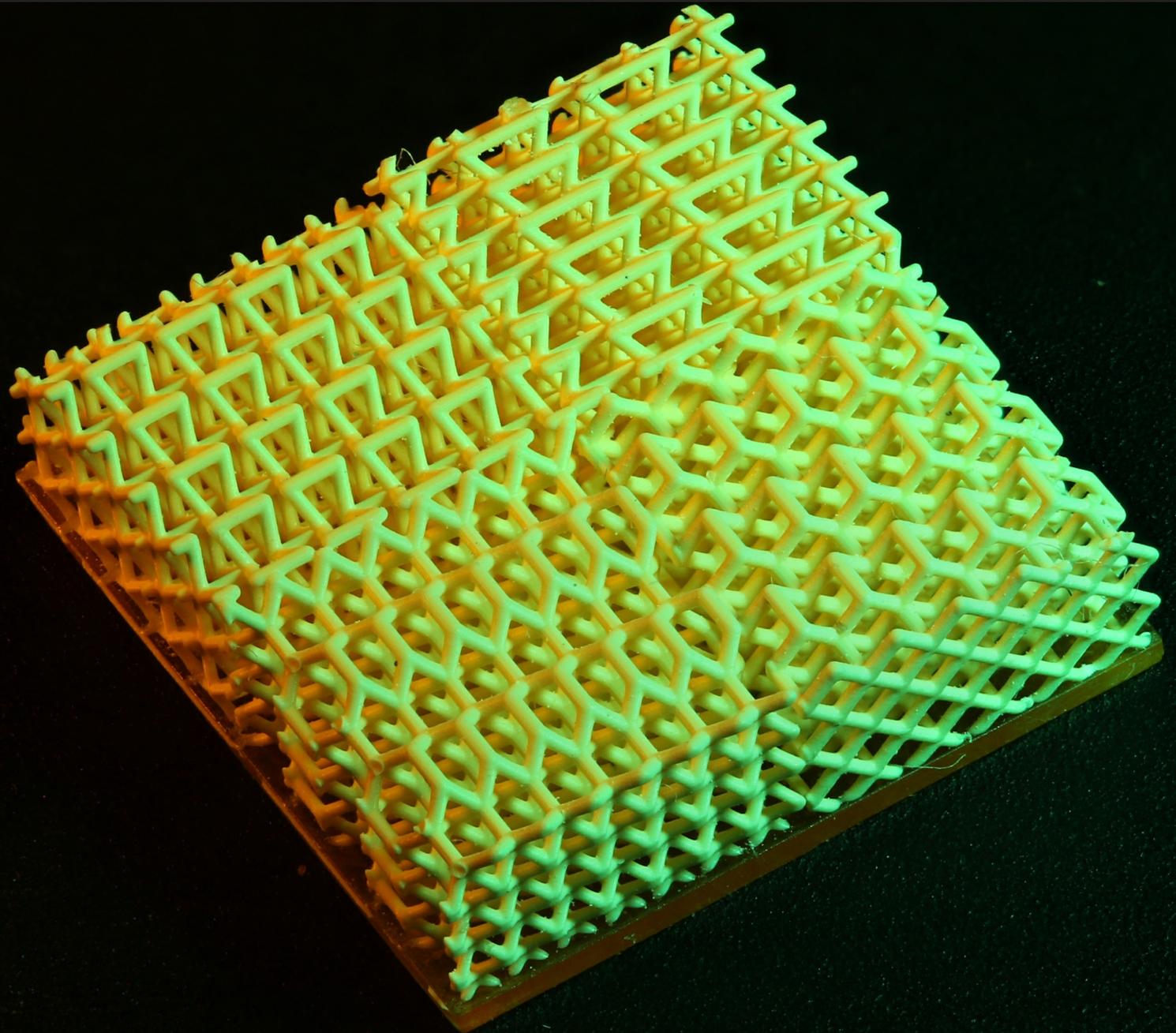
Huachen Cui (first author), Desheng Yao (co-author), Xiaoyu (Rayne) Zheng, and Ryan Hensleigh (co-author) in Zheng's lab.

advances in manufacturing technology has led to the requirement of clean-rooms and a complex procedure that produces films and blocks which are connected to electronics after machining. The expensive process and the inherent brittleness of the material, has limited the ability to maximize the material's potential.

Zheng's team developed a model that allows them to manipulate and design arbitrary piezoelectric constants, resulting in the material generating electric charge movement in response to incoming forces and vibrations from any direction, via a set of 3D printable topologies. Unlike conventional piezoelectrics where electric charge movements are prescribed by the intrinsic crystals, the new method allows users to prescribe and program voltage responses to be magnified, reversed or suppressed in any direction.

"We have developed a design method and printing platform to freely design the sensitivity and operational modes of piezoelectric materials," Zheng said. "By programming the 3D active topology, you can achieve pretty much any combination of piezoelectric coefficients within a material, and use them as transducers and sensors that are not only flexible and strong, but also respond to pressure, vibrations and impacts via electric signals that tell the location, magnitude and direction of the impacts within any location of these materials."





3D printing of piezoelectrics, sensors and transducers

A factor in current piezoelectric fabrication is the natural crystal used. At the atomic level, the orientation of atoms are fixed. Zheng's team has produced a substitute that mimics the crystal but allows for the lattice orientation to be altered by design.

"We have synthesized a class of highly sensitive piezoelectric inks that can be sculpted into complex three-dimensional features with ultraviolet light. The inks contain highly concentrated piezoelectric nanocrystals bonded with UV-sensitive gels, which form a solution - a milky mixture like melted crystal - that we print with a high-resolution digital light 3D printer," Zheng said.

The team demonstrated the 3D printed materials at a scale measuring fractions of the diameter of a human hair. "We can tailor the architecture to make them more flexible and use them, for instance, as energy harvesting devices, wrapping them around any arbitrary curvature," Zheng said. "We can make them thick, and light, stiff or energy-absorbing."

The material has sensitivities 5-fold higher than flexible piezoelectric polymers. The stiffness and shape of the material can be tuned and produced as a thin sheet resembling a strip of gauze, or as a stiff block. "We have a team making them into wearable devices, like rings, insoles, and fitting them into a boxing glove where we will be able to record impact forces and monitor the health of the user," said Zheng.

"The ability to achieve the desired mechanical, electrical and thermal properties will significantly reduce the time and effort needed to develop practical materials," said Shashank Priya, associate VP for research at Penn State and former professor of mechanical engineering at Virginia Tech.

New applications

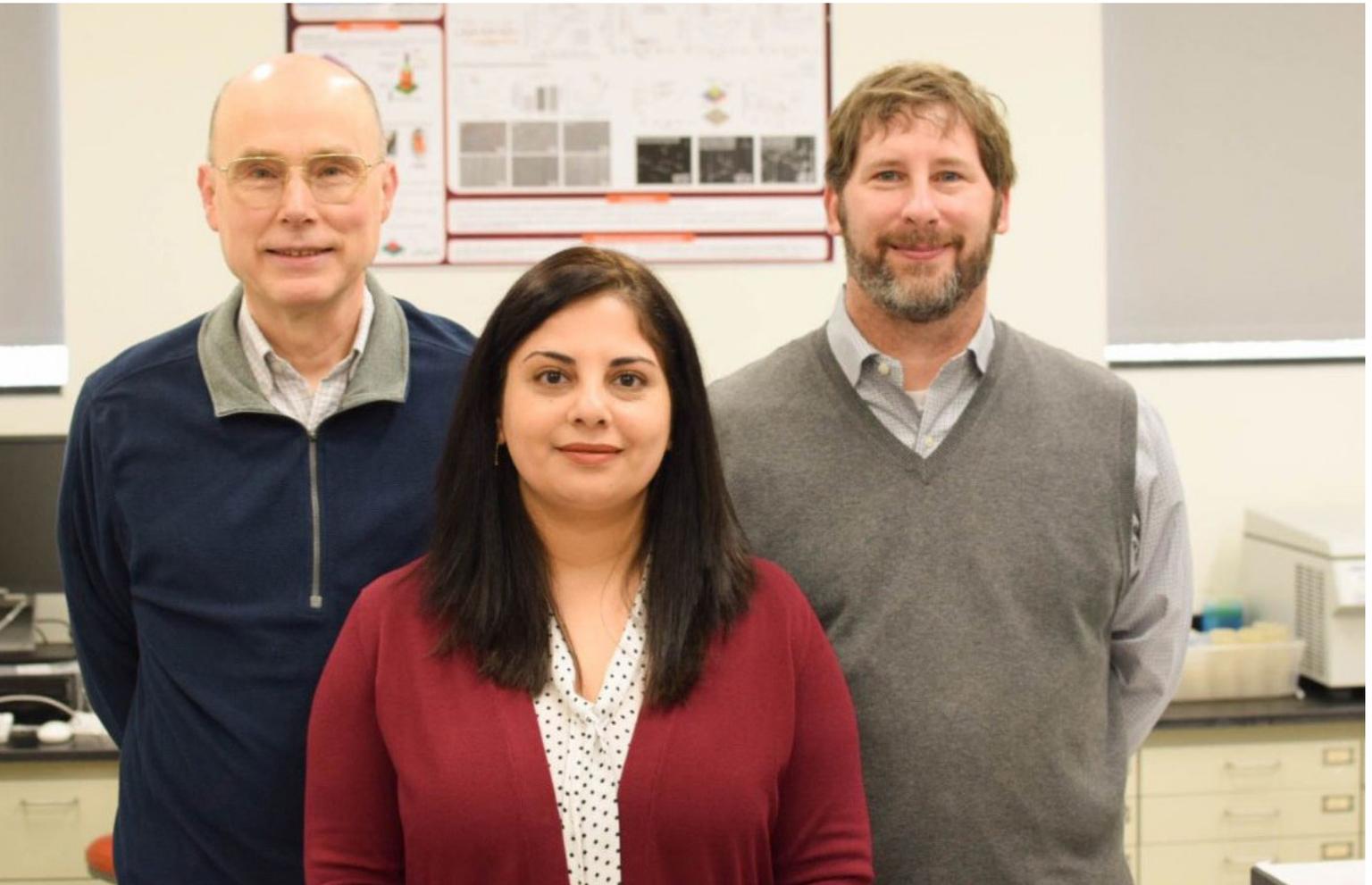
The team has printed and demonstrated smart materials wrapped around curved surfaces, worn on hands and fingers to convert motion, and harvest the mechanical energy, but the applications go well beyond wearables and consumer electronics. Zheng sees the technology as a leap into robotics, energy harvesting, tactile sensing and intelligent infrastructure, where a structure is made entirely with piezoelectric material, sensing impacts, vibrations and motions, and allowing for those to be monitored and located. The team has printed a small smart bridge to demonstrate its applicability to sensing the locations of dropping impacts, as well as its magnitude, while robust enough to absorb the impact energy. The team also demonstrated their application of a smart transducer that converts underwater vibration signals to electric voltages.

"Traditionally, if you wanted to monitor the internal strength of a structure, you would need to have a lot of individual sensors placed all over the structure, each with a number of leads and connectors," said Huachen Cui, a doctoral student with Zheng and first author of the Nature Materials paper. "Here, the structure itself is the sensor - it can monitor itself."

The team's work is supported, in part, by the National Science Foundation, Air Force Office of Scientific Research, the Office of Naval Research and the Virginia Tech Institute of Critical Technology Junior Faculty Award.

The paper in Nature Materials features the following authors: Huachen Cui (Mechanical Engineering), Ryan Hensleigh (Virginia Tech Macromolecules Innovation Institute), Desheng Yao (ME), Deepam Maurya (ME), Prashant Kumar (ME), Min Gyu Kang (ME), Shashank Priya, (ME & Penn State's Materials Research Institute), and Zheng.

Zheng is also an affiliate faculty member of the Department of Materials Science and Engineering.



Rick Davis (left), professor of chemical engineering; Bahareh Behkam (middle), associate professor of mechanical engineering; and Coy Allen (right), assistant professor of biomedical sciences and pathobiology in the Virginia-Maryland College of Veterinary Medicine. All three are affiliated with Virginia Tech's Macromolecules Innovation Institute and have teamed up on developing their new drug delivery system called NanoBEADS.



Interdisciplinary team creates drug delivery system

An interdisciplinary team of three Virginia Tech faculty members affiliated with the [Macromolecules Innovation Institute](#) has created a drug delivery system that could radically expand cancer treatment options.

The conventional cancer treatment method of injecting nanoparticle drugs into the bloodstream results in low efficacy. Due to the complexities of the human body, very few of

those nanoparticles actually reach the cancer site, and once there, there's limited delivery across the cancer tissue.

The new system created at Virginia Tech is known as Nanoscale Bacteria-Enabled Autonomous Drug Delivery System (NanoBEADS). Researchers have developed a process to chemically attach nanoparticles of anti-cancer drugs onto attenuated bacteria cells, which

they have shown to be more effective than the passive delivery of injections at reaching cancer sites.

NanoBEADS has produced results in both in vitro (in tumor spheroids) and in vivo (in living mice) models showing up to 100-fold improvements in the distribution and retention of nanoparticles in cancerous tissues.

This is a product of the five-year [National Science Foundation CAREER Award](#) of Bahareh Behkam, associate professor of mechanical engineering. Collaborators on this interdisciplinary team are Rick Davis, professor of chemical engineering, and Coy Allen, assistant professor of biomedical sciences and pathology in the [Virginia-Maryland College of Veterinary Medicine](#).

“You can make the most amazing drugs, but if you cannot deliver it where it needs to go, it cannot be very effective,” Behkam said. “By improving the delivery, you can enhance efficacy.”

This work, which combines expertise in mechanical engineering, biomedical engineering, chemical engineering, and veterinary medicine, was recently detailed in [Advanced Science](#).

Using salmonella for good

Humans have noticed, even as far back as Ancient Egypt, that cancer went into remission if the patient also contracted an infection like salmonella. Neither are ideal, but humans can treat salmonella infections more effectively than cancer.

In modern times, Allen said the idea of treating cancer with infections traces back to the late 1800s and has evolved into immunotherapy, in which doctors try to activate the immune system to attack cancerous cells.

Of course, salmonella is harmful to humans, but a weakened version could in theory pro-

vide the benefits of immunotherapy without the harmful effects of salmonella infection. The concept is similar to humans receiving a weakened flu virus in a vaccine to build immunity.

Over six years ago, Behkam came up with the idea of augmenting bacterial immunotherapy to also attack cancer with conventional anti-cancer drugs. The problem was the passive delivery of anti-cancer drugs doesn't work very well.

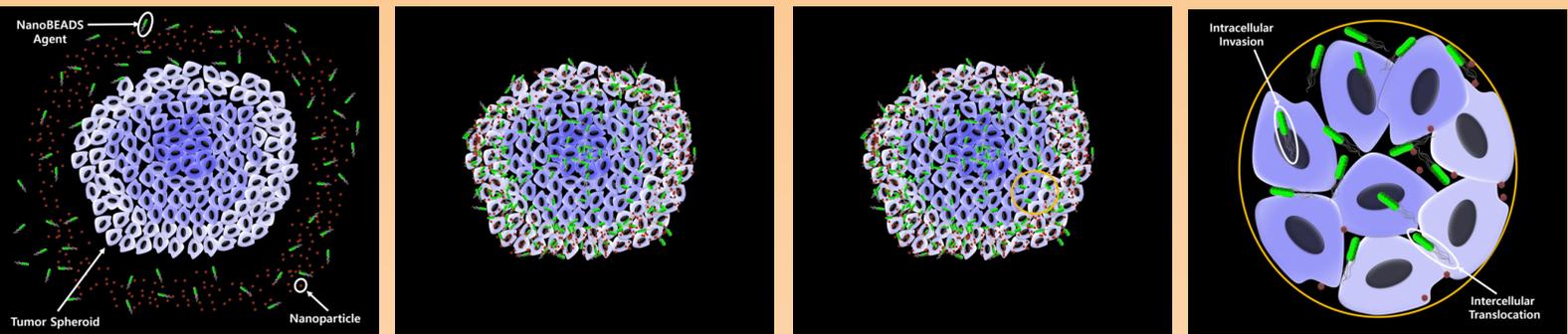
Given her background in bio-hybrid microrobotics, she wanted to use salmonella bacteria as autonomous vehicles to transport the medicine, in nanoparticle form, directly to the cancer site.

The work began with Behkam's first doctoral student, Mahama Aziz Traore, constructing the first generation of NanoBEADS by assembling tens of polystyrene nanoparticles onto E. coli bacteria. After thoroughly studying the dynamics and control aspects of the NanoBEADS systems for a few years, Behkam brought Davis into the project because he had experience creating polymer nanoparticles for drug delivery.

“She mentioned this radically different approach for delivering drugs and nanoparticles,” Davis said. “I walked away from the conversation thinking, ‘Man, if this thing could work, it would be fantastic.’”

Behkam chose this particular bacterial strain, *Salmonella enterica* serovar Typhimurium VNP20009, because it has been thoroughly studied and successfully tested in a phase one clinical trial.

“Its (salmonella's) job as a pathogen is to penetrate through the tissue,” Behkam said. “What we thought is if bacteria are so good at moving through the tissue, how about coupling nanomedicine with the bacterium to carry that medicine much farther than it'd



*NanoBEADS agents are constructed by conjugating poly(lactic-co-glycolic acid) nanoparticles with tumor-targeting *Salmonella typhimurium*. NanoBEADS enhance retention and distribution of nanoparticles in solid tumors by up to a remarkable ≈ 100 -fold, through intercellular (between cells) self-replication and translocation. This transport enhancement is achieved autonomously, without the need for any externally applied driving force or control input.*

"Its (salmonella's) job as a pathogen to penetrate through the tissue," Behkam said. "What we thought is if bacteria are so good at moving through the tissue, how about coupling nanomedicine with the bacterium to carry that medicine much farther than it'd passively diffuse on its own?"

Bahareh Behkam

passively diffuse on its own?"

Trial and error

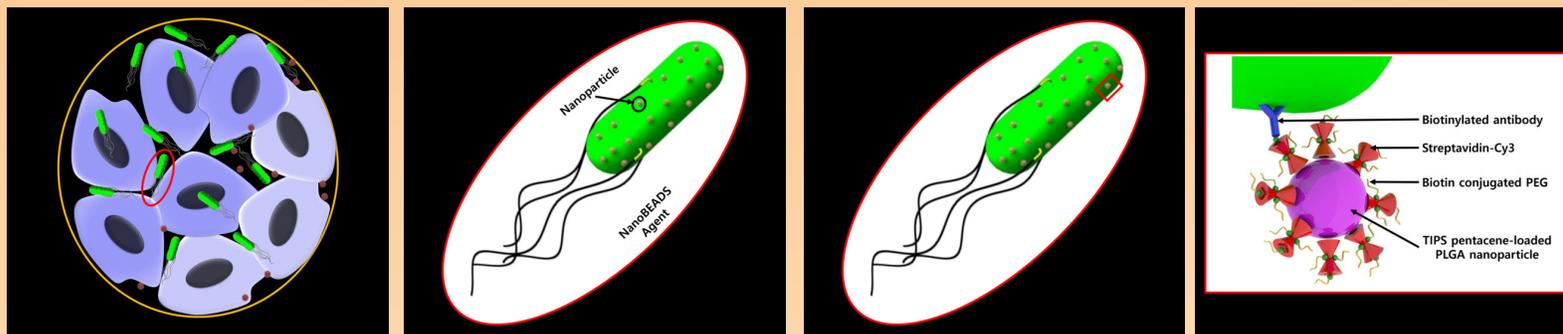
Although Behkam had a vision for the new drug delivery system, it took several years for it to become reality.

"The process of creating nanoparticles and then attaching them to bacteria in a robust and repeatable manner was challenging, but add on top of that ensuring the bacteria stay alive, discovering the mechanism of bacteria transport in cancerous tissue, and devising ways to quantitatively describe the effectiveness of NanoBEADS, and this was a difficult project," Davis said.

SeungBeum Suh, Behkam's former Ph.D. student, and Amy Jo, Davis' former Ph.D. student, worked together on attaching nanoparticles while keeping the bacteria alive. It wasn't until their fourth attempt that they started finding success.

"We collaborated to make these particles, and we attached them to the bacteria," Behkam said. "Then the question was what is the mechanism of their translocation in the tumor? How far do they go into the tumor? How do we present a quantitative measure of their performance?"

Behkam along with Suh and current doctoral student Ying Zhan tested their nanoparticle-attached salmonella in lab-grown tumors.



They found up to 80-fold improvements in nanoparticle penetration and distribution using the NanoBEADS platform, compared to passively diffusing nanoparticles.

Furthermore, Suh and Behkam found out that NanoBEADS largely penetrate the tumor by translocating through the space in between cancer cells.

Behkam wanted to strengthen the NanoBEADS results past the in vitro stage. With a top-flight veterinary school down the road, she enlisted Allen, her fellow MII faculty member, to test the NanoBEADS system in vivo. Tests in breast cancer tumors in mice produced results showing significant improvements compared to passive delivery.

The tests showed that there was about 1,000 times more salmonella cells in the tumor compared to the liver and 10,000 times more than the spleen.

“Most notably, the salmonella itself helped keep the particles in the tumor up to 100-fold better, which would suggest it would be an effective delivery vehicle,” Allen said.

The next step in the research is to load cancer therapeutics into the NanoBEADS system to test the potential enhancement in efficacy.

From bench to kennel to bedside

The collaboration highlights the diversity of interdisciplinary research possible through

MI and Virginia Tech.

“The synergistic integration of diverse expertise has been essential to the high-impact discoveries that resulted from this work,” Behkam said.

With the addition of the Virginia Tech Carilion School of Medicine and Fralin Biomedical Research Institute at VTC, Allen said Virginia Tech has the possibility to test scientific research “from bench to kennel to bedside.”

“The project could not move forward without each of the three parts,” Allen said. “The study would not have gotten into such a high impact journal without having the chemistry, the background of the pathogen, the idea, and having the physiological and clinical relevance of testing it in an actual tumor in an actual animal model.”

Davis said all drug delivery mechanisms have to go through animal trials, so having an “absolutely fantastic” college of veterinary medicine on campus took the research to a higher level.

“One thing that attracted me to this project was the ability to work with people like Bahareh and Coy who work with cells and animal studies to really translate the work,” Davis said. “It’s hard to find that combination of people in a lot of schools.”



Beyond senior design

Student organization embraces QL+ philosophy to enhance quality of life

In the 2017-2018 academic year, a new sponsor for mechanical engineering senior design teams arrived at Virginia Tech in the form of QL+, a non-profit dedicated to helping veterans and first responders. Teams tackled problems brought forth by challengers and made a difference in their lives.

Inspired by the initial challenges, Zackory Biggers, a junior in mechanical engineering from Lovettsville, Virginia answered a call to help form a new student organization, Quality of Life Plus Student Chapter at Virginia Tech, to help people in the New River Valley.

“Last year’s senior design team really got the student organization started,” Biggers said. “This is the first year we’ve been in action, with an executive board and working on projects.”

Biggers is the president of the club which has about thirty members representing a number of engineering and non-engineering disciplines.



The projects the group takes on are not senior design projects. In fact, there is no academic credit at all associated with the club, and students are doing work on their own time, using money they raise.

“We’ve been working with a rehabilitation center called Neuro-Restorative who have put us in touch with several of our challengers,” Biggers said.

Of the three projects the team is taking on this semester, one involves a 12-year old who was born with only part of his hand, with no fingers. The team meets with Ben and

his parents, Joel and Trina to come up with options for what they can do that will help Ben.

“We are looking at a prosthetic attachment that will help him hold a cup and potentially assist him in playing the piano,” Biggers said. “It’s a small thing, but something most people don’t think about – it makes it easier when eating a meal or carrying a drink through the house to have one hand free while carrying your cup, for instance.”

Talking to their challengers has given Biggers a new

appreciation for how to look at projects from different perspectives. “One of our challengers is only able to move one arm and it’s difficult for him to zip up his pants without assistance, so we made a device he can throw over his neck that will allow him to zip himself. Another person loved to fish, but had a difficult time reeling, so we made a device that attaches to his wheelchair that assists him in reeling in fish. Many of these things are things you take for granted and being able to restore that ability to someone who has lost it gives you a sense of pride in being able to do that.”

The student team maintains contact with QL+ representatives who support them with guidance when and where needed. The club has also reached out to CalPoly where a very successful club has been operating for several years.

Beyond finding challengers, Biggers’ biggest issue is finding funding. “We’ve really relied on support from family and friends through a crowdfunding site,” he said. “Our treasurer is looking at sponsorship opportunities from companies and we hope that evolves over time.”

Biggers stresses that as new as the group is, it couldn’t exist without extensive communication and coordination between members of the executive board.

“This couldn’t happen with one person,” Biggers said. “It’s taken a community of people to get funding, to find the challengers, and to work with them to make their project a reality. Also, the support of our faculty advisors, (associate professor of practice) Robin Ott (mechanical engineering) and (collegiate assistant professor) Christopher Arena (biomedical engineering and

mechanics), have been really helpful.”

The faculty advisors have helped Biggers and his team overcome one of their biggest hurdles – finding space to do the work – but the struggle continues.

“Money hasn’t been a real challenge yet,” Biggers said. “We’ve been very lucky to have the support of the local community, family, and friends. Now we need to put plans in place for the future to get storage space and workspace.”



Watch the team prepare a mold of Ben's arm.

To support the VT QL+ student organization as part of Giving Day, call 1-800-533-1144.

Or click their [crowdfunding site](#)

[Team Website](#)

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