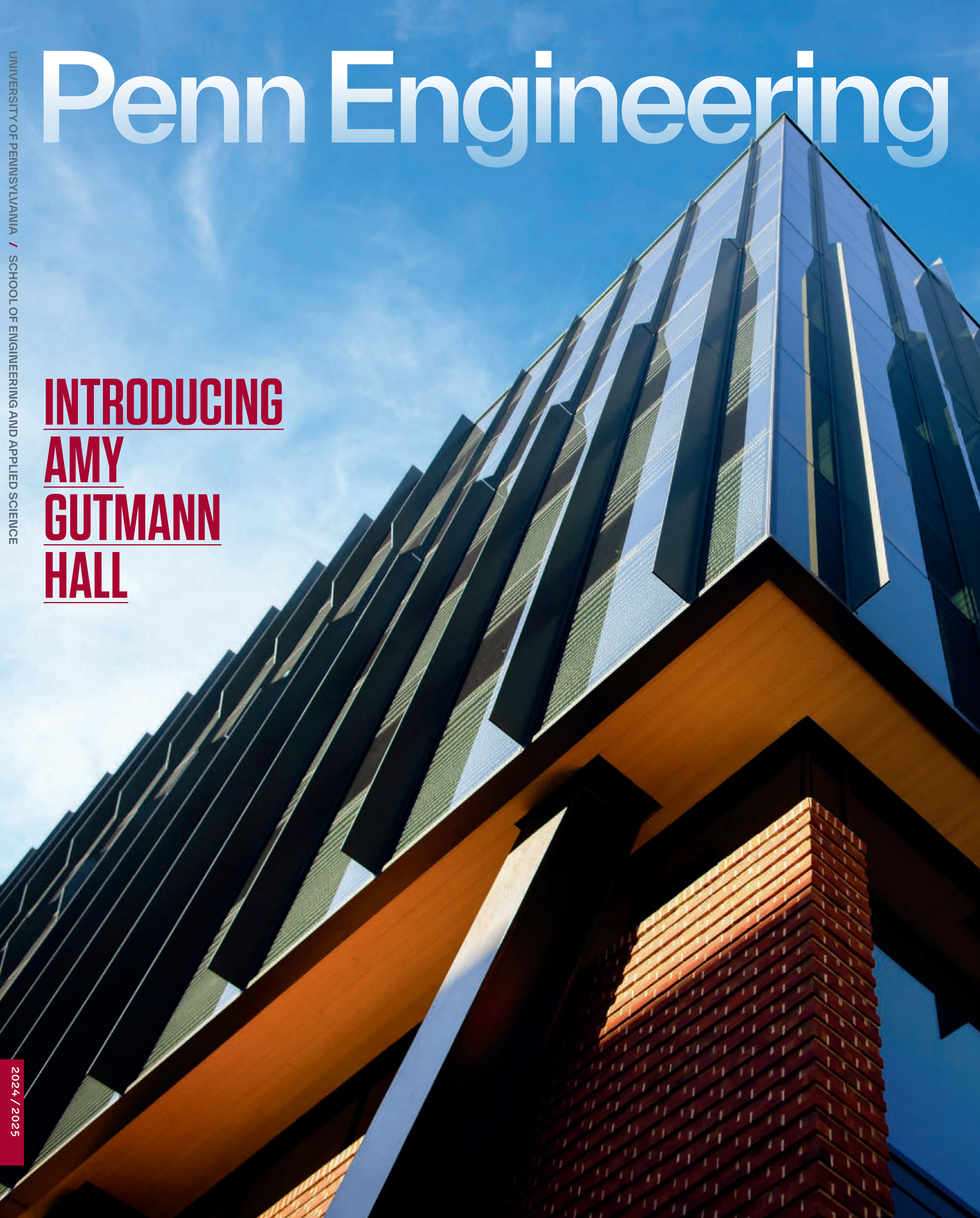
Penn Engineering



UNIVERSITY OF PENNSYLVANIA / SCHOOL OF ENGINEERING AND APPLIED SCIENCE

INTRODUCING AMY GUTMANN HALL

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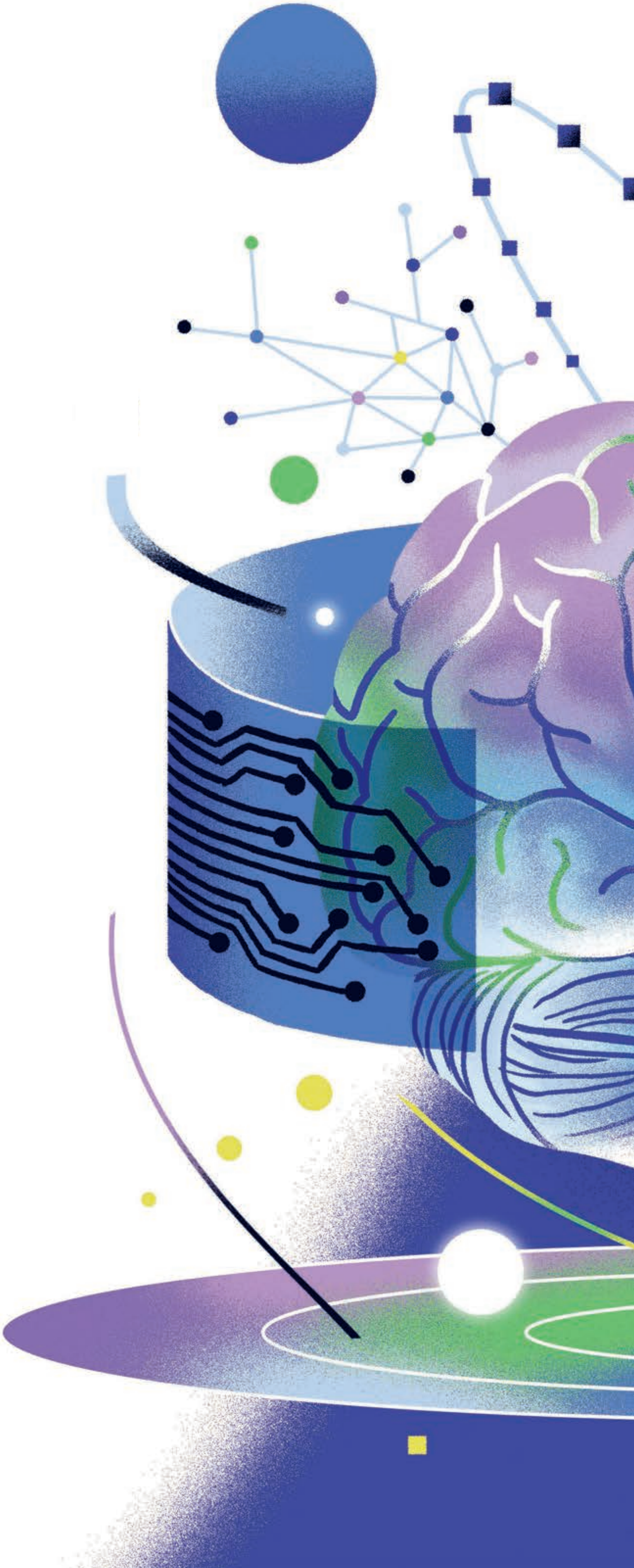
STOPPING SEIZURES BEFORE THEY START

BY Melissa Pappas



Neurological disorders such as epilepsy, Alzheimer's, Parkinson's and certain forms of dementia are the leading cause of disability and the second-leading cause of disease worldwide. These disorders disproportionately affect low-resourced communities due to lack of access to specialized health care, and many of these complex diseases lack curative solutions. The need to address neurological disorders is high, yet current diagnostics and treatments are not effective for preventative or personalized care and are not accessible or affordable enough to meet the needs of the more than 3 billion people living with neurological disorders.

Flavia Vitale, Associate Professor in Bioengineering in Penn Engineering and in Neurology in Penn's Perelman School of Medicine, works to meet this need, developing accessible and affordable solutions for the diagnosis, treatment and rehabilitation of people living with neurological disorders.

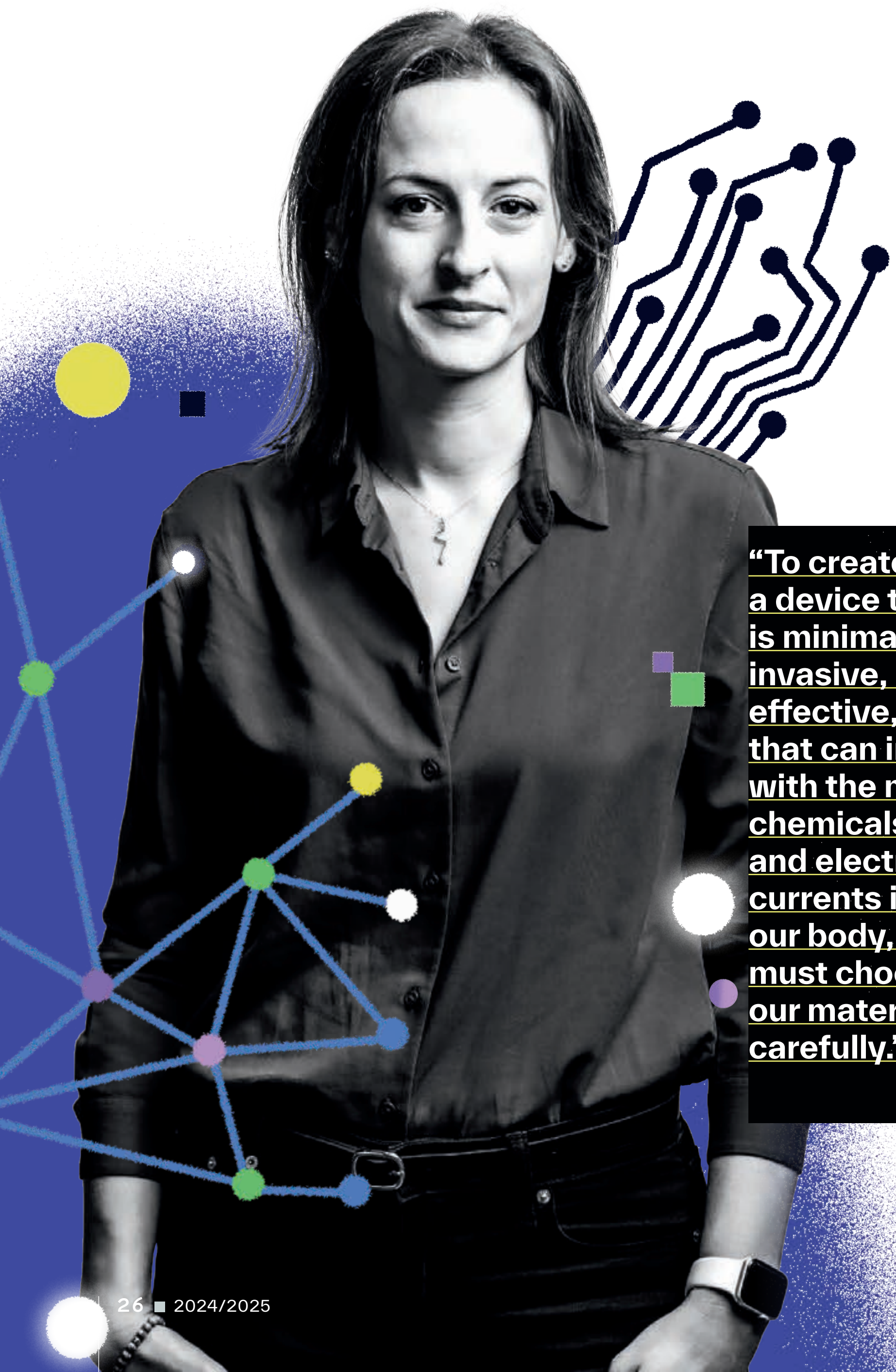
"I started my research career in biomedical engineering hoping to one day help humanity," says Vitale. "But it wasn't until I gained a more diverse skill set during my doctoral and postdoctoral research across chemical engineering and materials science that I was able to do that in a real way."

Vitale's multidisciplinary skills are what allow her to develop devices that help people living with brain disorders. Her lab's current research projects leverage innovation in materials and fabrication approaches to develop devices that are able to interface with and control different chemical and electrical signals inside the brain.

ILLUSTRATION BY **MATT CHINWORTH**

EXPANDING UNDERSTANDING

Focused primarily on understanding the brain activity involved in epilepsy-induced seizures, Vitale aims to design and develop brain-interface devices to pinpoint and suppress uncontrolled brain activity to prevent seizures from happening. She hopes that her work will lead to revolutionary health care for the 30% of epilepsy patients whose conditions are drug resistant. Currently, those patients either wait out the uncontrolled brain activity and oftentimes life-threatening convulsions, or hope to be eligible for invasive surgeries to either remove the part of the brain where seizures originate or to implant the seizure-controlling devices that are currently available.



"Very little is known about the brain during an epileptic episode," says Vitale. "We don't know what knobs to turn or what buttons to push to stop or prevent a seizure, nor can we ensure that when we remove a piece of the brain, those seizures will stop."

Current implants used to treat refractory epilepsy, the kind that is not treatable by medication, have been designed based on this incomplete understanding of the brain.

"These seizure-suppressing devices are not exact," says Vitale. "They cast a wide net, emitting electrical signals to the surrounding parts of the brain without much selectivity."

But, the brain is multimodal; it operates through both chemical and electrical interactions. Chemicals constantly flow through the synapses and ion channels of our neurons. Many of these molecules hold a positive or negative charge, and the flow of these ions causes electrical gradients, which give rise to action potentials measured in volts. It is these fluctuations in voltage across neuronal membranes combined with the chemicals themselves that create the intricate electrochemistry in our brain that allows us to move, think and feel emotions. Current seizure-suppressing devices are only speaking the electrical language to talk to the brain, completely neglecting the chemical communication.

In contrast, Vitale's work will combine the chemical and electrical languages of the brain together with her expertise in nanofabrication to design a new device.

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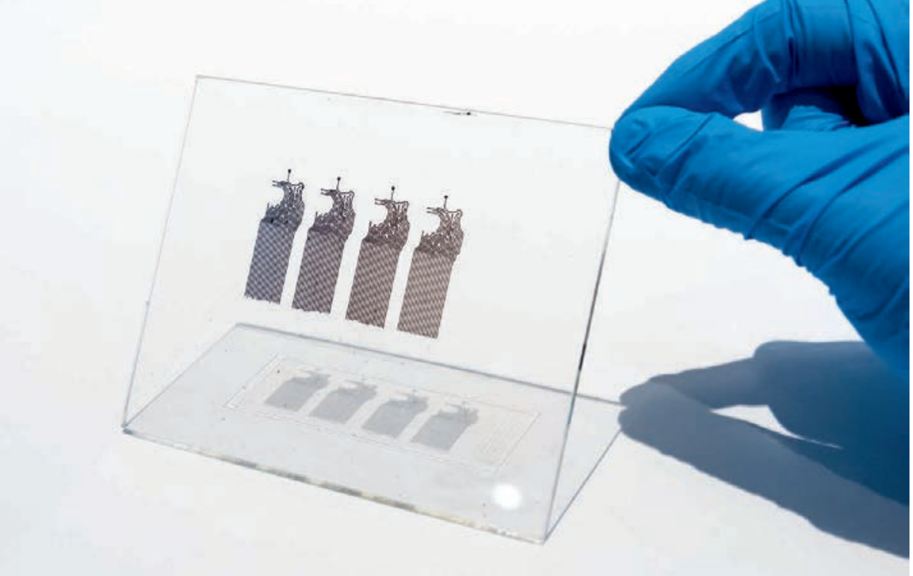
NOVEL DEVICES

"To create a device that is minimally invasive, highly effective, and that can interact with the multiple chemicals and electrical currents in our body, we must choose our materials carefully," says Vitale. "Right now, my group is turning to electrically conductive nanomaterials known as MXenes to do this work."

MXenes, pronounced "max-eens," are 2D-layered materials that exhibit properties of both ceramics and metals. They conduct heat and electricity like metals but are strong and heat-tolerant like ceramics. They have been applied to new technologies across energy storage, medicine and flexible displays, and researchers estimate that there are more than a million stable MXene compounds that remain undiscovered.

PHOTOS BY **KEVIN MONKO**



The Vitale Lab engineers the electrochemical, mechanical and optical properties of nanostructured materials and integrates them in soft, multimodal bioelectronic interfaces that can seamlessly monitor and modulate the nervous system at high spatio-temporal resolution and at multiple scales, from individual cells to large-scale circuits.

Vitale's chosen MXene compound can be functionalized with unique chemical-recognizing compounds to selectively write, detect and recognize specific neurotransmitters in the brain. They are also safe, affordable and easy to process, a win-win for an improved and accessible device.

Another bonus when using MXenes is their ability to be used in research-advancing experimentation.

"Because the chemical compounds and these devices made with MXenes are transparent, we can use these devices in light-controlled experiments," says Vitale. "We can use light to excite cells or regions in the brain, or we can use light and fluorescence indicators to look at fluorescence fluctuation inside the brain on a cellular level as an additional indicator of cellular activity."

INCREASING ACCESS

Vitale is a 2024 recipient of a National Science Foundation (NSF) CAREER Award for her work, which will further actualize some of her first long-term research projects at Penn. Looking ahead, she hopes to collaborate across disciplines to develop MXene-based interfaces to investigate brain disorders and then to design other responsive, wireless and AI-integrated devices that could infer brain state and help doctors and patients make informed decisions.

Additionally, funding from the CAREER Award also allows her to welcome new students into her lab. "One of the most exciting aspects of our work is our summer internship offered to a different high school student from the Philadelphia School District each year for the next five years," says Vitale. "Penn Medicine hosts a yearly cohort of about 25 high school students who participate in educational and training sessions on campus throughout the academic year. Of those students, those interested in neuroengineering will be invited to apply to the summer internship in our lab and get hands-on research experience."

Vitale will also share her work and career story through themed seminars on engineering health-care technologies to inspire students to see engineering as a tool to serve humanity, and will continue to train undergraduate and graduate students at Penn in research, guiding them in their careers across academia, industry and entrepreneurship at the epicenter of the innovations in her field.

"I am truly grateful to be doing this work at Penn," says Vitale. "My location on campus places me centrally between the medical and engineering complexes, coordinating with my intellectual needs for this work and the work I hope to pursue in the next decade as a result.

"After my postdoc, I realized that I knew a lot about technology and nanomaterials, but I still needed to understand the needs of clinicians, the everyday problems of doctors and the patients I was trying to help," she continues. "Being at Penn and collaborating with folks at the Penn Center for Neuroengineering and Therapeutics and Penn Health-Tech has been key in the connecting of those dots, helping me bring technologies from the lab to real people as fast as possible."