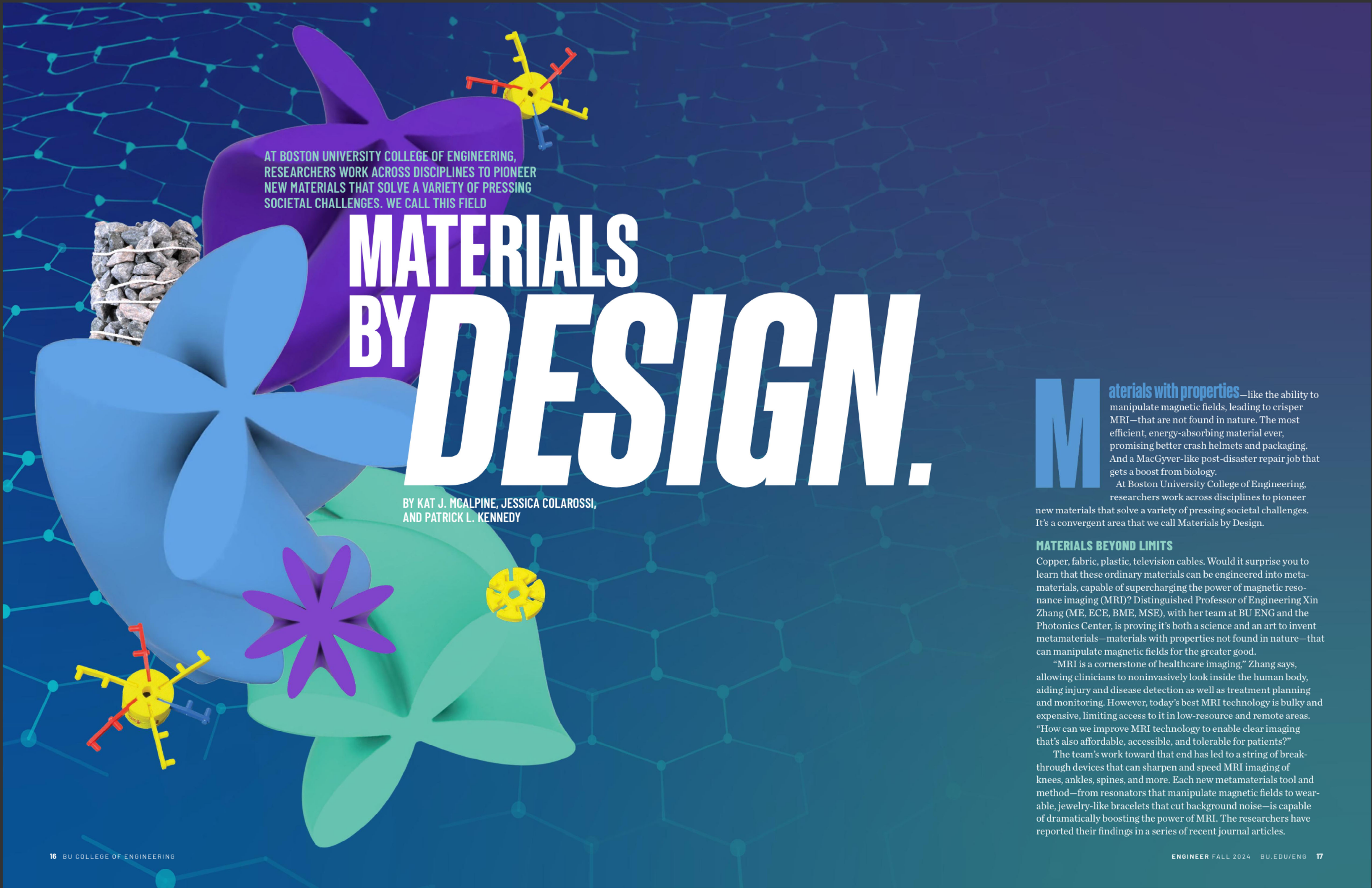




AT BOSTON UNIVERSITY COLLEGE OF ENGINEERING, RESEARCHERS WORK ACROSS DISCIPLINES TO PIONEER NEW MATERIALS THAT SOLVE A VARIETY OF PRESSING SOCIETAL CHALLENGES. WE CALL THIS FIELD

MATERIALS BY DESIGN.

BY KAT J. MCALPINE, JESSICA COLAROSSO,
AND PATRICK L. KENNEDY

Materials with properties—like the ability to manipulate magnetic fields, leading to crisper MRI—that are not found in nature. The most efficient, energy-absorbing material ever, promising better crash helmets and packaging. And a MacGyver-like post-disaster repair job that gets a boost from biology.

At Boston University College of Engineering, researchers work across disciplines to pioneer new materials that solve a variety of pressing societal challenges. It's a convergent area that we call Materials by Design.

MATERIALS BEYOND LIMITS

Copper, fabric, plastic, television cables. Would it surprise you to learn that these ordinary materials can be engineered into metamaterials, capable of supercharging the power of magnetic resonance imaging (MRI)? Distinguished Professor of Engineering Xin Zhang (ME, ECE, BME, MSE), with her team at BU ENG and the Photonics Center, is proving it's both a science and an art to invent metamaterials—materials with properties not found in nature—that can manipulate magnetic fields for the greater good.

"MRI is a cornerstone of healthcare imaging," Zhang says, allowing clinicians to noninvasively look inside the human body, aiding injury and disease detection as well as treatment planning and monitoring. However, today's best MRI technology is bulky and expensive, limiting access to it in low-resource and remote areas. "How can we improve MRI technology to enable clear imaging that's also affordable, accessible, and tolerable for patients?"

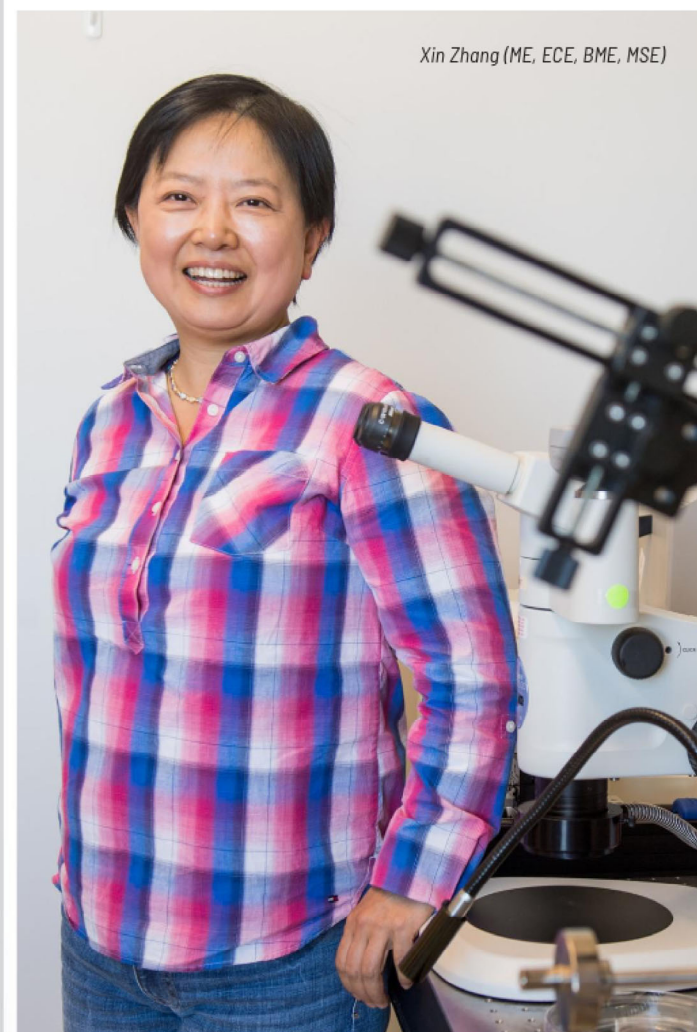
The team's work toward that end has led to a string of breakthrough devices that can sharpen and speed MRI imaging of knees, ankles, spines, and more. Each new metamaterials tool and method—from resonators that manipulate magnetic fields to wearable, jewelry-like bracelets that cut background noise—is capable of dramatically boosting the power of MRI. The researchers have reported their findings in a series of recent journal articles.

Zhang has studied the applications of metamaterials in a variety of fields, notably including sound-canceling technology. A major focus for her team in recent years has been metamaterials' potential to improve MRIs. By 2022, they had developed a helmet that could channel an MRI machine's magnetic field to deliver clearer images of the brain and drastically cut scanning time. Recently, they have built upon that work with computationally designed wearable metamaterials that can be fitted to any part of the body—even to an irregularly shaped area like the elbow or knee. The researchers showed how the metamaterials could be used to improve scans of the ankle with a cage-like brace of connected discs surrounding the joint.

"While we could manually design the helmet from our earlier work, we recognized that free-form deployable metamaterials fitted to other parts of the body would require computational aid," says Ke Wu, a postdoctoral fellow in Zhang's lab.

Wu developed algorithms and programs capable of analyzing a 3D scan of a part of the body and, within less than a second, calculating the geometry and arrangement of helical resonators—structures made of plastic and thin copper coils—that can manipulate the magnetic field of MRI. Critically, these arrays of coils help to improve the signal-to-noise ratio (SNR) of MRI of the target area, reducing the fuzziness of imaging that's caused when background electromagnetic signals seep into view.

Wu's computational programs use the principles of circle packing—a geometric approach to squeezing circles together without any of them overlapping—to determine the best array and architecture for arranging the magnetic coils. They can also be tuned to resonate with a particular radio frequency, while the freeform shapes can be integrated into comfortable, wearable cuffs.



Xin Zhang (ME, ECE, BME, MSE)



It's not a piece of artisan jewelry or a must-have fashion accessory. This is one of the ultracompact, lightweight coils engineered by BU researchers to wirelessly and passively enhance MRI imaging.

In related work, Zhang's team demonstrated an alternative wearable metamaterial design for MRI that replaces copper and plastic coils with loops made from coaxial cables—the same cables used to bring you the internet. Coaxial cables are designed to transmit high-frequency electrical signals and shield them from their surroundings, preventing unintended loss of signal. "This material has inherent advantages because it is lightweight, flexible, and restricts the electrical field to exactly where you want it," says Xia Zhu, a graduate student in Zhang's lab.

Zhu created fabric-based wearable metamaterials—each using only about \$50 of materials—designed to bring loops of coaxial cables as close as possible to the part of the body undergoing a scan. For example, a potential knee scan consists of a pad of lightweight fabric, covered with a handful of coils, bending to the curve of the patient's leg as they lie in the MRI machine. The researchers found it achieved "substantial electric field attenuation in its proximity, thereby minimizing electric field exposure to the imaging subject."

Pushing even further, the team sought to develop an entirely wireless, form-fitting wearable metamaterial that could boost SNR and passively tune and amplify the MRI signal. "To create a design this simple and elegant, we had to solve several problems first," says Zhang, who's affiliated with the BU Photonics Center, which provided technical assistance for much of the latest research.

With their longtime collaborator Stephan W. Anderson, a BU Chobanian & Avedisian School of Medicine professor of radiology, Zhang's team demonstrated that the coaxial cables can be arranged into freestanding cuffs without additional support materials—no fabric needed. They prototyped rings and cuffs sized to enhance MRI scans of the spine, the wrist, and a single finger—and in every experiment, proved their seemingly simple design could amplify

SNR and enable crisp MRI. The looped and ringed cables look like modern art or custom jewelry.

"Our recent designs demonstrate several strategies for using metamaterials to boost MRI using low-cost materials," Zhang says, "which we hope will be translated into technologies that allow more patients around the world to benefit from MRI."

A ROBOT ON A MISSION

Inside a BU ENG lab, a robot arm drops small, plastic objects into a box placed perfectly on the floor to catch them as they fall. One by one, these tiny structures—feather-light, cylindrical pieces, no bigger than an inch tall—fill the box. Some are red, others blue, purple, green, or black.

Each object is the result of an experiment in robot autonomy. On its own, learning as it goes, the robot is searching for, and trying to make, an object with the most efficient energy-absorbing shape to ever exist.

To do this, the robot creates a small plastic structure with a 3D printer, records its shape and size, moves it to a flat metal surface—and then crushes it with a pressure equivalent to an adult Arabian horse standing on a quarter. The robot then measures how much energy the structure absorbed and how its shape changed after being compressed, and records every detail in a vast database. Then, it drops the crushed object into the box and wipes the metal plate clean, ready to print and test the next piece. It will be ever-so-slightly different from its predecessor, its design and dimensions tweaked by the robot's computer algorithm based on all past experiments—the basis of what's called Bayesian optimization. Experiment after experiment, the 3D structures get better at absorbing the impact from getting crushed.

"OUR RECENT DESIGNS DEMONSTRATE SEVERAL STRATEGIES FOR USING METAMATERIALS TO BOOST MRI USING LOW-COST MATERIALS," ZHANG SAYS, "WHICH WE HOPE WILL BE TRANSLATED INTO TECHNOLOGIES THAT ALLOW MORE PATIENTS AROUND THE WORLD TO BENEFIT FROM MRI."