Tanya Domi:

Hi, this is Tanya Domi. Welcome to The Thought Project recorded at The Graduate Center of the City University of New York, fostering groundbreaking research and scholarship in the arts, social sciences, and sciences. In this space, we talk with faculty and doctoral students about the big thinking and big ideas generating cutting edge research, informing New Yorkers and the world.

Tanya Domi:

In 2018, physicist and engineer Andrea Alù joined the Advanced Science Research Center at The Graduate Center, CUNY. As founding director of the Photonics Initiative, broadly recognized as a leading scientist in optics and photonics, Alù and his team are working to understand how we can use metamaterials to interact with electromagnetic and mechanical waves and force them to behave in unusual ways opening the door to leapfrog advances in energy harvesting, data delivery, computing and medical treatment. Alù is the principal investigator for research projects supported by the U.S. Department of Defense, Simons Foundation, National Science Foundation, and several other major funders. He is the 2021 Blavatnik Award Laureate in physical sciences, in engineering, for his broad body of work on metamaterials. He is the first faculty member in CUNY and The Graduate Center to receive this distinguished award. Andrea Alù is with us today for the second time to talk about his breakthroughs and being named the 2021 Blavatnik National Award recipient. Welcome back to The Thought Project, Professor Alù.

Andrea Alù:

Thank you. It's great to be here.

Tanya Domi:

In the introduction, I mentioned metamaterials as well as electromagnetic and mechanical waves. I think it would be a good place to start our conversation with a bit of explanation for our lay listeners, non-scientists. What are metamaterials and what are electromagnetic and mechanical waves?

Andrea Alù:

These words may sound scary, but electromagnetic waves are everywhere around us. We are used to rely on them for the most common daily life activities. Light is the best known, the most common, electromagnetic wave. Our eyes see the objects around us by detecting and collecting light waves, scattered [inaudible 00:02:51] surface and many other common electromagnetic waves are all around us. They carry signals to our cell phones, radios, and TV sets, for instance. Mechanical waves are equally common, I would say, sound is the most familiar with, but the movement of water in the ocean, even earthquakes, are caused by mechanical waves. For centuries, physicists and engineers have dedicated their lives to try to understand the rules that govern how these waves propagate. And more recently, we have been able to realize that these waves can be harnessed to drive a broad range of technologies. For instance, they can power our energy grids, they can transmit our data and can heal our bodies.

Tanya Domi:

That is a lot of different things.

Andrea Alù:

By the way, I did not mention about metamaterials.

Tanya Domi:

Please.

Andrea Alù:

My research focuses on metamaterials that are engineered materials built from the nano scale up, in such a way to interact in special ways with light, sound, and other wave types. The word metamaterials comes from the Greek word meta that means "beyond". So, our metamaterials with nano fabrication tools go beyond what nature offers us. We can imprint in them new physical properties that do not exist in nature and materials, and we can tailor the optical properties, electromagnetic acoustic features, mechanical electrical terminal properties as well. With the modern nanotechnology, we can control their structure, their microstructure, or nanostructure up to the atomic scale.

Tanya Domi:

Which you can't see with your own eye, right? It is very, very difficult to see.

Andrea Alù:

Even common microscopes may not go as deep, so we need to use very special tools to fabricate them and characterize them. And interestingly, we can really synthesize truly exceptional interactions between waves and these materials. We typically start from conventional materials. For instance, we use glass, gold, silver, but by carefully patterning their nanostructure we can enable totally different responses for light, for sound, and these excitations become actually crucial for many applications and technologies.

Tanya Domi:

Can you give an example to how they are used in new technologies?

Andrea Alù:

Yes, I can give several examples. Actually, we work on many technologies, both for wireless communications, for biomedical sensing and imaging for energy harvesting. But to start, it will be good to understand how, actually, light and sound interact with common materials. With this material the interactions of light and sound are very weak. So typically, the size of common devices that manipulate them are necessarily large. Think, for instance, of the lenses that capture pictures on our cell phones. You may notice that they typically stick out from the body of the phone and that is because they cannot be too thin. Antennas that receive the radio signals that drive our cell phone communications also dominate the size of our phones. Solar panels that extract energy from sunlight have limited efficiency that can not only partially address the ever-growing energy needs of our society.

Andrea Alù:

From the fundamental point of view, our group has been asking, "what are the ultimate limits on which light, sound and other waves can interact with materials? Can we make these interactions much stronger? And can we actually engineer the best possible materials for a given functionality?" On one hand, we study driven by curiosity, the challenges of modern technologies. And at the same time, we explore ways in which we can overcome them with the meta materials.

Tanya Domi:

The discipline involved here is physics and engineering, right? These are what really shape photonics discoveries. Is that correct?

Andrea Alù:

Metamaterials are highly interdisciplinary discipline. It is very interesting how much many disciplines have to come together. You are right. Physics and engineering are the...

Tanya Domi:

Primary ones.

Andrea Alù:

... Fundamental. But also, material science, chemistry, acoustics, many disciplines come together to drive the technology and understand what are the fundamental limits that we can achieve.

Tanya Domi:

So, working at the ASRC is an ideal environment, is it not?

Andrea Alù:

Absolutely, absolutely. Since we moved to the ASRC, the past three years have been flourishing with new ideas because we can actually talk to experts in other fields and understand their challenges in technologies and try to address them, at the same time, learn new techniques to fabricate, characterize these materials.

Tanya Domi:

Very interesting. So, what new technologies or solutions could result from you and your team's discoveries? What can you look out and imagine?

Andrea Alù:

Yes, so I was talking about these common interactions of waves with materials that are typically weak. And drawing from these examples, today we can realize metamaterials that can realize lenses thinner than a human hair. We can realize, and we've been working on augmented reality technologies that blend themselves within our glasses so they can enhance the way in which we see things around us, and we add information to that, energy harvesting devices that have record high efficiencies, as examples. We also create materials that engage light and sound to realize ultrafast computers and improve biomedical imaging. Another recent aspect of our work has been to tackle fundamental limitations of common materials.

Andrea Alù:

A good example is the inherent symmetry with which light and sound travel in common materials. It is known as reciprocity. If a wave, for instance, a beam of light, a radio wave or an acoustic signal can go from point A to B in space, they are able to also travel back from B to A with the same efficiency in common materials. However, we have been building metamaterials that break the symmetry and based on these principles, we've been implementing devices that allow one way flow of light and sound functionalities that are fundamental to build better radar laser ultrasound technologies, and also make more efficient cell phone communications, automotive technologies and communication systems.

Tanya Domi:

That involves so much of our everyday life.

Andrea Alù:

Absolutely, that's the beauty. We can work on the fundamental aspects and most of our research is really curiosity driven, but it's nice to see how much impact we can also have on our daily lives, also grand societal challenges.

Tanya Domi:

So, object cloaking is one area of your work that has captured the imagination of many science fiction fans. Can you talk a bit about how this technology might work in real life compared to what we've seen on shows like Star Trek, for example?

Andrea Alù:

Another aspect of metamaterials is that we can tailor strongly the scattering of waves. We can make small objects appear much larger to our eyes and this can be very interesting to image tiny details, for instance, for biomedical imaging. But conversely, over the years, we have also shown that we can make large objects appear much smaller than they are. Sort of invisibility cloak for various wave types. We achieve this functionality by creating metamaterials that change the way light or sound waves are scattered around as they interact with our materials. The waves can be controlled and tailored by these materials to go straight through our cloaked objects without scattering. That means we don't only eliminate reflections like a stealth technology, but also eliminate their shadows.

Tanya Domi:

Because if you saw a shadow, you would know something is there.

Andrea Alù:

Yes, especially for radar technologies, for instance, which use that to detect objects, it is important. But, yes, so it's not just eliminating the shining of waves from the surface of an object, but also making it completely transparent and not detectable. This is also important for practical applications. For instance, we have been applying these concepts to build more efficient microscope sensors.

Tanya Domi:

Microscopes, I would think, would be important in the medical world.

Andrea Alù:

Exactly, yes. So, this cloak, the microscope tips, can faithfully image the details of any images. They go very close to it without perturbing these measurements using the absence of scattering and also radio transparent antennas that can of wireless communication systems. I was saying just to clarify for everyone, that there are also fundamental limitations, for instance, on the size of the objects, we can cloak to different types of waves. So, you should not necessarily dream today of a Star Trek device just yet, but there are many applications for modern technologies for which these are already very useful.

Tanya Domi:

That's interesting, and of course I'm sort of familiar because I served in the military about stealth planes, stealth combat aircraft, and the idea that it's not seen, but it is seen, it just disappears and then can reappear, is that right?

Andrea Alù:

Yes. So, our technologies are kind of a more advanced form of this stealth. Stealth airplanes only eliminated the back reflections from a rudder wave that tries to detect it. So, they're very good to kill some forms of rudder imaging, but not others, the more sophisticated ones. Our techniques can make more advanced form of stealth technology that suppresses also shadows and improves the undetectability of these objects.

Tanya Domi:

Fascinating. And of course, many people who watch Star Trek always latch onto the idea of cloaking. This past summer, you were named in a very prestigious award, the 2021 Blavatnik National Laureate Award for your work in physical sciences and engineering. Indeed, you are the first CUNY faculty member to ever receive such an award. This award is the largest unrestricted scientific prize for young scientists in the U.S. and you, indeed, were the first faculty member in CUNY, as well as at The Graduate Center. Tell us a bit about the award significance and what it means for your career.

Andrea Alù:

This award is a truly fantastic recognition for all the hard work and efforts that myself and my group members have done over the past several years. And it is also a huge boost for our future work end upcoming research explorations. I take the opportunity to thank, sincerely, Mr. Len Blavatnik, the Blavatnik Family Foundation, the New York Academy of Sciences that have selected me for this prestigious award. And I want to share it with my group members and collaborators at CUNY and in other universities over the years. We've been working together tirelessly on many open questions related to way physics. I also would like to acknowledge our several funding agencies that support this works, the companies, private foundations, and of course The Graduate Center for the continuous support and encouragement over the past three years.

Tanya Domi:

Congratulations, Professor Alù. It is a distinguished award.

Andrea Alù:

Thanks very much.

Tanya Domi:

Thanks for tuning into The Thought Project and thanks to our guest, Professor Andrea Alù of the Advanced Science Research Center, and the founding director of the Photonics Initiative.

Tanya Domi:

The Thought Project is brought to you with production, engineering and, and technical assistance by Kevin Wolf of CUNY TV. I'm Tanya Domi tune in next week.