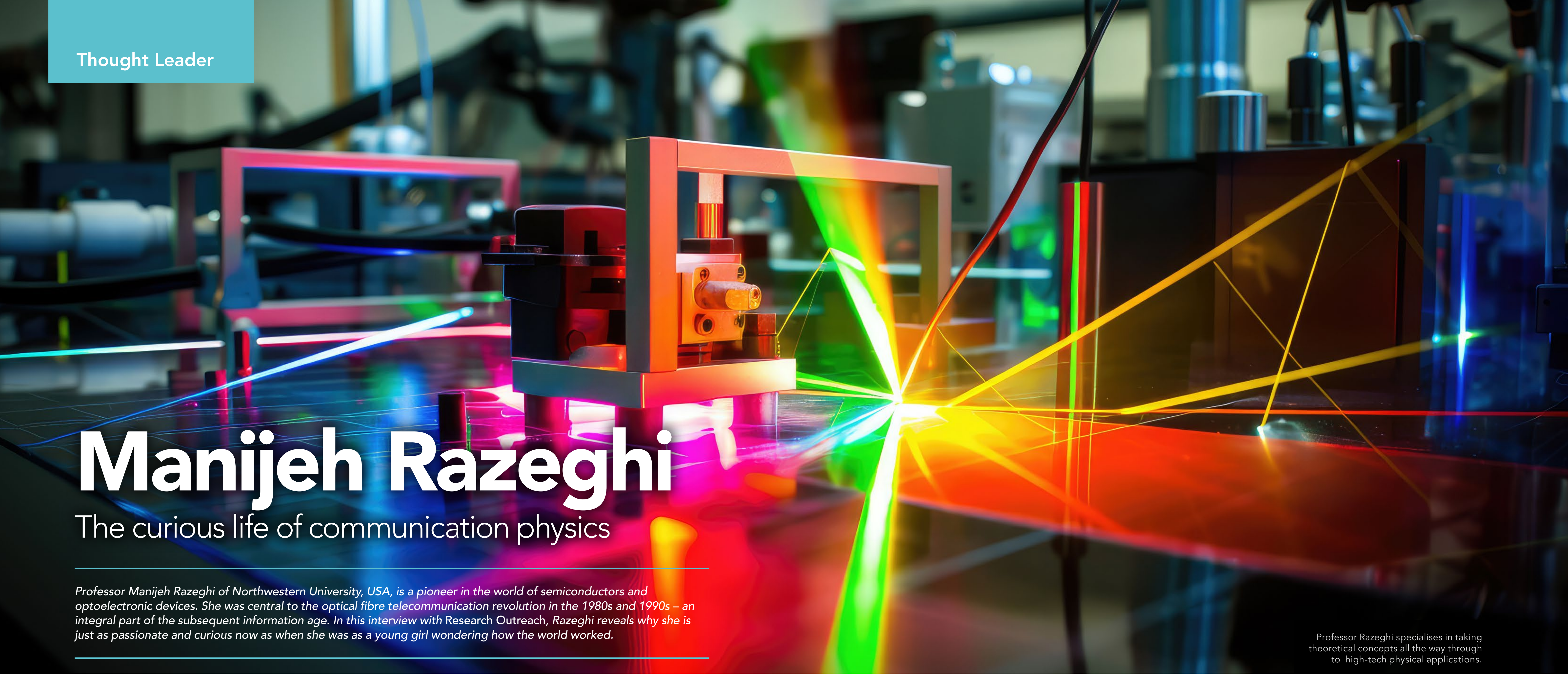


Manijeh Razeghi

The curious life of communication physics

Professor Manijeh Razeghi of Northwestern University, USA, is a pioneer in the world of semiconductors and optoelectronic devices. She was central to the optical fibre telecommunication revolution in the 1980s and 1990s – an integral part of the subsequent information age. In this interview with Research Outreach*, Razeghi reveals why she is just as passionate and curious now as when she was as a young girl wondering how the world worked.*

Professor Razeghi specialises in taking theoretical concepts all the way through to high-tech physical applications.

Professor Manijeh Razeghi was born in Iran and received the Doctorate d'état ES Sciences Physiques from the Université de Paris, France, in 1980. She began her research in semiconductor physics at the Thomson-CSF Exploratory Materials Lab. Here, Razeghi developed near-infrared InP-based laser diodes critical for optical fibre communications, revolutionising telecommunication in the 1980s. Her desire to use her knowledge not just for research but also to educate the next generation of scientists and engineers led her to accept a special position at Northwestern University in 1991 as the Walter P Murphy Professor and the Director of the Center for Quantum Devices (CQD).

CQD was designed and built by Razeghi based on her vision of a comprehensive facility that covers all aspects of device development. CQD is a unique combination of materials and device research that enables the rapid transition from groundbreaking concepts to technology demonstration. CQD, under Razeghi's guidance, has achieved a long record of outstanding accomplishments in the areas of lasers and photodetectors, ranging in wavelength coverage from ultraviolet to terahertz. These accomplishments have resulted in a huge number of publications including more than 1,000 papers, and many US patents. Razeghi has received several prestigious awards for her research, including the IBM Europe Science and Technology Prize (1987) and the Benjamin Franklin Medal for Electrical Engineering (2018).

Professor Manijeh Razeghi of Northwestern University, USA

Razeghi's research contributed to the development of affordable shoebox-sized lasers that can detect explosives in luggage, as well as electronic devices that are capable of delivering turbo-charged, superfast Wi-Fi. In this interview with *Research Outreach*, Razeghi tells us about her life and work, and why passion and curiosity are the cornerstones of both.

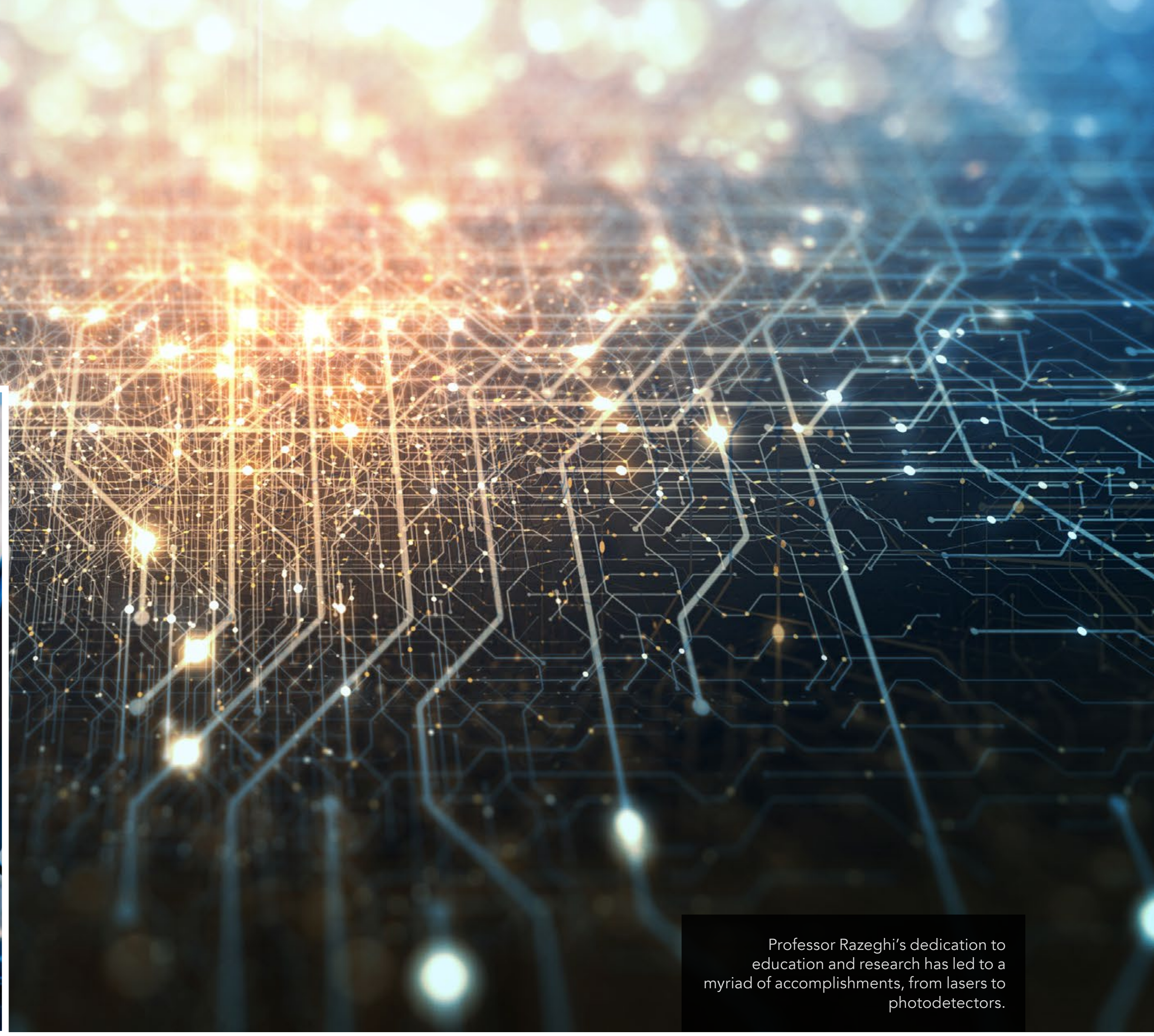
Could you tell us a bit about your field and what you've worked on so far?

The field of quantum semiconductor devices was established in the late 1970s, and my initial work in this field began in 1981, after I finished my doctorate in physics at the University of Paris-XI and went to work in the Central Research Lab at Thomson CSF. At that time, I did not know anything about semiconductors, but I was tasked with the development of metalorganic chemical vapour deposition (MOCVD) reactors and processes for InP–based lasers to be used in telecommunication. My in-depth study of MOCVD processes and creation of the highest-quality GaInAsP/InP heterostructures led to the demonstration of near-infrared (808 nm and 1,500 nm) laser diodes that could meet the stringent requirements of optical fibre communications systems. These InP-based laser diodes, grown by such a flexible method as MOCVD, paved the way for this entire industry throughout the 1980s. This research also provided the foundation for my book, The MOCVD Challenge, which is now in its 2nd edition.

I wanted to know how we can discover this world of the unseen.

After my move to Northwestern University in 1991, and the establishment of the Center for Quantum Devices (CQD), my research in this field expanded to include other quantum optoelectronic devices and materials – for instance, studies and demonstrations of infrared photodetectors utilising InP-based quantum wells and quantum dots.

Razeghi's work in semiconductor physics paved the way for near-infrared laser diodes crucial for optical fibre communications, transforming telecommunications.



Professor Razeghi's dedication to education and research has led to a myriad of accomplishments, from lasers to photodetectors.

This was followed by studies of other promising IR detector materials, such as Sb-based type-II superlattices composed of InAs/GaSb and later InAs/InGaSb grown by either MOCVD or molecular beam epitaxy. There were many world-first accomplishments during the 20+ years of development of these superlattices. This was due to the comprehensive facilities of CQD where everything from materials growth and testing up to complete device fabrication and characterisation can be accomplished rapidly and provide quick feedback on improvements to the materials and devices. CQD is the only facility that can develop a single photodiode from concept to a focal plane array and demonstration of an imaging infrared camera.

Similarly, the research on lasers was expanded to include new materials and device designs to create light emission at wavelengths from ultraviolet (UV) to terahertz (THz). For instance, using the MOCVD growth of nitride materials, CQD demonstrated the first blue laser. Nitride materials, such as GaN and AlGaN were also used to develop UV light-emitting diodes. In the infrared, lasers based on a technology known as quantum cascade lasers (QCLs) were pursued. These lasers are based on complex multilayer heterostructures using semiconductor compounds such as InP, InAs and Sb-based materials. Operation of these devices depends on the highest-quality materials as well as careful control of each atomic layer in the design. Despite entering the field after other researchers, I led my team to quickly surpass the previous results for QCLs in terms of power output, efficiency, longer wavelength emission, and tunability. The team's latest results are always highly anticipated and followed by others in the field, leading to numerous plenary and invited talks around the world.

In addition to lasers and photodetectors, CQD is also involved in the development of new materials for high-power transistors. Recently, we have been exploring the formation of the next generation of high-power electronics. As with any new material, studying the deposition processes is the first step. In addition, a key element in semiconductor transistor development is controlling the doping in the layers. In new materials, discovering the processes for p-type and n-type doping are critical. My group was able to achieve the first demonstration of a p-type Ga_2O_3. This work was a significant advancement which would allow the fabrication of future p-n junction based devices. Transistors utilising β-Ga_2O_3 thin films are of high interest for compact high-voltage switching systems and for use in 5G and beyond radio-frequency (RF) based communications.

These examples of past and current research provide an idea of the breadth of materials and devices that can be developed at CQD.

How has your scientific life and career been impacted by your personal journey, particularly as a woman in science?

I was always curious about everything, and especially about the things that I was surrounded by. When you are a child, you are very curious and receptive to the world around you, and you want to know how it all works. In other words, I wanted to understand the Universe and understand myself. We are living now in the quantum era of artificial intelligence (AI). But, when we go back to basics – atoms, electrons, protons – we need quantum mechanics to understand it.

Looking at the structure of the atom, we come to the electromagnetic spectrum. Our eyes can see only a small part of this spectrum: the colours of the rainbow. But most animals and fish can see much more than us. I wanted to know how we can discover this world of the unseen. I wanted to create a way that I could see and create light in the entire electromagnetic spectrum. That is my motivation. I came to the USA from France to create a facility that is unique in the world to conduct my research and inspire others.

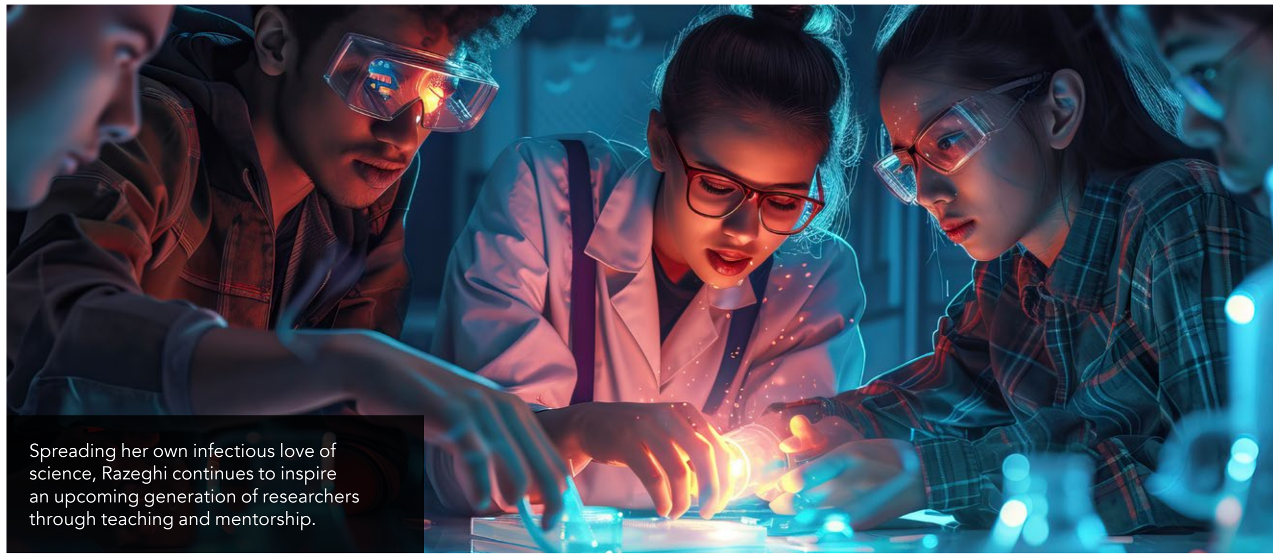
I love research, I love the science; my students say that it's contagious.

For any individual, your personal life and scientific role are related. When you are a scientist, the word 'work' has no meaning. It's your hobby. You have to have the passion; you have to have the curiosity. And if that's the case, every minute is enjoyable. But at same the time, you realise there is so much more to learn, and research is the means to discover new ideas and deeper understanding. I tell my students that we are being paid to do something that we love. That is my philosophy.

I was born and grew up in Iran. In the Persian culture, there was no difference between women and men, and I felt that I could succeed in anything that I wanted to pursue. But when I came to the USA and Europe, I saw women were the minority, especially in my fields of physics and later electrical engineering. In fact, I was often the only woman working in my area; I have been on the editorial board for *Nature: Light* for ten years and for most of that time I have been the only woman. Other than being in the minority, being a woman has not impacted my career, and I would like to encourage young women to consider physics and electrical engineering as an exciting and fulfilling career path.

At Northwestern's Center for Quantum Devices, Razeghi pioneers the cutting-edge development of semiconductor devices.

Razeghi's interdisciplinary approach to device development is testament to her unique ability to transform innovative ideas into real-world solutions.



Spreading her own infectious love of science, Razeghi continues to inspire an upcoming generation of researchers through teaching and mentorship.

Could you tell us a little bit about the process of how something goes from a theoretical concept to a physical application?

I created the Center for Quantum Devices, which is unique in the world, for the development of a wide variety of semiconductor devices, because each device has some important application. We start the development first with theoretical modelling of the concept, and after that the creation of the actual material we designed. For each material, we need a new epitaxial reactor, a new machine to create the quantum structure. I have been directly involved in the custom design of these reactors used in CQD by working directly with the manufacturers. Once the material is deposited, atomic layer by layer, the electrical and optical properties are characterised and compared to the theoretical prediction. This is a test of both the theory and the material deposition. Next, the material properties are verified, and if the material is of high quality, then device fabrication is performed. For every step, very sophisticated, complicated, and expensive equipment is required. After the device, for instance a laser, is fabricated, the next step is the measurement and analysis of the device's performance. When you have a system that is working with the desired properties for a known or future application, such as wavelength, power, and operating temperature, etc, it can transition to production.

However, the value or importance of a new device when it is first demonstrated is not always appreciated immediately. For instance, one of the areas that I was working in when first moving to the USA was creating ultraviolet light diodes to study viruses like anthrax or coronavirus. UV light can deactivate the DNA of the virus, bacteria, or pathogens, destroying their ability to multiply and create diseases. At the time, it wasn't fully recognised that one of the UV diodes I made in the 1990s, emitting at 280 nm, could kill more than 99% of the coronavirus in the air and on surfaces. However, during the pandemic in 2020, these UV diodes became very important for quickly disinfecting a wide variety of materials and surfaces. This invention came too early, and it can take ten, 15, or 20 years for science to have an impact.

Sometimes it is not just a single device that is important but the combination of devices, such as pairing light emitters with detectors, that provides a breakthrough technology. By pairing our UV light emitting diode with our UV photodetector, we created a new system that rapidly detects and identifies certain harmful biological agents such as Anthrax, Tyrosine, COVID-19, in the air and on surfaces. This is an important application for health and safety and is still one of the most significant research subjects in my group and around the world.

For all of the students that come to me, from the beginning, at 18 years old, I'm teaching them this device development process. I tell all my students to come to the lab, do the research. That is the best way that you can understand yourself and the world around you. The research isn't easy so I try to encourage the students by being an enthusiastic role model. I love research, I love the science; my students say that it's contagious. I try to transfer the energy that I have for science to all of my students. When they finish their degrees, whether BSc or PhD, they transfer the technology they've learnt to a different laboratory or different companies around the world. My students are able to go everywhere that they want because they have had to work hard to get this knowledge, and have a multidisciplinary background with broad experience in what it takes to make a device.

What is one of the most challenging areas that you are currently exploring?

Another important research area in my group is in the terahertz frequency band. This band has very long wavelengths with low photon energies, making it one of the most challenging wavelengths for which to build room-temperature quantum semiconductor detectors and laser diodes. The pairing of uniquely designed quantum semiconductor materials with innovative laser designs has led my group to demonstrate the first room-temperature, compact THz laser source. However, there is still much work to be done to further improve these devices and get them closer to implementation outside the laboratory. We will continue to improve the design and performance of these devices since THz semiconductor laser diodes could have far-reaching impacts in healthcare and global communications over the next decade and beyond.

Light at THz frequencies has many unique properties. It can pass through a variety of substances, including synthetics, textiles, paper, and cardboard. Unlike x-rays, THz waves do not have any ionising effects due to their low energy and are generally considered biologically harmless. This makes THz waves much safer and healthier than x-rays when used for security checking and medical diagnosis. Another significant application is in the area of high-speed communications. THz frequencies are orders of magnitude higher than those used for the current wireless communication. The higher the frequency of the 'light', the faster the data is sent and information can be delivered. Hence, there is a great potential to apply THz technology for the next generation of high-speed wireless communications.

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