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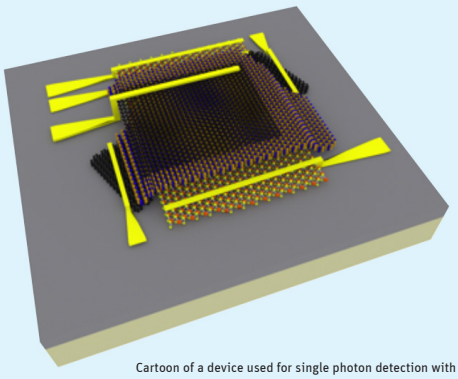
KERNEL

Editorial

Quantum technologies have already leaped into our lives, powering the appliances, digital cameras, computers and GPS we use everyday. At IISc, diverse researchers are coming together to help nudge India's quantum ambitions forward. Read more about their efforts in this issue of *Kernel.*

Our lab feature uncovers the work that goes into building drones for healthcare and other applications. We also include stories on a blood biomarker for differentiating bacterial from viral infections and the discovery of electron species that could provide interesting insights into material properties.

TAKING THE QUANTUM LEAP



Cartoon of a device used for single photon detection with 2D materials (Image: Arindam Ghosh)

A NEW INITIATIVE AT IISc ENVISIONS A CRUCIAL ROLE IN INDIA'S QUANTUM QUEST

Quantum mechanics – the physics of subatomic particles – underlies all that we currently know about atoms, what they are made of and why they behave the way they do. But it is not just a physicist's tool to try and understand the universe at extremely small scales. The devices that you are most likely using to read this article – computers and smartphones – also rely on technologies that operate on quantum mechanical phenomena.

The modern semiconductor-based electronics industry is entirely dependent on our understanding of the quantum nature of matter. The second half of the 20th century witnessed what is now called the first quantum revolution – technological breakthroughs such as semiconductors, MRI imaging, lasers and so on.

Many believe that we are presently living through the second quantum revolution. The era of 'quantum technologies' has arrived with many promises – sensors and measurement devices with unprecedented precision, secure communications via what is called the "quantum internet", and quantum computers capable of solving problems far beyond the scope of existing supercomputers.

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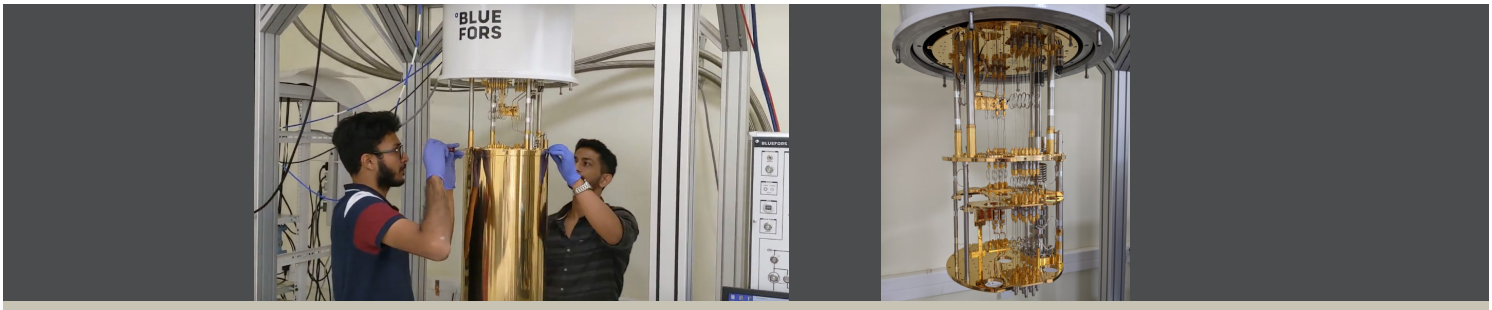
Refrigerator to protect superconducting qubits from thermal and ambient noise. L: Students preparing system for cooldown, R: Inside of fridge with microwave cables (Photos courtesy: Vibhor Singh)



"The new term 'quantum technology' is connected to unique applications of quantum mechanics or of quantum mechanical principles, which were by and large ignored in our technological advances during the last 100 years," says Arindam Ghosh, Professor in the Department of Physics, IISc.

In recent years, research on quantum technology has received a massive boost worldwide. A USD 1.13 billion quantum technologies project was announced by the EU in 2016 and a national quantum initiative worth USD 1.2 billion was launched by the US in 2018. Russia followed suit in 2019 by committing USD 790 million towards basic and applied quantum technology research.

India is not too far behind. The Government of India announced the National Mission on Quantum Technologies and Applications (NM-QTA) in 2020 – to encourage both fundamental and applied research in the country – and has proposed to allocate Rs 8000 crore over a span of five years. IISc too has taken a step forward in this direction. The IISc Quantum Technology Initiative (IQTI), launched in November 2020, aspires to lay a solid foundation for quantum technology within the Institute, and contribute to the country's R&D efforts.

If you are wondering why governments worldwide have taken such an interest in quantum technologies, the answer lies in the outcomes that they promise. The anticipated technological advances can impact many socio-economic sectors – molecular and material design can transform sensors, healthcare, pharmaceuticals, agriculture and engineering; secure communications can benefit finance and defense services, and so on.

"Simple examples which are already in place include the atomic clock which, by using quantum technology, has improved by orders of magnitude in precision and accuracy – its direct consequence being a significant improvement in the GPS resolution," explains Apoorva Patel, Professor at the Center for High Energy Physics (CHEP), IISc, who is one of the faculty members leading IQTI.

Another advancement that is likely to happen soon, he adds, is improved precision in the measurement of magnetic and electric fields, giving rise to many practical applications. Measuring magnetic fields with greater precision, for example, can lead to smaller MRI machines that will produce images with better clarity while using lower radiation doses.

Research related to such quantum technologies has been going on at IISc for a long time but in a disconnected manner, in individual laboratories. In 2019, Patel along with several others received generous funding from the Ministry of Electronics and Information Technology (MeitY), Government of India, to establish the Center for Excellence in Quantum Technology at IISc, partnering with the Raman Research Institute (RRI) and Center for Development of Advanced Computing (CDAC). IQTI, which will now consolidate all quantum technology-related research in the Institute, is the first such large-scale initiative in the country, according to Patel and Ghosh, with well defined short- and long-term goals.

IQTI aims to establish a framework which will promote collaborations between physicists, computer scientists, material scientists and engineers. Currently, more than 40 faculty members from diverse departments are part of the initiative. "This also involves people who are not necessarily connected to quantum [research], but they may have technology or materials which can be immediately utilised in the development of quantum technologies," says Ghosh. IQTI will focus on four broad areas: quantum sensing and metrology, quantum communications and cryptography, quantum materials and devices, and quantum computation and simulations.

One goal is to establish a campus-wide quantum-secured communication network within the next 4-6 years. "Quantum theory allows you to transmit signals in a way that is protected from eavesdroppers or interceptors in the middle, by a process where – if there is any interception – the receiver will know that the signal has been compromised," explains Patel.

Research related to quantum computing is also happening in the lab of Vibhor Singh, Assistant Professor in the Department of Physics, who works with superconducting qubits – platforms that are being explored worldwide to build large-scale quantum computers. Qubits or quantum bits are the basic data units of a quantum computer, analogous to bits in its digital counterparts. Although companies like Google and IBM have managed to create superfast devices having 53-54 qubits, Singh points out that the more fundamental problems, like finding the best strategy to scale up qubits, remain unsolved. His team is trying to come up with small prototype systems – working at the level of single or two qubit devices – which, if successful, might help in scaling up the number of qubits faster and in a more straightforward manner. In fact, building an 8-qubit quantum processor is something IQTI hopes to achieve in the near future.

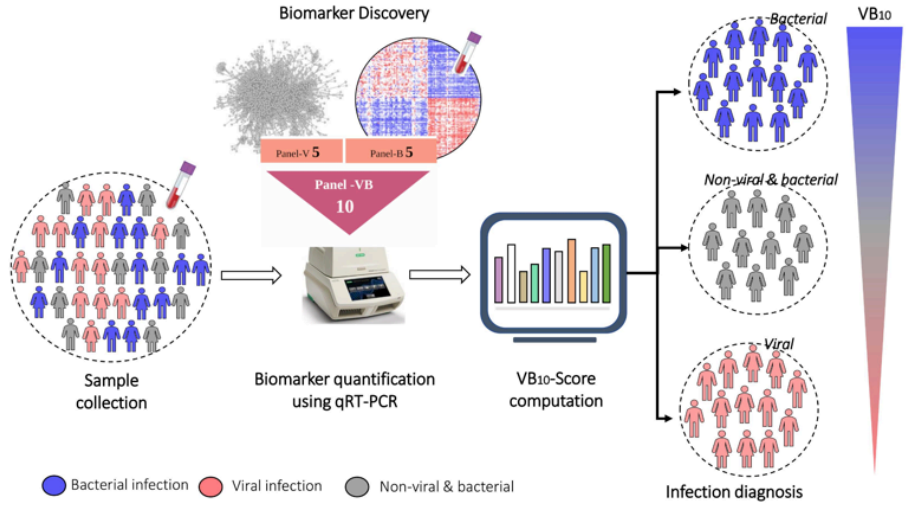
Patel and his team also played a crucial role in developing QSim, a Quantum Computer Simulator Toolkit, which was launched by MeitY in August 2021. A collaborative effort by IISc, IIT Roorkee, and CDAC, this educational toolkit seeks to help students and researchers in the country write and debug quantum code, which is essential for developing quantum algorithms.

Another highlight of IQTI is a two-year MTech degree programme in Quantum Technology – the first of its kind in India – which admitted its first batch of students in August 2021.

Patel points out how the country's nuclear and space programmes were conceived and nurtured at IISc decades ago. "However, to develop them from scratch to a level that is comparable to the best in the world, it took India almost 50 years. Huge efforts are required both in terms of manpower as well as towards building infrastructure. The long-term vision for IQTI is to do something similar for India in quantum technology."

- Sritama Bose

Image: Sathyabaarathi Ravichandran



BLOOD-BASED BIOMARKER TO DISTINGUISH BETWEEN BACTERIAL AND VIRAL INFECTIONS

SUCH A SIGNATURE CAN POTENTIALLY HELP CLINICIANS OPTIMISE TREATMENT AND AVOID INDISCRIMINATE USE OF ANTIBIOTICS

A recent study has identified a set of molecular biomarkers that can be used in the differential diagnosis of acute bacterial and viral infections. The biomarkers are messenger RNA (mRNA) molecules found in the blood; differences in their levels can predict with high probability if an infection is viral or bacterial.

The human body responds to bacterial and viral infections differently, by producing specific types of molecules – such as proteins and RNA – in the blood. While antibiotics can treat bacterial infections, they are ineffective against viral infections. However, indiscriminate use of antibiotics to treat any kind of infection has given rise to bacterial strains that are now resistant to our entire arsenal of antibiotics. “Antibiotics are given even for viral infections in some cases because of misdiagnosis. With current methods, it can take a lot of time to test for bacterial or viral infections,” explains first author Sathyabaarathi Ravichandran, Research Associate in the lab of Nagasuma Chandra, Professor in the Department of Biochemistry.

A quick method to detect acute viral and bacterial infections and distinguish between them can be immensely useful in the clinic, as accurate diagnosis will win half the battle and guide the clinician towards the optimal treatment path. It will also prevent the rise of such antimicrobial resistance. In their new study, published in the journal *EBioMedicine,* the researchers have developed such a test using patient blood transcriptomes and sophisticated computational modelling.

A transcriptome is a full set of mRNA molecules expressed by a biological cell, which is measured using Next-Generation Sequencing (NGS) technologies. During an infection, specific genes are turned on, leading to an increase in the production of specific mRNAs and their corresponding proteins. The scientists analysed transcriptomic data of patients (from publicly available databases, and samples collected from MS Ramaiah Medical College in collaboration with a clinical team) and discovered a 10-gene RNA signature in the patients’ blood that is produced in varying quantities for viral and bacterial infections.

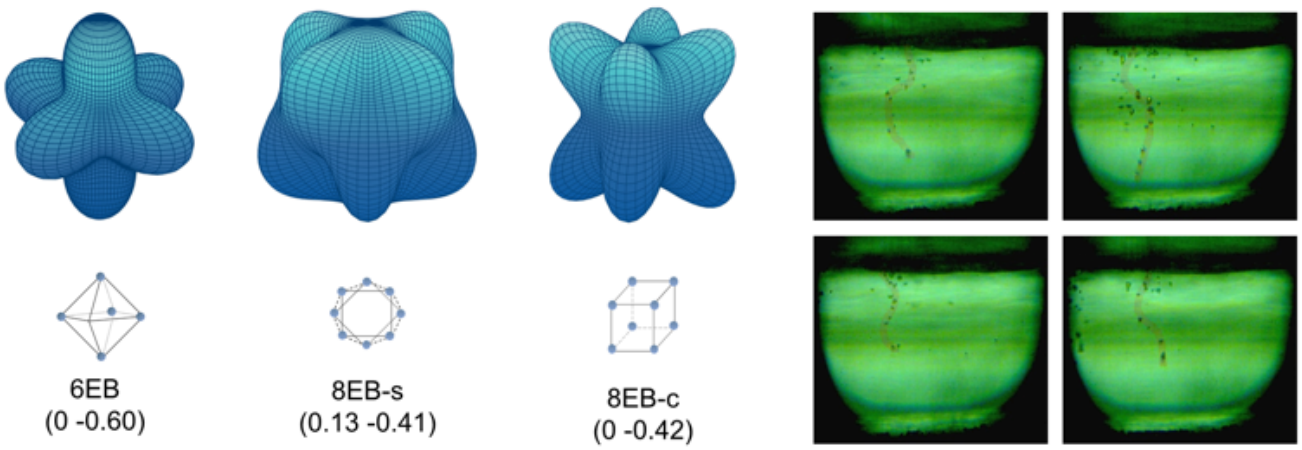
To enable it to be used in clinical practice, the researchers devised a standalone score called VB_{10}, which could be used for diagnosis, monitoring the stage of recovery after infection, and estimating the severity of the infection. VB_{10} accurately indicated whether a given blood sample had a bacterial or viral infection, across different bacteria and viruses and across different age groups.

The authors suggest that the test could be useful for differentiating COVID-19 infection from bacterial infections as well. In the study, they looked at various viral infections for which transcriptomic data is publicly available. This allowed them to develop a generic VB_{10} test score for viral infections. As soon as transcriptomic data became available for COVID-19, the team tested their approach and found that the test scores could differentiate between SARS-CoV-2 infection and common bacterial respiratory infections.

This work was done in collaboration with clinicians at MS Ramaiah Medical College and researchers Amit Singh, Dipshikha Chakravortty and KN Balaji at IISc. The team hopes to begin a trial study to translate their research from the lab to the clinic. “This test can be done using qRT-PCR. Given how common RT-PCR has become due to the pandemic, getting this test off the ground should not pose a major challenge,” says Chandra. The researchers expect it to be useful early on during the infection, and work against any strain. This can supplement the current COVID-19 diagnosis tests.

- Debayan Dasgupta
(with input from authors)

Image: Neha Yadav



DISCOVERY OF FEW ELECTRON BUBBLES IN SUPERFLUID HELIUM

THEY CAN PROVIDE INSIGHTS INTO HOW MATERIAL PROPERTIES ARE INFLUENCED BY ELECTRON INTERACTIONS

Researchers at IISc have experimentally shown the existence of two species of few electron bubbles (FEBs) in superfluid helium for the first time. These FEBs can serve as a useful model to study how the energy states of electrons as well as the interactions between them in a material influence its properties.

The team included Neha Yadav, a former PhD student at the Department of Physics, Prosenjit Sen, Associate Professor at the Centre for Nano Science and Engineering (CeNSE) and Ambarish Ghosh, Professor at CeNSE. The study was published in *Science Advances.*

An electron injected into a superfluid form of helium creates a single electron bubble (SEB) – a cavity that is free of helium atoms and contains only the electron. There are also MEBs – multiple electron bubbles that contain thousands of electrons.

FEBs, on the other hand, are nanometre-sized cavities in liquid helium containing just a handful of free electrons. The number, state and interactions between free electrons dictate the physical and chemical properties of materials. Studying FEBs, therefore, could help scientists better understand how some of these properties emerge when a few electrons present in a material interact with each other. According to the authors, understanding how FEBs are formed can also provide insights into the self-assembly of soft materials, which can be important for developing next-generation quantum materials. However, scientists have only theoretically predicted the existence of FEBs so far. "We have now experimentally observed FEBs for the first time and understood how they are created," Yadav says. "These are nice new objects with great implications if we can create and trap them."

Yadav and colleagues were studying the stability of MEBs at nanometre sizes when they serendipitously observed FEBs. "It took a large number of experiments before we became sure that these objects were indeed FEBs. Then it was certainly a tremendously exciting moment," says Ghosh.

The researchers first applied a voltage pulse to a tungsten tip on the surface of liquid helium. Then they generated a pressure wave on the charged surface using an ultrasonic transducer. This allowed them to create 8EBs and 6EBs, two species of FEBs containing eight and six electrons respectively. These FEBs were found to be stable for at least 15 milliseconds (quantum changes typically happen at much shorter time scales) which would enable researchers to trap and study them.

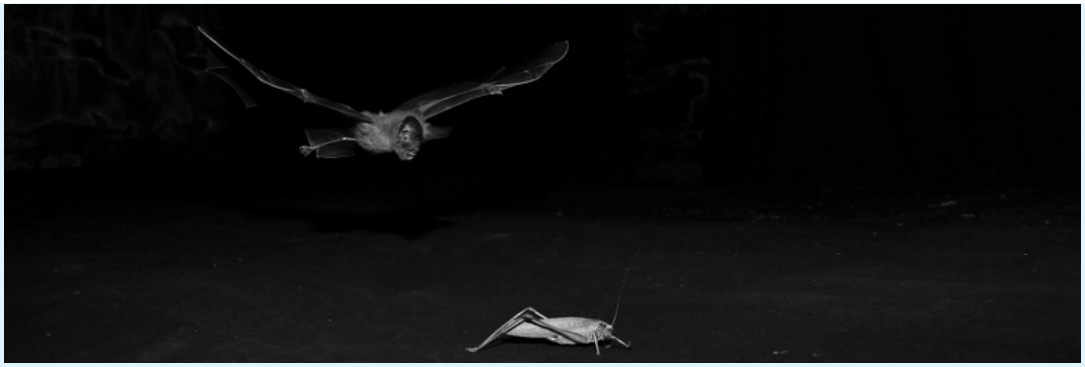
"FEBs form an interesting system that has both electron-electron interaction and electron-surface interaction," Yadav explains.

There are several phenomena that can be deciphered through FEBs, such as turbulent flows in superfluids and viscous fluids, or the flow of heat in superfluid helium. In the same way that current flows without resistance in superconducting materials at very low temperatures, superfluid helium also conducts heat efficiently at very low temperatures. But defects in the system, called vortices, can lower its thermal conductivity. Since FEBs are present at the core of such vortices – as the authors have found in this study – they can help in studying how the vortices interact with each other, and how heat flows through the superfluid helium.

"In the immediate future, we would like to know if there are any other species of FEBs, and understand the mechanisms by which some are more stable than the others," Ghosh says. "In the long term, we would like to use these FEBs as quantum simulators, for which one needs to develop new types of measurement schemes."

- Joel P Joseph

Photo: Stefan Greif



EAVESDROPPING BATS TAKE LONGER TO CAPTURE CRICKETS CALLING IN GROUPS

In a new study, Harish Prakash and Rohini Balakrishnan from the Centre for Ecological Sciences (CES), with collaborators from Tel Aviv University, explored whether calling in a group reduces risk for katydids (bush crickets) against bats, which are their predators. They found that bats were more attracted to three speakers simultaneously playing katydid calls than a single speaker. Does this mean calling together in a group might be riskier? Yes. But that is just one part of the story.

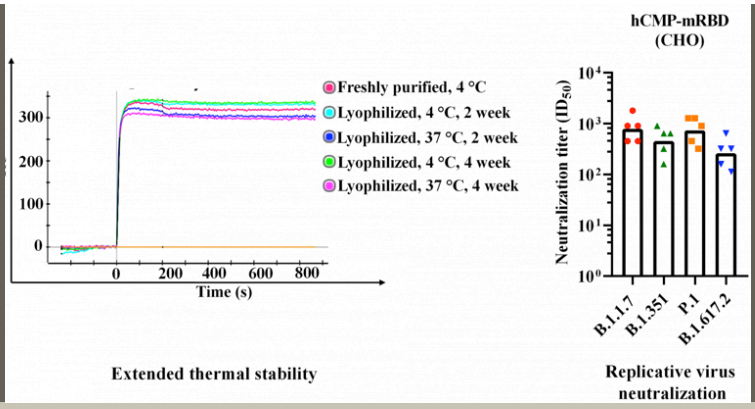
The researchers also found that bats took considerably longer to capture a katydid calling in a group of three than a lone katydid. This delay gives the katydid an opportunity to stop calling, and escape from being eaten. Therefore, although a chorus of katydids can attract bats, the bats' inefficiency in capturing them when they are in groups can benefit the prey.

A possible reason for the delay is the confusion effect: it is harder for a predator to target and capture an individual when it is among many others.

Previous studies have looked at this only in visual predators like monkeys, geckos and fish. This study provides the first evidence of an auditory confusion effect in eavesdropping predators such as bats.

- Harish Prakash

Image courtesy: Raghavan Varadarajan



FIGHTING COVID-19 VIRAL VARIANTS WITH A HEAT-TOLERANT VACCINE

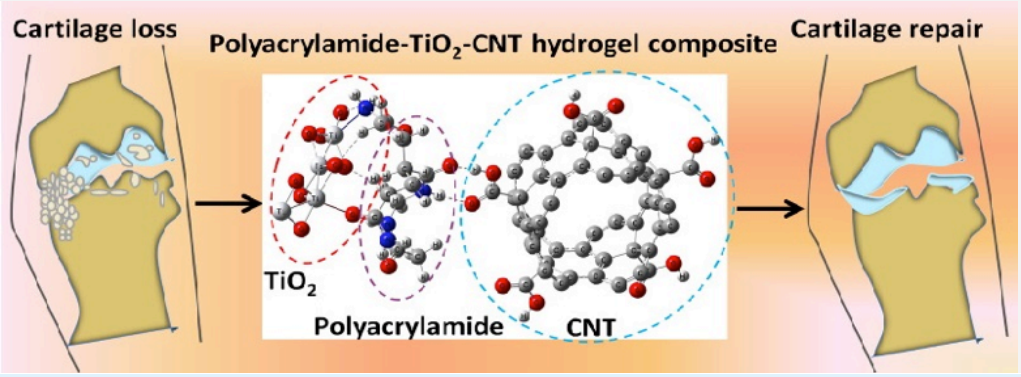
A 'warm' COVID-19 vaccine candidate being developed by an IISc and Mynvax team was found to trigger a strong immune response and protection in mice and hamster models, in results published recently in *ACS Infectious Diseases.* Crucially, the vaccine formulation also triggered neutralising antibodies – those that bind to the virus and prevent infection – against all four current SARS-CoV-2 variants of concern: Alpha, Beta, Gamma and Delta.

The vaccinated sera (blood) samples from animal models were tested for their neutralising ability against the variants by researchers at CSIR-IMTech, Chandigarh and the Australian Centre for Disease Preparedness, run by CSIRO, Australia's national science agency.

The vaccine candidate has been designed by genetically engineering the Receptor Binding Domain (RBD) of the surface spike glycoprotein of SARS-CoV-2.

In previous reports, an earlier version of the vaccine candidate was found to be stable at 37°C for a month without losing its shape, and withstand transient exposure to temperatures as high as 100°C; this was also true of the current, improved versions. Such vaccines are especially useful in countries like India where cold storage and transportation are expensive and challenging. One of the improved formulations is being rapidly moved to clinical development.

Image: Shikha Awasthi



CARTILAGE REPAIR USING HIGH-STRENGTH HYDROGELS

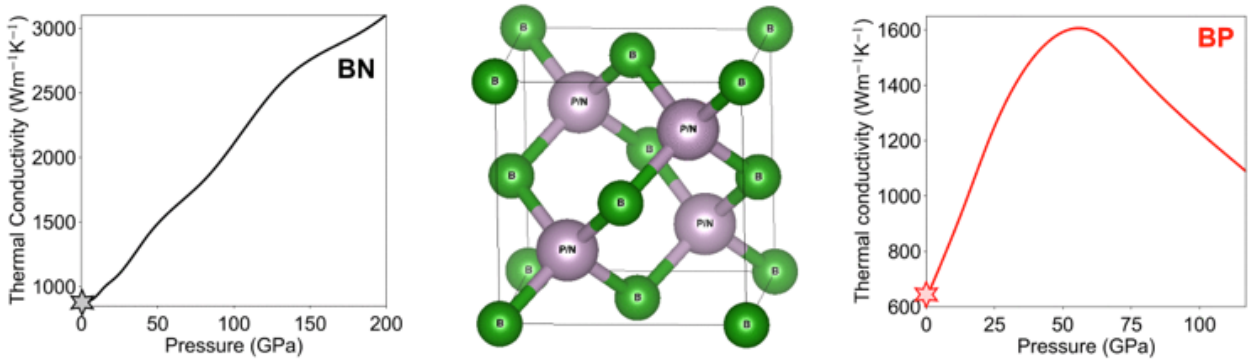
Cartilage is a type of connective tissue that acts as a shock absorber and deters abrasion between bones. Although it is usually tough and flexible, injuries, hormonal abnormalities or diseases can cause damage and make it hard for the cartilage to heal. Recent advances are focused on using polymers called hydrogels to replace injured or diseased cartilage. Despite having some properties needed for cartilage tissue repair, commonly-used hydrogels made of polyacrylamide (PAM) lack the required mechanical strength and puncture resistance.

Researchers at the Departments of Materials Engineering, Mechanical Engineering and Inorganic and Physical Chemistry in IISc have now developed hybrid hydrogels by combining PAM with either carbon nanotubes (CNTs) or titanium dioxide (TiO_2) or both. They also carried out computational studies to understand the binding features and structure of these hybrid hydrogels.

The study, designed by postdoctoral fellow Shikha Awasthi, found that the most stable composite hydrogel (PAM+TiO_2+CNT) had remarkable self-healing ability, high mechanical strength, and compatibility with biological tissue. Its dense and compact structure helps it withstand degradation. The researchers also used a method called needle insertion to show that the hybrid hydrogel is puncture-resistant. Such materials offer great promise for cartilage repair applications.

- Debraj Manna

Image: Navaneetha Krishnan Ravichandran



IDENTIFYING NEW MATERIALS WITH NOVEL THERMAL PROPERTIES

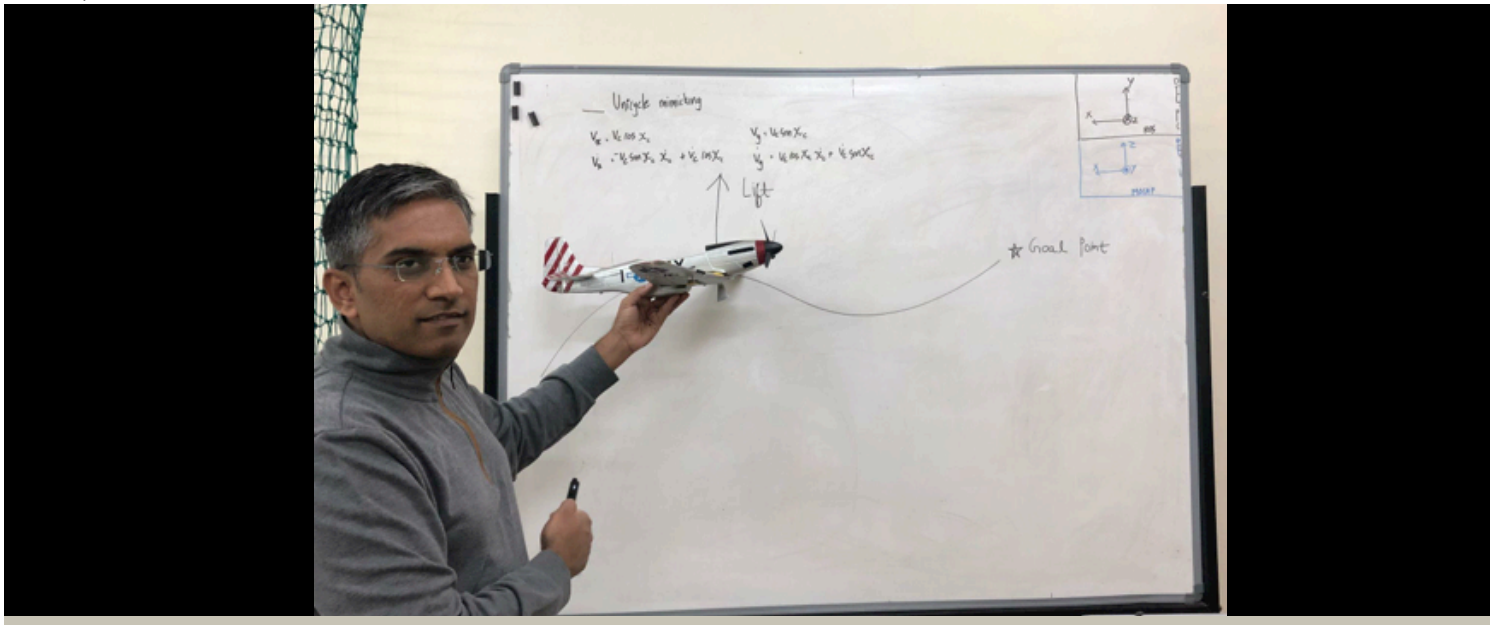
In crystalline electrical insulators, heat is carried by phonons, which are quantised vibrations of the crystal lattice. As these phonons travel through the material, they collide with each other, thereby limiting the material's thermal conductivity (k). Predicting how frequent and strong these collisions are ("collision rates") for each material under different experimental conditions is computationally expensive. This can slow down the discovery of new materials, with their k values and trends tailored to our needs.

New research led by Navaneetha Krishnan Ravichandran at the Department of Mechanical Engineering now provides a way to identify materials that show intriguing temperature- and pressure-dependencies of k, without performing these full, expensive computations.

In an earlier publication, Ravichandran and collaborator David Broido at Boston College, USA developed a set of guidelines to identify materials with unusually weak rates of three-phonon collisions. In the new study, the researchers used these insights to predict an unusual pressure-dependence of the k of a material called boron phosphide (BP) – the material showed a sharp rise in k with pressure, with a peak and subsequent drop, in stark contrast to the linearly increasing trend seen in most other materials.

- Navaneetha Krishnan Ravichandran

Photo courtesy: Ashwini Ratnoo



EYE IN THE SKY

ASHWINI RATNOO'S RESEARCH IS GEARED TOWARDS MAKING DRONE FLIGHT MORE EFFICIENT FOR HEALTHCARE, TRANSPORTATION AND OTHER SERVICES

Unmanned Aerial Vehicles (UAVs), popularly known as drones, are small aircraft that fly without a pilot. Drones can weigh anywhere from a few grams to over 100 kilograms, depending on their use. They either have a ground-based controller or are completely autonomous, with a built-in controller in the form of a computer program that guides them.

UAVs have a wide range of applications including surveillance, cargo transport, warfare, agriculture, journalism and recreation, to name a few. These vehicles have also been of great help during the COVID-19 pandemic, in remote surveillance and disinfection of areas.

The controller of an autonomous vehicle acts as its brain and has two functions: perception and planning. It must perceive its surroundings and execute a suitable plan on how to move in that situation. Ashwini Ratnoo's lab at the Department of Aerospace Engineering works on the planning part of this autonomous UAV brain.

Research on drones has been gaining more prominence these days because they can fly beyond the visual line of sight (BVLOS) of the person controlling them. They can provide visuals of even the most inaccessible areas making them indispensable in disaster management and warfare, among other fields. For a drone to be able to function autonomously, it must be programmed with computer algorithms that make human-like decisions with precision. Ashwini's team develops algorithms that plan and control the trajectories of UAVs, particularly in complex and urban settings.

Here is an example: It is not easy to organise timely delivery of medicines or organs for transplantation in a crowded city. A lot of manpower is involved, and elaborate traffic management is needed if they are transported by road. This is an easy job for a drone, but flying one over a populous urban space comes with many safety concerns, explains Ashwini. That is why drones are still not being used to their full capacity and potential.

To address this issue, his lab is working on developing 'Drone Skyways' in collaboration with the Robert Bosch Centre for Cyber Physical Systems (RBCCPS) and ARTPARK at IISc. They are developing trajectory planning algorithms that create a corridor, a virtual road, for UAVs to travel safely. These drones fly at an altitude designated as "Class G" that is closest to the surface of the earth. Flying a drone in this airspace requires a lot of preparedness in terms of safety and security. Ashwini's research group has participated in developing "CORRIDRONE", a novel drone skyway framework with an efficient design that includes geo-fencing, a virtual fence along the corridor. CORRIDRONE allows for safe point-to-point movement of multiple drones without collision and can be set up in any given airspace.

Unmanned vehicles are not restricted to the sky. Autonomous ground vehicles, considered the future of road travel, are also on Ashwini's radar. With support from the Wipro IISc Research and Innovation Network (WIRIN), his team is involved in trajectory planning for such vehicles. "In autonomous ground vehicles, perception is slightly more challenging because there are a lot of occlusions [obstructions] to vision. For example, there's a wall on the left, a tree on the right and so on. So, a lot of effort goes into the perception side," says Ashwini. The specific challenges, be it for aerial or ground vehicles, pertain to the space used by an autonomous vehicle. The trajectory must be compatible with the dynamics of the vehicle. For example, a path riddled with sharp turns is difficult for the vehicle to manoeuvre if it encounters an obstacle. Another challenge is the computational complexity of the algorithm itself. A complex algorithm takes longer to execute, making the vehicle inefficient.

The algorithms that his team is developing are based on the theory of dynamical systems. "What we use is something called bifurcation theory, which essentially generates a variety of

Indoor motion capture facility for UAVs (Photo courtesy: Autonomous Vehicles Laboratory)

motion patterns for the drones based on the same control structure, but by varying just a certain parameter within that control structure," explains Ashwini.

Trajectory plans are also created for the use of multiple UAVs in the same airspace to perform tasks like surveillance. This effort is sponsored by the Ministry of Education's IMPRINT India Initiative.

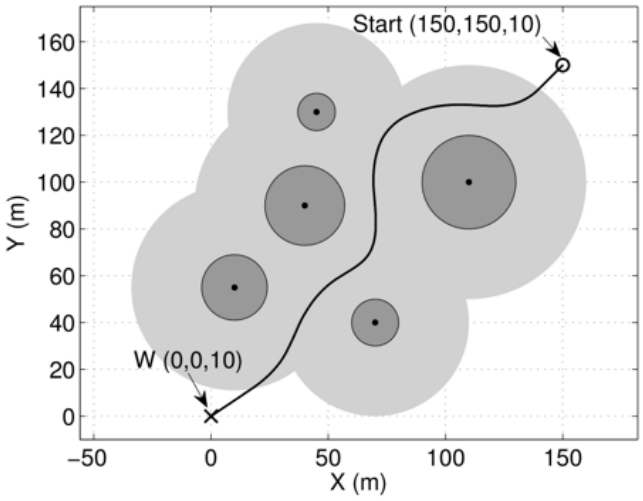
Apart from his work with RBCCPS and WIRIN, Ashwini has several other collaborative projects. With IIIT Delhi, the team is working on landing trajectories for drones, also called 'vertical descent'. With the University of Cincinnati in the US, they have worked on multi-drone coordination known as 'platooning', wherein a group of drones follows a leader drone to perform a specific task. Work on drone recovery methods is underway in collaboration with IIT Madras. Ashwini's lab has also worked closely with the Ministry of Defense in the past. These projects were funded by DRDO and BrahMos Aerospace, via the Centre for Excellence in Hypersonics at IISc.

Ashwini's tryst with science began during his school days. "[The] more shaping element was in high school, where we got introduced to mechanics and I was fascinated by particle mechanics; how points move in a plane, motion of bodies, and so on," he says. To pursue his interest in the physical and system sciences, he obtained a Bachelor's degree in engineering from MBM Engineering College in Jodhpur, Rajasthan, followed by a Master's degree from the Department of Aerospace Engineering at IISc. After a PhD from the same department in 2009, Ashwini went to Israel for his post-doctoral studies at the Technion-Israel Institute of Technology. He returned to India in 2012 to join the Department of Aerospace Engineering as an assistant professor.

With his work on drones, Ashwini hopes to make remote corners of the country more accessible. The applications of drones are endless, and no longer limited to surveillance and cargo movement. In the future, drones will be one of the sought-after modes of transport, according to him. "People are already talking about drone taxis."

- Sangeetha Devi Kumar

UAV trajectory through multiple obstacles (Image courtesy: Autonomous Vehicles Laboratory)



Office of Communications (OoC)
Indian Institute of Science (IISc)
Bengaluru - 560012
kernel.ooc@iisc.ac.in
https://kernel.iisc.ac.in/

भारतीय विज्ञान संस्थान

EDITORIAL TEAM
Deepika S
Karthik Ramaswamy
Narmada Khare
Ranjini Raghunath (Coordinator)
Samira Agnihotri

DESIGN
TheFool.in