QUANTNEWS

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Inside this Issue

IISc's Journey in Quantum Computing

Demystifying Quantum Computing: A beginner's guide to the theory and latest developments

By Rohith KMS

Quantum vs Classical Computers

In 1977, when MIT scientists Ronald Rivest, Adi Shamir, and Leonard Adleman developed their namesake encryption algorithm, RSA, it ushered in a new revolution in cybersecurity. Even today, almost all credit card transactions and online communications are protected by the almost impossible-to-crack codes that the algorithm can generate. But change is coming – quantum computers that can crack these codes much faster are not too far into the future. "RSA encryption relies on the computational difficulty of factoring a large number," explains Baladitya Suri, Assistant Professor at the Department of Instrumentation and Applied Physics (IAP) at IISc. A classical computer is expected to take trillions of years to decrypt the most secure RSA keys. However, using Shor's algorithm, a fast quantum algorithm for factoring large numbers, RSA encryption can be broken easily.

Factoring can be thought of as the reverse of multiplication in a sense – it is the process of breaking down a number into prime factors that, when multiplied together, give back the starting number. For example, take the number 12318269. It can be written as a product of two prime numbers 2749 and 4481. While any computer can multiply the two numbers in a fraction of a second, factoring 12318269 is a much more difficult problem. A traditional (so-called 'classical') computer is expected to take 300 trillion years to factor in the 617-digit numbers used in the most secure form of RSA encryption. This computational difficulty is what makes RSA encryption so secure. However, an ideal quantum computer (with 5000 perfect 'qubits', the quantum equivalent of bits) capable of running Shor's algorithm can theoretically crack the code in a few seconds, thus rendering the RSA encryption obsolete.

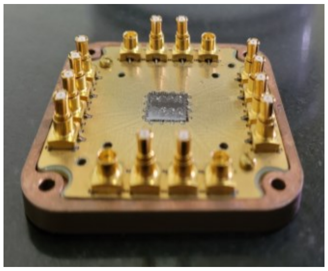
Another important quantum algorithm that has far-reaching implications is Grover's search algorithm, which allows efficient searching of unsorted databases. Suri explains this using the analogy of a telephone directory: "If you are given the name of a person, searching for their phone number is easy because the names are sorted alphabetically. However, if you are given a phone number and asked who it belongs to, it becomes a difficult problem because the phone numbers are unsorted. The only option is to check the phone numbers one by one. Grover's search algorithm can do this efficiently." For such problems like factoring large numbers and searching unsorted databases, quantum algorithms are far more efficient than any classical algorithms that currently exist.

Richard Feynman, the eminent physicist, originally proposed another area where quantum computers offer great advantage – the simulation of quantum physics phenomena. Computer simulations have emerged as an important research tool to study systems and phenomena whose understanding requires a knowledge of quantum physics, such as the interactions between molecules and properties of solid-state devices like LEDs, MOSFETs and solar cells. However, simulating quantum systems using techniques like the Density Functional Theory (DFT) requires a lot of computational time on available classical supercomputers, and even then, the simulations are limited to a few hundred atoms. "The conventional methods [for simulating quantum systems], which are typically Monte-Carlo algorithms, are horribly inefficient," explains Apoorva Patel, Professor at the Center for High Energy Physics (CHEP), IISc. "Quantum systems have a very large number of possible states, and Monte-Carlo algorithms work by exploring each possibility one-by-one and that takes a huge amount of time." Quantum algorithms, on the other hand, can process all these states simultaneously by combining them into a "superposition", thus greatly simplifying the problem.

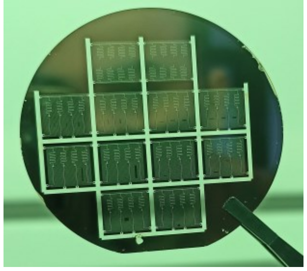
How quantum algorithms use superposition, interference, and entanglement

“The three essential ingredients involved in efficient quantum algorithms are superposition, entanglement, and interference,” says Chandrashekar CM, adjunct faculty member at IAP. In a classical computer, the smallest unit of data is a bit, which is either a 0 or a 1. Whenever any computation is done in a classical computer, it is done one bit at a time. On the other hand, quantum bits, which are called ‘qubits’, can be combined to form a “superposition state”. Patel uses the analogy of mobile phone signals to explain superposition: A cell tower has to simultaneously transmit signals to all the mobile phones in a locality, so it combines all the signals into a single wave that is a superposition of all these signals. A phone receives this signal, and extracts only the relevant component that corresponds to the conversation that the phone user is interested in.

Quantum algorithms act on this superposition state, thus processing multiple signals at once. Extending the cell tower analogy, a quantum algorithm can be thought of as a process similar to changing the entire signal emitted from a cell tower, thus changing each of the individual components simultaneously. “The challenge is to engineer the quantum algorithm in a clever way such that the required information collapses into a single stream at the output, which is then measured to give the answer,” Patel explains. "The physical principle which is involved in that collapse is the interference of waves,” he adds.



A cryogenically compatible multi-I/O microwave packaging box for the placement of superconducting quantum chips. Packing is essential to minimize the cross-talk between multiple components on the same die. PC: Prof. Vibhor Singh



Photograph of a 2-inch wafer with multiple dice showing various components such as feedlines, planar resonators, and superconducting qubits. PC: Prof. Vibhor Singh

Interference occurs when two waves are added together, resulting in an increase in intensity (constructive interference) or a decrease in intensity (destructive interference). Quantum algorithms arrange interference in such a way that the required information undergoes constructive interference, while the rest undergoes destructive interference and cancels. “We don’t have a prescription to determine which problems allow for such clever interference, so constructing quantum algorithms is a trial and error process,” says Patel. This also means that quantum computers cannot always outclass classical computers, which perform quite well in many computational tasks.

Quantum algorithms generally require some qubits to be “entangled”. Entanglement is a specific kind of quantum correlation between the qubits, wherein measuring the state of one qubit provides information about the state of another qubit.

The physical realisation of qubits

To understand the difference between classical and quantum computers, one can start with the difference between their basic building blocks – bits and qubits. In the hard disk of a classical computer, bits are physically represented on a film of magnetic material. The magnetisation of a region can be in one of two directions, say up or down. A ‘read head’ then reads the magnetic field on the film as either a 0 or a 1 depending on the magnetisation. A ‘write head’ can change this magnetisation. Thus, a bit is a two-level system, one level representing a 0 and the other a 1, and can only be in one of these two levels.

In contrast, a qubit can be in a superposition of these two levels, meaning it can continuously interpolate between the two states. For example, a qubit can be in a superposition of 50% of the state 0 and 50% of the state 1.

When one measures such a qubit, it has a 50% chance of 'collapsing' to state 0 and a 50% chance of collapsing to state 1. In the language of quantum mechanics, the states 0 and 1 correspond to waves that can be mixed together in a certain proportion. There is an important caveat – these proportions can be complex numbers. "If you write a superposition as 'a' times state 0 plus 'b' times state 1, then 'a' and 'b' have to be complex numbers, otherwise we don't get the complete dynamics of quantum mechanics," explains Patel.

Complex numbers are essential to explaining quantum mechanics. "Quantum mechanics is not easy to explain in classical terms that most people are familiar with," says Chandni Usha, Associate Professor at IAP. This difficulty is one of the reasons why there is a lot of confusion and misinformation about quantum computing.

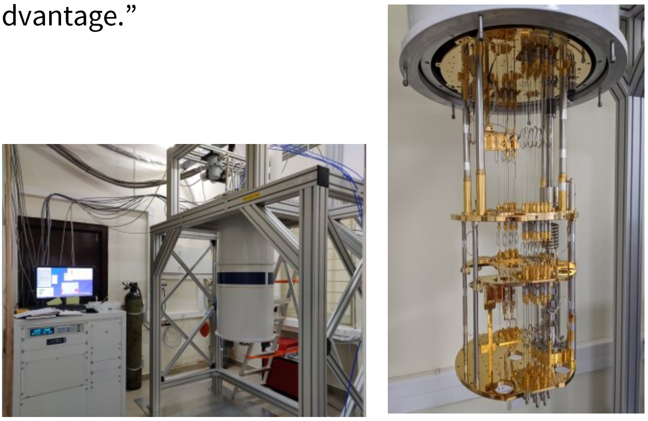
In any case, it is essential to understand that a qubit possesses a crucial requirement that is absent in classical bits – the ability to create a superposition of states. Any two-level system where superposition is possible can be considered as a qubit, and several systems have been proposed as candidates. "The hardware for quantum computing has not yet been pinned down to one particular quantum system. People have been exploring various systems such as ions, cold atoms, superconducting circuits and photons," explains Chandrashekar, who works on photonic qubits. "Of these, the two systems which are at the top of the competition are superconducting circuits and photons."

Photonic qubits

Photons are packets of light energy. Light has a dual nature – it is both a wave and a particle. The famous double slit experiment by the scientist Thomas Young demonstrated the wave nature of light. When light passes through two closely-spaced slits, it shows an interference pattern, which is characteristic of waves. However, light also behaves as a particle, for instance, during the photoelectric effect. This dichotomy is resolved using quantum mechanics by saying that until one measures which slit a photon has passed through, the path of the light is in a 'superposition' of paths through both the slits.

The moment one tries to determine the path of light, it 'collapses' to one of the slits with a certain probability specified by the superposition. Hence, the path of light can be considered a qubit. Another possibility that can be considered a qubit is the polarization of light, which can also exist in a superposition of two states until measured.

Since the path or polarization of a photonic qubit has to be measured one at a time, it is essential to have single-photon emitters. These photons also have to be "indistinguishable", meaning they must match in phase too. Anshu Pandey, Associate Professor at the Solid State and Structural Chemistry Unit (SSCU), works on making single photon emitters using quantum dots, which are semiconductor structures a few nanometers in size. "For quantum computing, we need emitters that can generate a steady stream of indistinguishable single photons quickly, reliably and consistently, which is an extremely challenging task," he says. "Photons generally interact very little, so it is very hard to create entangled states reliably. This is where the superconducting qubits have an advantage."



Dilution refrigerator, where the physical qubits are placed
PC: Prof. Baladitya Suri

Superconducting qubits

Superconducting qubits use electrical circuits called LC oscillators, which consist of a capacitor and an inductor. These circuits are cooled down to very low temperatures, which brings the electrons in them into a superconducting state. "These are different from the typical LC oscillator circuits that one studies in high school, because the inductor is a non-linear device called a Josephson junction. A non-linear quantum oscillator has unequal spacing between the energy levels, unlike the infinite equally-spaced levels that are found in a linear oscillator.

The lowest two levels are then used as a qubit," explains Vibhor Singh, Associate Professor at the Department of Physics. Control and measurement of superconducting qubits is achieved using microwaves because the resonance frequency of these qubits is in the range of microwave frequencies. "If you send microwave signals of suitable amplitude, phase and frequency, you can control the quantum state of the qubits," he says.

In his lab, Singh has a device with four superconducting qubits. To control and measure these qubits, they use a complicated array of signal generators and analog mixers that requires 3-6 hours of calibration every time they want to run a 15-minute experiment. The difficulty involved has led Singh to collaborate with Chetan Singh Thakur, Associate Professor at the Department of Electronic Systems Engineering (DESE), to build SQ-CARS, a scalable system for doing quantum measurement and control. SQ-CARS offers immense advantage over the earlier setup that Singh had in his lab – researchers do not have to calibrate the array every time they want to set up an experiment, and the cost of the equipment is greatly reduced – from $120,000 to less than $10,000. "For each qubit, previously one needed 2-3 different instruments. With a single SQ-CARS device, one can control 8 qubits. Moreover, we can have a closed feedback loop which was not possible in the earlier device," says Thakur.

Superconducting qubits have their disadvantages as well. Suri, who also works on superconducting qubits, says, "Superconducting qubits are prone to unwanted interactions with the environment, leading to a lot of noise in the system that causes the qubits to lose their quantum state. This phenomenon is called decoherence." Superconducting qubits can maintain their quantum states for at most a few milliseconds, and the entire computing operation must be done in that time. This greatly limits the capability of superconducting qubits. "This is where photonic qubits have the upper hand. The lack of interaction between photons is an advantage, because coherent photons do not decohere easily. This also means that photonic qubits can be processed at room temperature without much noise," says Chandrashekar.

Challenges in building quantum computers and scope for research

Both photonic qubits and superconducting qubits have their advantages and disadvantages, and it is not clear eventually which technology will emerge as the winner. There are other systems being explored as qubits as well. For example, Chandni is exploring graphene-based quantum dots, which can potentially be used for making qubits. "We still don't know what the right technology is, and a lot of work remains to be done. However, there is so much buzz generated around quantum computing that sometimes people lose track of how science is done," she says. A lot of scientists like her are wary of over-optimistic claims by articles such as a recent *TIME* magazine article that states that quantum computers powerful enough to crack RSA encryption are only a "few years away from being openly available."

Currently available quantum computers have several limitations that need to be addressed before they can match the hype that surrounds them. However, these limitations also mean that there is a lot of exciting work to be done in the field. Quantum computing is a multidisciplinary field, requiring people who work on theory and quantum algorithms, experimental physicists and engineers. IISc is one of the few places in India, where such richly multidisciplinary work is possible.

***Rohith KMS** got to received their Bachelor's degree in Materials Science from IISc in 2020. They are passionate about communicating the joy and wonder of science to audiences of all ages and backgrounds. Since graduating, they have worked as a physics teacher, science writer, and a curator at a science museum. Currently, they are interested in using simulations and games as educational tools. You can find out more at rohith-kms.github.io*

News Snippets

Moiré Magic: Science in Twists

By Tuhin Kumar Maji

Imagine two ultra-thin sheets of material, so delicate they're as thin as silk, laid perfectly over each other. But twist them slightly, just a hair's breadth, and something magical happens – an entirely new phenomenon. This new phenomenon leads to intricate patterns between the layers, like a hidden code written in ripples of light and shadow. This is the world of twisted bilayer 2D materials, which has recently become a fascinating field.

This twist angle (θ) between two 2D layers creates a mesmerising moiré pattern, forming periodic potential fluctuations, like a dance floor, for tiny particles called excitons. In this microscopic ballet, the dance floor is the "moiré pattern," a mesmerising mesh formed by the twisted layers. Here, tiny ballerinas of energy, known as excitons, spin across the moiré stage.

Recently, a few researchers from IISc, led by Kausik Majumdar from the Department of Electrical Communication Engineering, demonstrated the tuning of moiré potential using a bilayer of two different 2D materials. The goal was to tune the moiré potential dynamically, which is like adjusting the dance floor's features. In this playground, there are two main ways to play. One way is to apply a gate voltage to the excitons. This is like giving the excitons a little swing, making them play more energetically. The other way is to shine light. This is like tickling the excitons, making them giggle and jump.

The most exciting part? The scientists found that when they played with the excitons in different ways, the excitons showed interesting changes. For example, sometimes the excitons would live longer, and sometimes they would live shorter.

Sometimes they would change colour, and sometimes they would make different sounds. The scientists were excited by these findings because this means that we can control the behaviour of excitons in new and interesting ways

This could lead to new technologies, such as solar cells that are more efficient or light-emitting diodes that are brighter and more colourful.

In both cases (gate voltage or optical excitons), the harmonic to anharmonic switching of the moiré potential manifests through a corresponding change from an equal to unequal inter-excitonic spectral separation. In such a scenario, the researchers explored several intriguing features of the moiré excitons, including giant lifetime tunability, anomalous Stark shift, and dipolar repulsion-induced large spectral blueshift.

In a nutshell, these discoveries aren't just about observing moiré excitons but also hold potential for future experiments and applications. Think of it as peeling back layers to reveal exciting possibilities in dynamically tuning moiré potential. This journey challenges existing norms, revealing the anharmonic potential of these quantum dancers. These findings also open the doors to future experiments, promising a dynamic era of tuned moiré interactions. Brace yourself for the next scientific revelation in this ever-evolving quantum saga.

Reference: Chatterjee S et al., *Nature Communications* (2023)

The Magic of Twisted Bilayer Graphene

By Tuhin Kumar Maji

Graphene takes center stage in the realm of unusual materials and quantum mysteries. In science, discoveries often emerge from unexpected twists, sometimes from unexpected layers. Such was the case with Twisted Bilayer Graphene (TBG), which redefined our understanding of what happens when pencil lead is twisted precisely.

The story begins not in a bustling lab but in the quiet contemplation of Pablo Jarillo-Herrero, a physicist working at the Massachusetts Institute of Technology (MIT) in 2018. He envisioned two sheets of graphene – the wonder material known for its single-atom thickness and extraordinary conductivity – placed atop each other, not perfectly aligned but slightly askew. It turned out that this "twist" would become the key to unlocking a treasure trove of new properties. The electrons, usually zipping freely through the single graphene layer, danced to a different beat. Depending on the twist angle, their flow could be choked, transforming the material into an insulator, or they could waltz in perfect synchrony, leading to the holy grail of physics: superconductivity.

But the story of twisted bilayer graphene is just beginning. Its potential is yet to be fully unveiled, layer by layer, twist by twist. In one study, led by U Chandni and her PhD student Saisab Bhowmik at the Department of Instrumentation and Applied Physics, they explored how this magical material behaves when paired with another unique material, tungsten diselenide (WSe_2). The key player in this tango is spin-orbit coupling, which influences how electrons spin like tiny dancers. They wanted to understand how the little spins and valleys (imagine them as dips and bumps in the graphene landscape) interact, and they found some interesting stuff.

Their experiments uncovered a map of different phases in TBG, like finding secret doors. They observed that electrons can exist in different "valleys" within the material. Chandni's team discovered that spin-orbit coupling helps organise these valley dwellers.

Not only that, imagine turning on a tiny magnetic field, like waving a conductor's baton. The researchers found that this can completely change the electron dance, even reversing their magnetisation, like switching the lead dancers of a concert. The way electrons move through the material, their "Fermi surface," can be reshaped like a dance floor under construction. By adjusting the number of electrons and the magnetic field, Chandni's team could modify this dance floor (the Fermi surface), influencing the electron flow.

These findings reveal the incredible potential of magic-angle twisted bilayer graphene and open up exciting possibilities for future applications. Imagine electronics that can be fine-tuned with magnetic fields or devices that harness the unique valley ordering of electrons for next-generation computing. By understanding the intricate steps of electrons, researchers can choreograph a future filled with innovative technologies and groundbreaking discoveries.

Reference: Bhowmik S et al., *Nature Communications* (2023)

Tuhin Kumar Maji *is currently a National Postdoctoral Fellow at the Indian Institute of Science, Bangalore. He holds a bachelor's degree from Ramakrishna Mission Vidyamandira, Belur Math, under the University of Calcutta. Furthering his academic pursuits, Tuhin earned a master's degree in Physics from the Indian Institute of Technology Madras (IITM). In 2021, he successfully obtained his Ph.D. in Nanoscience and Nanotechnology from the S. N. Bose National Centre for Basic Sciences, Kolkata.*

Tuhin's contributions have garnered him several awards and recognition at both national and international conferences, solidifying his reputation as a prolific researcher in the field.

Currently, Tuhin serves as a Senior Postdoctoral Fellow at IISc Bangalore, working under the guidance of Prof. Arindam Ghosh in the Department of Physics. His current research focuses on exploring the exotic structural and electrical properties of bimetallic gold-silver heterostructures.Tuhin has an impressive publication record with over 36 peer-reviewed publications, accumulating 537 citations and boasting an h-index of 12.

Understanding the Dissipative Mechanism of a New 2D Superconductor

By Md Aarif Ali

Interfaces within solid materials serve as the cornerstone of modern technology. Consider transistors, ubiquitous in electronic devices, which manipulate electrons at semiconductor interfaces. Beyond this, the interface between any two materials can exhibit distinct properties drastically different from each material, paving the way for innovative breakthroughs.

A novel interfacial superconductor has emerged, posing intriguing fundamental inquiries and promising applications in quantum information processing or quantum sensing. Superconductivity in mercury, discovered by H Kamerlingh Onnes in 1911, exhibits zero electrical resistance at 4.2 K. Zero resistance implies the transmission of current at any distance with no losses. Notable superconductors include aluminum, niobium, magnesium diboride, cuprates like yttrium barium copper oxide, iron pnictides, etc. These materials only become superconducting at temperatures below a certain value, known as the critical temperature.

Like semiconductors, superconducting materials bear immense technological significance, from MRI magnets to accelerated electrical connections and potential advancements in quantum technology. While most superconducting materials and devices exist in a 3D realm, offering well-understood properties, a pivotal discovery in 2004 uncovered a 2D electron gas (2DEG) between oxide insulators— $LaAlO_3$ (LAO) and $SrTiO_3$ (STO) — capable of achieving superconductivity. This superconductivity could be manipulated like a transistor, activated and deactivated using electric fields.

Yet, achieving this superconducting state necessitated cooling the sample to about 0.2 K, a temperature proximate to absolute zero (-273.15°C), demanding specialised equipment like a dilution refrigerator, known for its substantial operational costs.

Despite the low transition temperatures, the LAO/STO interface has been extensively studied for insights into superconductivity, spintronics, and magnetism.

Recently, in 2021, researchers at the US Department of Energy's Argonne National Laboratory found an interfacial superconductivity in $KTaO_3$ (KTO) at relatively higher temperatures. This oxide interface boasts a significantly elevated transition temperature of 2.2 K, approximately ten times higher than prior materials, rendering it superconducting without reliance on a dilution refrigerator. Its exceptional characteristics raise numerous intriguing inquiries.

Exploration of energy dissipation in these 2D superconductors under perpendicular magnetic fields at low current excitations has spanned two decades. However, dissipation mechanisms at higher current drives remain largely unexplored. In a recent endeavour, Professor Srimanta Middey's research group from the Department of Physics at Indian Institute of Science delved into the underlying mechanisms triggering dissipation at high current drives in the KTO (111) interfacial superconductor. With detailed temperature-dependent transport measurements and analysis, they have identified strong indications of flux-flow instability proposed by Larkin and Ovchinnikov, in association with Joule heating effects caused by hot-spots. Their findings are detailed in the paper titled "Flux-flow instability across Berezinskii-Kosterlitz-Thouless phase transition in $KTaO_3$ (111) based superconductor" in Communications Physics.

Reference: Ojha SK et al., *Communications Physics (2023) the hot spots*

A Leap towards Quantum Control and Readout Systems for Quantum Processor

By Md Aarif Ali

From our smartphones to the most powerful supercomputers, the backbone of modern computing lies in the manipulation of digital ones and zeros. Yet, a wave of researchers anticipates a monumental shift, advocating for computers to harness the peculiar behaviours of the quantum realm. These quantum-based systems promise groundbreaking advancements spanning diverse domains – from revolutionising drug discovery and cryptography to empowering machine learning and advancing climate science.

At the heart of these futuristic computing aspirations lie the principles of quantum mechanics, governing the behaviours of matter and light at atomic and subatomic scales. These principles underpin myriad innovations, including MRI imaging, lasers, atomic clocks, and nanoscale microscopes. However, transforming these principles into tangible quantum computers necessitates mastery of a distinct skill: precise control over the behaviours of quantum systems while retaining their inherently perplexing quantum nature.

Enter the qubit, the elemental unit of quantum information. Qubits are the bedrock of quantum applications encompassing computing, sensing, and communication. Qubits manifest in various forms – trapped ions, semiconducting quantum dots, nitrogen-vacancy centers, and, notably, superconducting qubits. Among these realisations, the pursuit of scalable quantum computing platforms gravitates towards superconducting qubits.

These qubits demand high-frequency electromagnetic signals in the gigahertz range for control and nanosecond-scale readout pulses. Conventional setups to generate and capture such signals often entail complexity and cost, involving numerous components. However, the solution may lie in a bespoke Field Programmable Gate Array (FPGA)-based system, consolidating the functionalities of traditional equipment onto a singular board.

Yet, with such strides in development, three key challenges loom large: ensuring high-fidelity microwave signal handling, scalability, and crafting a user-friendly interface.

In a recent breakthrough, researchers at the Departments of Physics and Electronic Systems Engineering at IISc have confronted these challenges head-on. Their innovation, the Scalable Quantum Control and Readout System (SQ-CARS), leverages the Xilinx RFSoC FPGA board. The team meticulously tested the SQ-CARS system, conducting diverse experiments with superconducting transmon qubits, and benchmarking its performance against established traditional setups.

This development marks a major leap in the quest for scalable, efficient, and user-friendly quantum control and readout systems. The SQ-CARS development not only addresses pressing challenges in quantum computing infrastructure but also propels us closer to unlocking the immense potential of quantum technologies across various applications.

Reference: Singhal U et al., *IEEE Transactions on Instrumentation and Measurement (2023)*

Md Arif Ali *earned his Bachelor's degree from Scottish Church College of the University of Calcutta. He attended the Indian Institute of Technology Kanpur (IITK) to complete his master's degree. Arif received a Ph.D. in 2023 from IITK with the thesis "Developing a smart superconducting fault current limiter, exploring and producing high J_c state in Bi-2223".*

Currently, he is working on fabricating a superconducting device, SQUID magnetometer, at the Centre for Nano Science and Engineering in collaboration with the Department of Physics at the Indian Institute of Science, Bangalore, as an Institution of Eminence Postdoctoral Fellow.

Tech Titans: Insights from MTech Students

Learnings from Quantum Hackathons and Coding Challenges

By Oza Harshkumar Ajaykumar

I have gained valuable insights and skills by participating in various events like IBM Quantum Challenges, QHack Xanadu Hackathon, and iQuHack from MIT. Here are some key takeaways:

From Theory to Application:

Bridging the gap between theory and practical problem-solving is a crucial skill. Hackathons and coding challenges provide a platform to apply theoretical knowledge gained during coursework. For instance, in a QHack challenge, we used Grover's search algorithm to locate a "lazy colleague" within a company, demonstrating how algorithms can address real-world issues.

Access to State-of-the-Art Hardware:

Engaging in challenges like the IBM Quantum Challenge granted me access to cutting-edge hardware, such as their 127-qubit processor. Solving problems related to understanding the layout of qubits inside the processor highlighted the importance of hardware knowledge in optimizing performance.

Different Programming Packages:

Participation in diverse competitions introduced me to various programming platforms and hardware access methods.

This exposure allowed me to explore other implementations of the same algorithms and compare their performance.

Competitive Nature:

Some hackathons incentivise accurate and early submissions with prizes. This fostered a competitive mindset, promoting faster learning and growth.

Time Management:

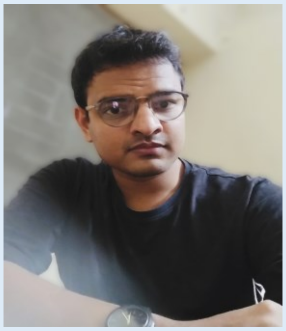
Time-bound submissions in these challenges honed my ability to manage time effectively while maintaining accuracy. This skill is crucial when working on projects with tight deadlines.

Collaboration:

This emerged as a critical strength in hackathon competitions. Through work distribution and intense discussions, I strengthened my technical understanding.

I had the opportunity to interact with individuals from diverse backgrounds.

Oza Harshkumar Ajaykumar



I hail from the scenic city of Ahmedabad and earned my Bachelor's degree in Electrical Engineering from IIT Indore in 2021. Following that, I gained six months of industry experience. Later, I enrolled in the master's programme in Quantum Technology at IISc in 2022. I enjoy engaging in activities such as playing Snooker, Badminton, Chess, and the Flute during my leisure time.

Quantum Sensing and Imaging: Revolutionising Healthcare, Environmental Monitoring, and Beyond

By Prasanth Kumar A S

Quantum sensing harnesses the unique behaviours of quantum particles to detect and measure physical properties with unparalleled accuracy. Unlike classical sensors, which operate based on classical physics principles, quantum sensors exploit quantum phenomena such as superposition and entanglement. This allows them to achieve levels of precision that were once thought to be impossible. These sensors leverage atomic and light properties for precise measurements, offering potential applications in various sectors. While quantum sensors offer unparalleled benefits for sensing, their sensitivity to the environment presents challenges for quantum computers. These advanced sensors excel in measuring acceleration, magnetic fields, rotation, gravity, and time with superior accuracy compared to classical devices.

Applications include more miniature and accurate atomic clocks, fog-penetrating cameras, and underground structure mapping.

Despite the transformative potential in energy, transportation, healthcare, and security, their commercial viability requires greater recognition.

Researchers aim to raise awareness, especially for critical infrastructure safety, like air traffic control and water utilities. However, obstacles hinder quantum sensor adaptation in real-world settings. Unpredictable technology adoption and perceptions of quantum tech as futuristic impede progress. Unlike quantum computers, quantum sensors are already used commercially, such as in GPS. Yet, establishing pathways for broader commercial benefits is crucial.

Quantum gravity and gas sensors on satellites offer precise data for climate modelling. Quantum magnetic sensors monitor brain signals, while gravimeters track underground water and volcanic activity.

Quantum sensors – 1,000 times more accurate than classical ones – promise reliable navigation in signal-challenged areas.

Overcoming funding and attention hurdles are vital for faster quantum sensor commercialisation in diverse environments. commercialization

How Do Quantum Sensors Redefine Precision in Healthcare Diagnostics and Imaging?

One of the most promising quantum sensing applications in healthcare is magnetic resonance imaging (MRI). Traditional MRI machines rely on expensive superconducting magnets, which require extreme cooling.

Quantum sensors offer an alternative approach by detecting the weak magnetic fields associated with the body's natural magnetic properties. This reduces the cost and complexity of MRI machines and enhances imaging resolution, enabling detailed visualisation of tissues and organs. Additionally, quantum sensors are making strides in the field of molecular imaging. These sensors can identify biomarkers associated with specific diseases by detecting subtle changes in molecular properties. This has the potential to revolutionise early disease detection, allowing for timely intervention and personalised treatment plans.

Could Quantum Sensors Transform Environmental Monitoring to Foster a Sustainable Future?

Beyond healthcare, quantum sensing plays a crucial role in environmental monitoring.

Quantum sensors can accurately measure environmental parameters, providing critical data for climate studies, pollution control, and resource management.

In climate science, quantum sensors are employed to measure greenhouse gas concentrations. Quantum gas sensors, for instance, can detect trace amounts of gases such as carbon dioxide and methane. This capability is instrumental in understanding climate change dynamics and formulating effective strategies for mitigation.
Moreover, these sensors contribute to monitoring air and water quality. These sensors can detect pollutants at deficient concentrations, offering early warnings of environmental threats.

In urban areas, quantum sensors are utilised for real-time monitoring of pollutants, aiding in developing sustainable urban planning strategies.

Exploring Beyond Traditional Boundaries

The versatility of quantum sensing extends beyond healthcare and environmental monitoring. Quantum sensors are finding applications in fields as diverse as archaeology, security, and navigation. In archaeology, these sensors are utilized to detect buried structures and artifacts.

Archaeologists can uncover hidden historical treasures without excavation – preserving cultural heritage – by measuring subtle changes in the Earth’s magnetic field.

In the realm of security, quantum sensors contribute to the development of detectors that are susceptible to various threats, including explosives and biological agents. The ability to detect these substances at extremely low concentrations enhances security measures in public spaces, transportation hubs, and critical infrastructure.

Prasanth Kumar A S

I am in my second year of the MTech programme in Quantum Technology at IISc Bangalore, having previously earned an MSc in Physics from the University of Hyderabad. Presently, I am engaged in a research project under the guidance of Dr. Ambarish Ghosh at CeNSE, focusing on quantum sensing using NV diamond centers.

My Internship Experience at Mercedes-Benz R&D India

By Aman Tyagi

I pursued an internship at Mercedes-Benz Research and Development India, Bangalore, in the Strategic & IP Innovations department, on quantum computing applications. Being a passionate automotive enthusiast, securing an internship at Mercedes-Benz was almost a dream come true, and the experience surpassed all my expectations. It was a first-of-a-kind experience for me in a corporate setup and my first encounter with quantum computing at an industry-level scale.

When I stepped into the company's state-of-the-art facilities, I was greeted with an atmosphere of innovation and excellence. The Mercedes-Benz R&D internship programme was structured to provide interns with a holistic view of the automotive industry, allowing us to gain hands-on experience in various departments. My work at the company involved finding attainable quantum computing applications in the short term. I worked closely with the patents department, analysed what is currently happening in the global market regarding quantum applications and added my insights towards what could be done more.There was emphasis on innovation and staying ahead of the curve regarding high-tech applications.

In the initial couple of weeks, I primarily focused on awareness of quantum computing and its applications in the automotive sector. Most of the time was spent interacting with people from various departments and my colleagues, and the aim of the interactions was to clear any misinformation, clear the hype around quantum computing, and give a reality check on the advent of quantum computing in the sector. Another topic of discussion was how quantum computing would change their work and what benefits it would bring.

For the next couple of weeks, I was involved in exploring what work happens at the MBRDI office and gathering ideas on what can be worth exploring in the near term with reference to quantum computing. One of the highlights of my internship was working closely with the engineering team.

I had the opportunity to witness the cutting-edge technologies and the meticulous attention to detail that goes into creating a Mercedes-Benz vehicle.

The exposure to advanced engineering processes and collaboration with experienced professionals significantly enhanced my technical skills and deepened my understanding of automotive design and engineering. To come up with quantum use cases, I had to brainstorm ideas with my colleagues, which gave me an idea of the effort that is required to develop use cases and ideas from scratch.
The scope of ideas wasn't limited to just computing but was quite diverse, encompassing all aspects of quantum technologies, including sensing, communication, simulation, materials, and more. This gave me an idea of the company's commitment to innovation and ideation.

Mercedes-Benz strongly emphasises sustainability, and it was inspiring to be part of a company that is actively working towards creating more eco-friendly and energy-efficient vehicles. I participated in seminars and talks that focused on integrating sustainable materials and reducing the environmental impact of the manufacturing process, aligning with the company's commitment to environmental responsibility. I witnessed the efforts that were going on inside the organisation to address corporate responsibility towards sustainability, and environmental and socio-economic responsibility.

The company's commitment to diversity and inclusion was evident throughout my internship. I had the privilege of working with a diverse team of professionals who were not only experts in their respective fields but also passionate about fostering an inclusive work environment.This aspect of the internship greatly enriched my overall learning experience. During the last couple of weeks, my main responsibility was to develop an architectural layout or a plan that one could follow to develop intellectual property in the domain of quantum technologies in the automotive industry. Given the stage that quantum technology is currently in, it is important to demonstrate a significant advantage of the technology to the players in consideration. Due to the technology still being nascent, organisations' are keen on the development of patents and IP in the domain, which was my focus at the end of my short stint at MBRDI.

Another point I would highlight is the mentorship programme at Mercedes-Benz, which was another invaluable aspect of my internship. I was assigned a mentor who provided guidance, shared insights into the industry, helped me navigate the professional landscape, and provided valuable feedback throughout the internship. I am sincerely grateful for the great mentorship I was provided.

In conclusion, my internship at Mercedes-Benz was an immersive and transformative experience. The company's commitment to excellence, sustainability, diversity, and innovation has left a lasting impression on me. It taught me what to keep in mind while developing new technologies, what their intended purpose is, and how they can benefit society. I am grateful for the opportunity to have been part of such a dynamic and forward-thinking organisation. The skills and knowledge gained during this internship will be instrumental in my career.

Aman Tyagi

I am a final-year student in the MTech—Quantum Technology programmes at IISc Bangalore. I completed my bachelor's in technology in engineering physics with a minor in materials science and technology at Delhi Technological University, Delhi. Currently, I am working in the field of simulation and modeling of devices for superconducting quantum computing at IISc.

IQTI and QuRP events

IQTI-Industry Conclave 2022

The first IQTI Industry conclave was hosted on 8th July 2022, bringing together 22 participants from 13 industries. This platform helped to understand the requirements and expectations of industries from academia in the Quantum technology domain. This also catalyzed building industry-academia partnerships and paved the way for joint proposal writing.

Q-Daksha Student Internship Program

Q-Daksha student internship program 2023 was launched on National Science Day (28th Feb 2023). A total of 159 registrations were received, and we offered Internship opportunities to 10 selected students from Karnataka, and 7 underwent internships at one of the quantum labs at IISc during their summer semester break.

Q Daksha 2024 will reopen for registration on 28th Feb 2024.

Q-Karyashala 2023

Q-Karyashala, a 2-day workshop on quantum technologies, was organized on June 27th and 28th, 2023, and aimed to provide attendees with an opportunity to deepen their understanding of quantum technology. 84 participants (57 from Karnataka and 27 from other states) from different universities and industries attended the workshop. The workshop included pedological talks and an interactive session, allowing attendees to engage with the speakers and clarify their doubts. We received positive feedback from participants who attended the workshop. They found it to be informative and engaging.

Participants engaging in pedagogical talks

Visit to the Micro and Nano Characterisation Facility and the National Nanofabrication Centre

Interactive session

QuanTalks – Popular science talks

'QuanTalks' A series of talks exploring various topics related to quantum technology was hosted. Renowned experts and visionaries presented pedagogical talks, cutting-edge research, innovative developments, and prospects within quantum technology. Click here to access the repository of QuanTalks.

QuRP Co-Sponsors RPGR 2023 Conference

QuRP co-sponsored the RPGR (Recent Progress in Graphene Research and 2D Materials) conference held from November 20th to 23rd, 2023.

QuRP-RPGR partnership program 2023

As a part of co-sponsoring, QuRP provided an exclusive opportunity for students and faculty members from Karnataka to participate in the international conference through the QuRP-RPGR partnership program.

QuRP-RPGR partnership program 2023 allowed 27 eligible candidates (20 students and 7 faculty members) to engage with the RPGR 2023 conference, out of which 7 candidates (3 students and 4 faculty members) were given the opportunity for poster presentation.

Poster presentation by QuRP-RPGR partnership program participants

Special public talk

QuRP, in collaboration with CEFIPRA (Indo French Center), organized a special public talk by Prof. Serge Haroche, 2012 Nobel Laureate.

Link to the recording: [Prof. Serge Haroche,2012 French Nobel Laureate Talk at IQTI on the History of the science of Light. - YouTube](#).

IQTI-Industry Conclave 2023

The IQTI-Industry Conclave 2023 was organized on 30th June 2023 and launched the IQTI-Industry Partnership Program (IIPP). It was a one-day event that brought together industry experts in quantum technology. The technical talks, brainstorming sessions, and Mtech thesis expo showcased the latest advancements and capabilities in Quantum Technology at IISc.

QuRP at BTS 2023

QuRP participated in the Bengaluru Tech Summit 2023 between November 29th to December 1st, 2023. QuRP showcased its initiatives and projects in Quantum Technology to promote skill development and industry/startup-academia partnership in Karnataka. Many students and faculty members showed keen interest in the Q Daksha and Q Karyashala programs.

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