IISc Quantum Technology Initiative (IQTI)

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1. Background

Attempts to understand a variety of phenomena observed at the atomic scale led to the formulation of quantum physics in the early part of the twentieth century. That allowed us to understand how properties of bulk materials arise from their quantum origin, and subsequent harnessing of these properties produced technological applications, such as semiconductors, superconductors, and lasers, in the second half of the twentieth century. These applications have made an enormous impact on society, and without them, ubiquitous electronic gadgets, computers, mobile phones, and the internet would be unthinkable. Nowadays, this breakthrough is referred to as the first quantum revolution. It has been incessantly driven and sustained by the miniaturization of the elementary device components. In the process, technological developments reached such a stage towards the end of the twentieth century that it has become possible to control and manipulate individual quantum degrees of freedom. The paradigm shift from observation to control has opened a new door, and what we can achieve with such capabilities is dubbed the second quantum revolution. It aims to make novel quantum devices that would make essential use of quantum properties (such as superposition, entanglement, squeezing, and tunneling of quantum states) in their function.

The building blocks of these quantum devices are fundamental physical objects—spins, atoms, and photons, generically described as qubits. They can be put together in many different ways to construct sensors and measurement devices, communication systems, computers as well as some other unimagined future applications. The ongoing attempts worldwide focused on the construction of customized quantum systems and materials, are directed towards bringing transformative advances in science, economy, and society. They envisage orders of magnitude enhancement in the precision of sensors and metrological instruments, strategies for secure communications that would herald the arrival of a quantum internet, quantum computers that can tackle computationally hard problems, and disruptive advances in imaging and energy manipulation techniques.

India did not invest sufficiently in the first quantum revolution and is dependent on other nations for modern electronic gadgets. India also has been a late entrant in the race for the second quantum revolution. But the immense potential of quantum technologies to give rise to transformative applications has been recognized, and the Government of India announced the "National Mission on Quantum Technologies and Applications (NM-QTA)” in 2020. The mission aims to lay a solid foundation in the field of quantum technologies by supporting fundamental and translational research, leading to the invention of new products, services, and the creation of a skilled human resource. While NM-QTA desires to catapult India to the midst of the second quantum revolution, limitations in the existing expertise and facilities available in India pose significant constraints on its advancement.

The Indian Institute of Science aspires to deploy a dedicated effort to address these challenges, by establishing a framework to promote collaborations between physicists, material scientists, computer scientists, and engineers. IISc, being the key institute instrumental in helping India develop past strategic missions (Indian nuclear technology and space technology programs were conceived and nurtured at IISc), has a multi-disciplinary research faculty with an interest in quantum science and technologies. Prior to the present interest in quantum technologies, IISc has played a pioneering role in the country, for efforts to become self-reliant in areas of Condensed Matter Physics, Nanoelectronics, and Nanoscience. Recently, with funding support from the Ministry of Electronics and Information Technology, IISc has established a multidisciplinary Center for Excellence in Quantum Technology, in collaboration with the Raman Research Institute (RRI) and the Centre for Development of Advanced Computing (C-DAC), to deliver quantum-enhanced technologies.

2. Vision

Worldwide, developments in quantum technology show the following trends: (a) Practical applications are expected to appear first in sensing and metrology (already happening), then in communications and simulations (on the verge of happening), then as feedback to foundations of quantum theory, and ultimately in quantum computing. The number of physical qubits in a quantum device is approximately doubling every year, which exceeds Moore's law often used to characterize progress in traditional electronics. (b) Conventional classical technologies are simultaneously improving as well. They can compete with and counteract quantum technologies in hostile situations, where the latter would be highly fragile. The very principles that promise potentialities of quantum technologies in cooperative settings, also expose their limitations. Addressing both these aspects together is crucial.

In this context, IISc is launching its quantum technologies initiative, IQTI, to participate in and contribute to the national initiative and strategic demands, and to achieve technology readiness at par with international programs. It will leverage the Institute's research expertise in the area of quantum technologies, and at the same time, form a visionary research and development platform through national and international collaborations. We envisage this initiative not to be just academic science; it would actively engage with industry and strategic partners to create technology with economic benefits and social impact. IQTI would use the well-established academia-industry interface of IISc to establish a vibrant start-up culture and ecosystem, in order to convert the promises of fundamental research into entrepreneurial activities for product development.

The multi-disciplinary nature of the ongoing R&D in IISc fits seamlessly in the requirement of quantum technology development, from core hardware and back-end engineering support to algorithms for cryptography and machine learning. IISc intends to build on-field deployable systems for quantum-enhanced performance, as well as explore new fundamental and engineering routes for disruptive quantum applications.

The multifaceted collaborative efforts of IQTI will target the following areas:

1. Core quantum technology:

(a) Quantum computation

(b) Quantum communication

(c) Quantum sensing and metrology

2. Theoretical and modeling support:

(a) Quantum and quantum-inspired algorithms, Software simulators

(b) Quantum information theory and error correction

(c) Quantum cryptography and post-quantum cryptography

3. Peripheral technology development:

(a) Quantum materials: Discovery, modeling, and design

(b) Quantum materials: Device Technology

3. Objectives

The aim of IQTI is to enable the promise of quantum science and technology, by operating in sync with the global developments in this field. Although this is an open-ended expedition in many aspects, it requires clarity for short-term goals and a vision for long-term targets. Anticipating inclusive, sustained, and globally competitive growth, some of the short-term and long-term objectives of IQTI are the following:

Short-term aims: (0-3 years)

- Reliable and high-fidelity elementary quantum components (e.g. individual qubits, single photon sources, single-photon detectors, NV-center magnetometers, waveguide interferometers).
- 8-qubit quantum processor with superconducting transmon technology.
- Software simulators to verify and validate noisy quantum devices.
- Quantum-inspired algorithms that can be executed on existing computers and devices (E.g., randomized algorithms, recommendation systems, generative adversarial networks, amplitude amplification with wave dynamics, post-quantum cryptography).
- Peripheral devices (electronics and nanotechnology) to interact with quantum components, incorporating efficient hybridization techniques.
- Novel materials and architectures (e.g. layered devices).
- On-field trials, reliability testing, packaging, etc. of viable peripheral and quantum-enhanced components.
- Infrastructure development for large-scale semiconductor and device processing needed for quantum applications (e.g. back-end electronics, and photonics).

9. Introduction of MTech and PhD programs specializing in Quantum Technology.

Longer term aims: (4-6 years)

1. Improve the accuracy of all the short-term targets achieved.
2. Multi-qubit quantum processors based on transmons, optical and other platforms. Especially, scaling up the number of qubits in the superconducting transmon processor.
3. Campus-wide quantum-secured communication network.
4. High-precision sensors, measurement devices, and transducers. They will include magnetometry at ~$fT/Hz^{1/2}$ resolution with NV-centers, nano-g inertial sensing with cold atoms and trapped ions, and so on.
5. Hardware simulation of few-body quantum systems (e.g. molecular chemistry and biology, physics models, material design).
6. Creation of new devices by integrating elementary components.
7. Quantum illumination and imaging (LiDAR) at lab scale.

Within each of these focus areas, IQTI will steer

1. Basic research at both experimental and theoretical levels.
2. Translational research in emerging technologies for the market.
3. A national and international quantum research network through a visitors' program. That would also introduce dedicated adjunct faculty positions, named chair professorships, industry-affiliated positions, etc.
4. Directed research through strategic partnerships to address problems of national interest.
5. Establishment of facilities for quantum device fabrication, testing, and characterization.
6. Training and capacity building for the next generation of scientists, engineers, technicians, and technocrats.
7. Research collaborations, meetings, and knowledge exchange with leading domestic and international institutions.
8. Industrial collaborations and entrepreneurship development.

4. Organizational Capacity

4a. Academic Strength and Research Interests of IISc

IISc's strength is the breadth of its existing technical expertise, and ability to adopt and rapidly develop new expertise covering a wide spectrum from basic sciences to engineering and technology.

Academic strength:

The ongoing quantum technology-centric activities in IISc can be broadly categorized as below:

1. Core quantum technology

- Quantum computation: Building and bench-marking multi-qubit processors with superconducting transmon qubits (*In progress through funding from the Ministry of Electronics and Information Technology).*
- Quantum communication: Development of photonic technology components and their on-chip integration for quantum communication, with the aim to demonstrate a prototype quantum network within the Institute *(In progress through funding from the Ministry of Electronics and Information Technology*).
- Quantum sensing and metrology: Quantum-enhanced sensors of electric and magnetic fields using NV-centers in diamond, integrated photonics for quantum sensing and imaging applications, and interferometric devices to assist inertial navigation.
- Quantum materials and devices: Development of platforms for new qubit architectures, quantum emitters in patterned layered materials, single photon detectors using van der Waals heterostructures and superconductors, quantum-enhanced fibre optic channels etc.

2. Theoretical and modelling support

- Quantum computing and communication algorithms.
- Quantum-inspired algorithms for data analysis and logistics problems.
- Emulation of quantum logic circuits and measurement, Simulators of noisy quantum devices.
- Quantum error correction, quantum cryptographic protocols.
- Post-quantum cryptography.
- Quantum reinforcement learning and machine learning.
- Modelling and prediction of quantum materials.

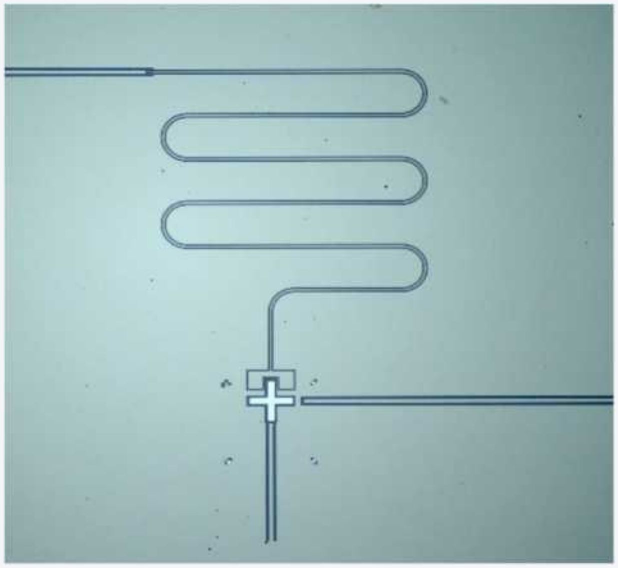
3. Peripheral technology development and engineering backup

- Exploring and improving material synthesis and characterization for applications in all verticals of quantum technology.
- Device engineering, technology development and optimization to improve the coherence time and the gate fidelity of spin, photonic and transmon qubits.
- Microwave and radio frequency engineering design. Architectures for microwave antenna and radio frequency communications.
- Engineering of novel photonic architectures, coupled with emerging material synthesis, for high sensitivity ultra-fast optical sensing.
- Reliable technology for chip and system-level integration of quantum components (packaging, thermal stability, EMI, variability control).
- Low-temperature control electronics and measurement platforms.
- Heterogeneous integration of classical, neuromorphic and quantum technologies.

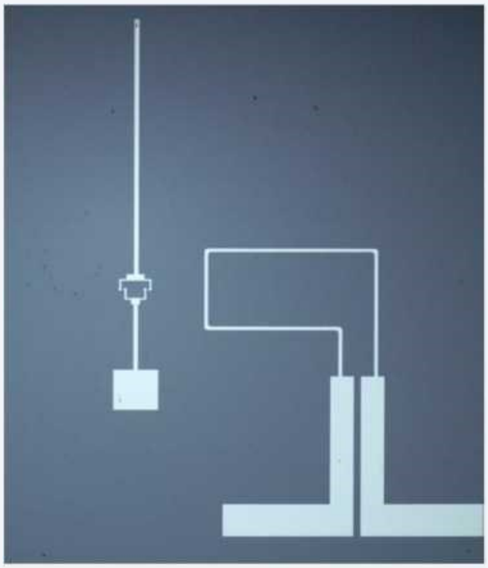
Research Interests:

A) Fundamental quantum technology

Superconducting transmon qubits: At present, the leading technology for building a quantum computer is based on transmon qubits in the circuit-QED architecture. Stable qubits with good control and coherence times have been demonstrated. Several groups around the world are constructing systems of 10 - 50 physical qubits. Challenge is the integration of individual components while keeping errors under control. With a basic set-up, single transmon qubits have been fabricated at IISc. We would like to expand this to multi-qubit systems, simultaneously developing packaging and DC/RF wiring configurations for cryogenic large-density architectures.
[Vibhor Singh (PH), Baladitya Suri (IAP), Chetan Singh Thakur (DESE)]



The primitive circuit-QED setup. An x-mon qubit (shown by plus-shape structure) coupled to a readout resonator (wiggly lines).



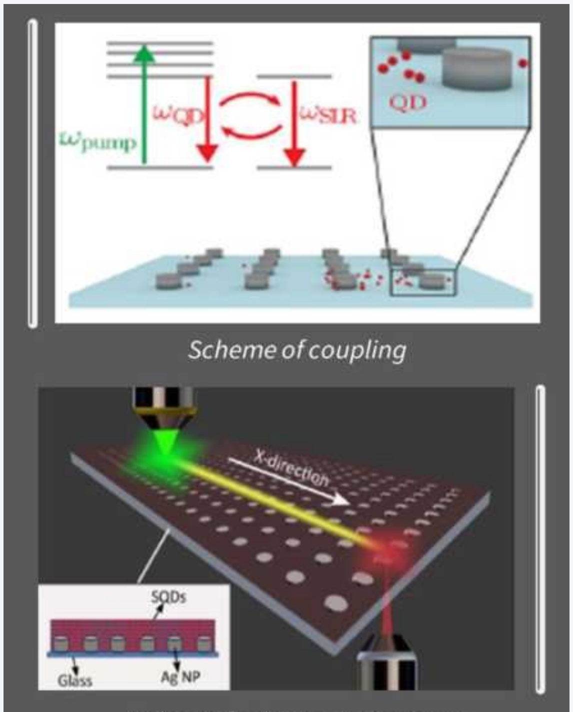
A transmon qubit designed for 3D cavity architecture with a fast-flux line.

Source: Dr. Vibhor Singh's group, Dept, of Physics, IISc

Photonic quantum processor:

Photons can carry quantum information in their polarization, space, and time/phase degrees of freedom, and can be made to interact in nonlinear materials and waveguides. An on-chip photonic quantum platform operating at room temperature can be put together using emitters with controllable photon numbers and photon number resolving detectors. As identical particles, photons can demonstrate quantum supremacy in the boson sampling problem. They can be prepared in magic states, which are the starting point for distributed measurement-based computing and the creation of multi-partite entanglement.

[Jaydeep Basu (PH), Shankar Kumar Selvaraja (CeNSE)]



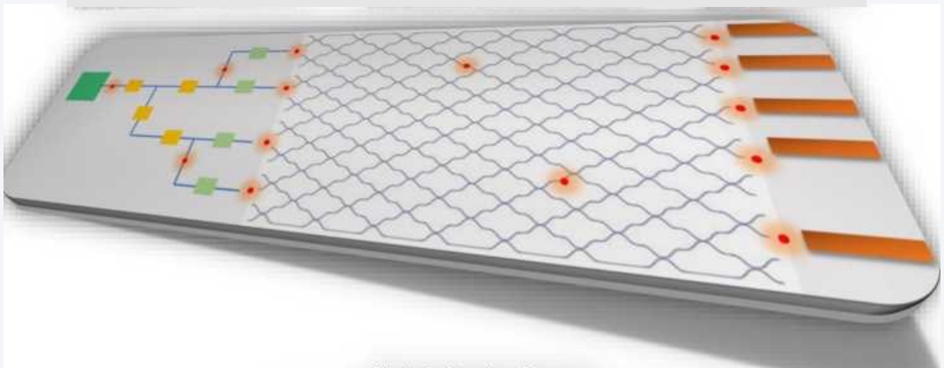
Scheme of coupling

Scheme for long range energy propagation

Source: Prof. Jaydeep Basu's group, Dept, of Physics, HSc

Single photon sources: Heralded photon sources, providing on-demand entangled photons, are crucial ingredients for quantum communications and quantum random number generation. Such photons have to be generated and filtered on-chip with high conversion efficiency, in telecom as well as optical frequency range. Point defects in layered materials and semiconductor heterostructures are being explored as promising nonlinear dielectric materials for this purpose.

[Shankar Kumar Selvaraja (CeNSE), Anshu Pandey (SSCU)]



Photonic Quantum Processor.

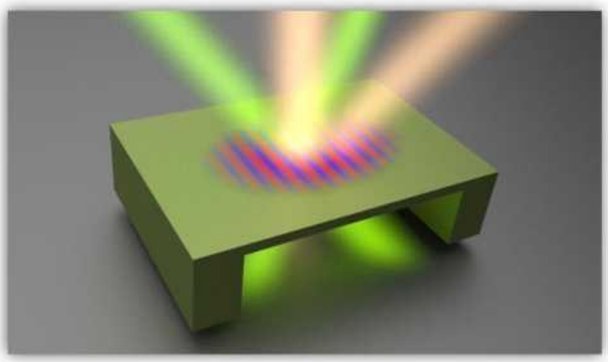
Source: Prof. Shankar Setvaraja's group, CeNSE, HSc

Single photon detectors: van der Waals hybrids of graphene and transition metal dichalcogenides are extremely responsive to optical excitations. They can be used to construct photon number-resolving detectors, which are essential for quantum measurements and quantum communications. They can be part of precise nanoscale electromechanical sensors, ultra-fast bolometers, and qubit readout schemes as well. The basic low-temperature nanoelectronics facilities exist at IISc.
[Arindam Ghosh (PH), Kausik Majumdar (ECE)]

Quantum communications: Quantum sources and detectors need to be coupled to communication channels (either fiber-based or free space) through necessary photonics and electronics. The components (waveguides, couplers, relays, ring resonators, etc.) must preserve quantum coherence and match frequency during signal processing. Error correction protocols are essential to eliminate the noise that may enter during signal conversion between different components. A campus-wide low-loss communication network with integrated photonic devices is being designed to demonstrate quantum key distribution and teleportation. [Varun Raghunathan (ECE), Asha Bharadwaj (IAP), T. Srinivas (ECE), Shayan Srinivasa Garani (DESE)]

Color defects in diamonds: Nitrogen vacancy (NV) centers in diamonds are highly sensitive and robust magnetometers. They can be hyperpolarized and integrated with motile colloids. When combined with well-established magnetic resonance imaging methods for electron spins, they can have wide-ranging applications—from industrial to medical ones. Silicon vacancy centers in diamonds have high coherence and can help in forming quantum memories. [Ambarish Ghosh (CeNSE)]

Quantum Sensing/Metrology:
Quantum metrology looks at ways to leverage the rules of quantum mechanics to improve measurement sensitivity, in order to detect tiny changes in physical observables.
There is enormous interest in utilizing entanglement, squeezing and nonlinearities of quantum dynamics to improve measurement sensitivity significantly beyond what the classical systems permit.
Sensitive qubits can be prepared and carefully positioned in two-dimensional transition metal chalcogenides and related semiconductors.
Measurement and characterization of their fundamental dynamics can improve photon signal sensitivity and thermometry by orders of magnitude.
[Akshay Singh (PH), Arindam Ghosh (PH), Kausik Majumdar (ECE)]



*Schematic of transient grating.
Source: Dr. Navaneetha Ravichandran's group, ME Dept., IISc.*

Hybrid quantum systems: Recent advances in quantum computing and measurements amply demonstrate the utility of tapping into hybrid systems that leverage the advantages of two or more types of systems. These systems would include coherent acoustic oscillators that interface qubits and communication systems, mechanical resonators that can function as quantum memory, electrons trapped in nanobubbles near liquid helium surface, and quantum sensors coupled to nanodevices.
[Vibhor Singh (PH), Akshay Naik (CeNSE), Ambarish Ghosh (CeNSE)]

Quantum devices using 2D materials: Layered 2D materials and heterostructures of 2D-3D materials offer a variety of possibilities to explore quantum devices. They span spin, charge, and excitonic valley qubits, designs for transmon qubits and Josephson junctions, single photon emitters and detectors, and so on. Engineering challenges for large-area fabrication, reliability, contact resistance, etc. need to be overcome.
[Arindam Ghosh (PH), Kausik Majumdar (ECE), Mayank Shrivastava (DESE)]

B) Theory, computation, and software

Quantum algorithms: First-generation quantum computers will be moderately sized and error-prone (not fault-tolerant). Demonstration of quantum supremacy with them requires finding suitable problems and solution strategies superior to their classical counterparts. Variational methods and universality properties of physical systems are useful ingredients in this search. Methods to verify the quantum results, without relying on classical cross-checks, are needed as well.
[Apoorva Patel (CHEP)]

Quantum simulations: First non-trivial applications of quantum computers are likely to be in direct simulations of models of quantum statistical mechanics, quantum field theory, and molecular chemistry. Efficient techniques for these need to be developed, which have polynomial computational complexity with respect to both the input and the output number of bits.
[Apoorva Patel (CHEP), Rahul Pandit (PH)]

Quantum simulators: All quantum devices will be noisy and imperfect due to unavoidable environmental disturbances. They will need verification and validation of their performance. For systems of 10-20 qubits, the consequences of specific noises and imperfections can be estimated using their classical simulators, and that can help in improving the design and reliability of quantum devices.
[Apoorva Patel (CHEP)]

Quantum error correction and information theory: Error correction protocols are essential to eliminate the noise that may enter at any stage of quantum information processing.

They are also needed to protect signal conversion between different components, to deal with occasional component failure, and to protect distributed quantum correlations over networks. Quantum information theory provides the framework to quantify capabilities of quantum channels and to design error correction codes. The fault-tolerant design strategy requires an error rate below a specific threshold and sufficient redundancy to guard against local disturbances. Graph-state analysis can provide efficient codes that safeguard multi-party entanglement and communications, against eavesdropping and node failure. Quantum algebraic codes over qubit/qudit states with entanglement-assistance can provide superior performance than without it.
[Shayan Srinivasa Garani (DESE), Navin Kashyap (ECE), Vinod Sharma (ECE)]

Open quantum systems: Identification of dominant environmental errors, and methods to suppress them, require careful modelling of quantum devices. The control and measurement components also bring in noise, and identification of decoherence-free subspaces that avoid noise is important. Models and algorithms need to be developed for noise-aware optimal control, fidelity estimation and error mitigation. Stochastic differential equations provide a useful framework, and the methods can mimic those followed in VLSI design and simulations. [Soumyendu Raha (CDS), Soumitra K. Nandy (CDS)]

Post-quantum cryptography: Public key cryptographic systems, such as RSA, are vulnerable to quantum computers. New classical communication protocols that would be resistant to quantum attackers are being developed, such as lattice codes, multi-variate polynomials over finite fields and isogeny computation over elliptic curves. Rigorous cryptanalysis for quantum-safe key agreements and signatures is under investigation.
[Sanjit Chatterjee (CSA)]

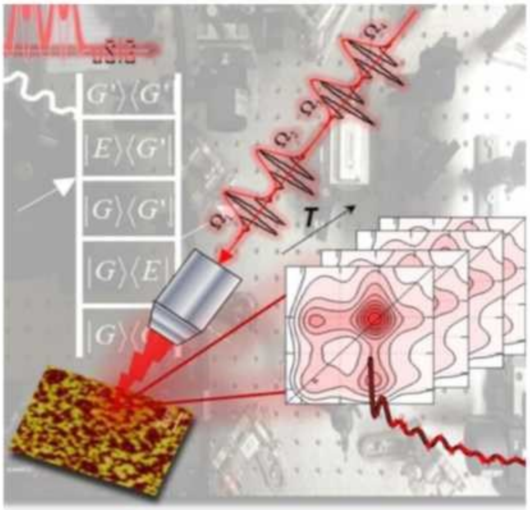
Quantum-inspired algorithms: Discoveries of efficient quantum algorithms have taught us to look at classical solutions to the same problems from a new perspective, leading to improved classical algorithms. Examples are randomized algorithms for optimization problems, spanning widely disparate areas such as recommendation systems, transport logistics and financial markets. These solutions have huge technological potential because they can be deployed with existing hardware. Yet another possibility is to exploit classical wave dynamics in amplitude amplification tasks, with applications to energy transfer and catalysis.
[Apoorva Patel (CHEP)]

Quantum-enhanced analysis methods: Machine-learning and artificial intelligence have become popular in problems analyzing immense quantities of data. They rely on clever combinations of multiple feature-identifying signals to identify the target objects. Quantum-enhanced methods would extend these to situations, where multiple signals do not merely add but can interfere constructively as well as destructively. Their applications can range from analysis of experimental data, images and communications to astrophysical and genome studies.
[Chiranjib Bhattacharyya (CSA), Apoorva Patel (CHEP), Sudhir Vempati (CHEP)]

C) Materials technology and engineering

The synthesis of materials, and the ability to precisely control and manipulate their properties, will play a major role in the next generation of quantum systems. IISc already has world-leading expertise in growth of 2D materials, heterostructures, oxides and other high-quality materials. This expertise will be leveraged to develop quantum materials with defect centres in ultra-pure materials, topological insulators, layered materials as well as heterogenous and designer materials. These quantum materials would be the precursors to developing a variety of quantum devices.

Discovery of new materials: Novel materials such as quantum defects with high spin-photon coupling, semiconductors with ultra-high thermal conductivity, heterostructures for quantum electronics and low-noise amplifiers, materials that suitably couple spin, phonon, and electronic transport, are important targets. The Mott transitions in perovskite oxides, for example, can be used as triggers in new generation of high-performance bolometers for microwave and infrared detection. Such materials need to be first designed with simulations, then synthesized, and finally characterized by spectroscopy and electron microscopy, before incorporation in practical devices. [Abhishek Singh (MRC), Navaneetha Ravichandran (ME), Pavan Nukala (CeNSE), Vivek Tiwari (SSCU), Srimanta Middey (PH)]



Femtosecond Multidimensional Spectroscopy can resolve the quantum coherent superpositions between qubits, and the coupling of qubits to a dissipative bath. Source: Prof. Vivek Tiwari's group, SSCU, IISc.

Topological materials: These can lead to noise-resistant quantum devices. Candidates being investigated are: Ferroelectric thin films that can accommodate skyrmions and vortices, materials simultaneously displaying spin Hall effect and superconductivity, frustrated spin liquids and Kitaev spin liquids that can possess Majorana excitations, and chiral Weyl materials.
[Pavan Nukala (CeNSE), Chandni U. (IAP), Srimanta Middey (PH), S.A. Shivashankar (CeNSE)]

Quantum thermodynamic systems: Van der Waals heterostructures can be used to make quantum batteries and supercapacitors with small leakage, which are needed for high-speed electronics. MEMS/NEM'S resonators can be designed to reach the quantum limit of energy loss. [Abha Misra (IAP), Saurabh Chandorkar (CeNSE)]

Optomechanical systems: In addition to electronic control, optomechanical systems have the advantage of being systems that can be easily coupled to different quantum systems including spins, photons and transmon qubits. In a large complex network of quantum systems, these mechanical or acoustic systems can play a major role as quantum memory, isolators, transducers, and couplers of qubits and communication systems.
[Vibhor Singh (PH), Akshay Naik (CeNSE)]

Quantum memory: Electromagnetically induced transparency in optomechanical systems can be used to store information in mechanical modes of resonators. Multiferroic materials can be used for sensors and new types of memory.
[Akshay Naik (CeNSE), S.A. Shivashankar (CeNSE)]

Quantum system design: Many-body localization in disordered systems resists thermalization and decoherence. An understanding of their dephasing mechanisms can help improve the performance of quantum memory and sensors.
[Subroto Mukerjee (PH), Sumilan Banerjee (PH)]

Neuromorphic devices: Quantum computers will not be very efficient in solving several computational problems that can be easily addressed by von Neumann and neuromorphic architectures. They are therefore expected to be special-purpose devices that would complement other forms of computing rather than replace them. So, it has been projected that future computing systems would consist of all three forms, thereby requiring heterogeneous integration of qubits, bits, and neurons. A technology platform that can cater to all three forms of computing is needed. 2D materials offer one such platform, and IISc faculty has years of experience in developing devices and technology modules based on 2D devices.
[Chetan Singh Thakur (DESE), Arindam Ghosh (PH)]

Quantum dot-based devices: Portable, power-free, cost-effective, and eco-friendly devices can be made for the detection and estimation of toxic elements in water. Nano electroactuation using graphene quantum dots can be used to guide stem cell functionality.
[Bikramjit Basu (MRC)]

Engineering and technological challenges: Overcoming these is going to be a key step that would translate science into practical technology. The efforts will include device design and engineering approaches to improve the coherence time and gate fidelity of various types of qubits, and efficient microwave engineering for creating multi-qubit entanglement while suppressing crosstalk.

Technology platforms for mK electronics and on-chip quantum control electronics:
Control electronics in recently demonstrated quantum computers is forced to be far away from the qubits, because the superconducting transmon qubits operating at a few mK temperatures are kept inside a dilution refrigerator, whereas the control electronics is in a room temperature setup. This separation causes loss of gate fidelity, integration challenges, interferences and errors. A quantum computer designed for any practical purpose cannot afford such an operation. The problem can be addressed by bringing the control electronics next to the qubits, with a possibility to have the qubits and the control electronics on the same chip. That needs development of a technology platform for ultra-low temperature electronics.

System integration: To ensure reliable integration of components at the chip and system level, expertise is required in chip packaging, thermal design and management, electromagnetic shielding, as well as control over device and process variability.

4b. Existing Facilities & Infrastructure *National Nanofabrication Centre (NnfC):*

The National Nanofabrication Centre has a 14,000 ft^2 clean-room facility with capability for:

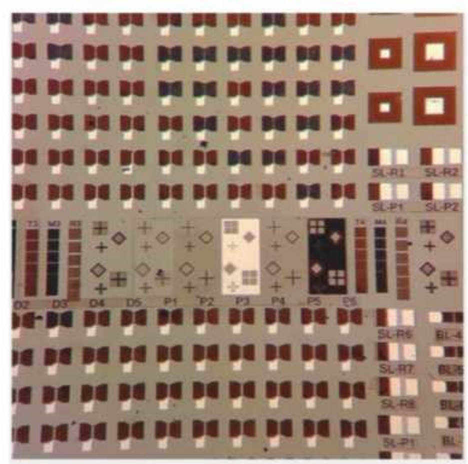
- Photolithography with resolution of 1 pm for optical and 10 nm for e-beam lithography.
- Developing unit processes for chemical & physical vapour deposition (CVD) of most commonly used semiconductors and dielectrics, such as Si, SiGe, Ge, SiO2, SiNx, Al2O3, TiO2, etc.
- Developing unit processes for wet and dry etching of most commonly used semiconductors and dielectrics.
- Fabricating complete MEMS sensors, gas sensors, GaN HEMTs, Si solar cells, novel 1D and 2D devices including graphene and MoS2, and photonic circuits.
- Developing new and customized processes for MEMS/NEM'S devices, microfluidic structures, and semiconductor devices for industries and other laboratories.
- A new ultra-high vacuum sputtering unit and a reactive ion etching unit for quantum devices.
- Inline characterization using various metrology tools.

National Nanofabrication Center at CeNSE, IISc

Micro and Nano Characterization Facility (MNCF):

The one of its kind micro and nano characterization facility (MNCF) aims to be a one stop solution for all characterization needs of any nanofabrication process. It is rare to find such a comprehensive array of tools under a single roof, anywhere in the world. Capabilities include:

- Complete electrical characterization of devices from DC to 110 Mhz, and at 4K to 400K temperature, using an array of probe stations and parameter analysers.
- Ability to characterize RF devices upto 70GHz.
- Ability to measure power conversion efficiency and external quantum efficiency (EQE) of solar cells.
- Metrology of thin films using optical profilometer, acoustic microscopy and atomic force microscope (AFM), including advanced modes such as piezo response, conductive, magnetic-force, scanning-tunnelling atomic force microscopy, etc.



GaN FET developed by Prof. Mayank Shrivastava's group (DESE, IISc)

- Comprehensive characterization of bulk materials and thin films using Raman spectrometry, photoluminescence (PL), electroluminescence (EL), Fourier transform infrared spectrometry (FTIR), X-ray diffraction (XRD), X-ray reflection (XRR), photoemission spectrometry (UPS and XPS), and UV-Visible spectrometer.

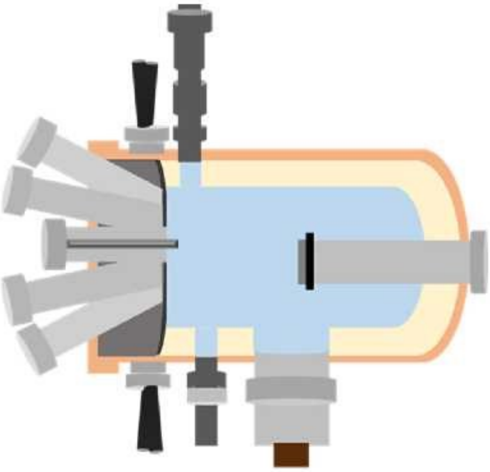
- Field emission scanning electron microscopy (FESEM) with dual beam focused ion beam (FIB), EDS and monochrometer (MonoCL), TEM.

<u>Other facilities (distributed across different groups):</u>

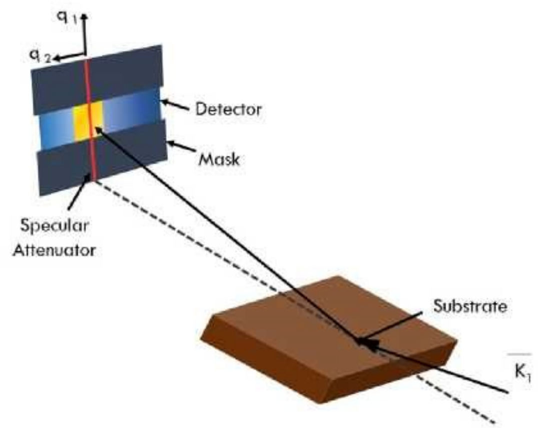
- Low temperature (4K) confocal Raman/PL setup for measurements with different excitation wavelengths (2 Nos: one with DC ports, and one with DC and RF ports).
- Low temperature (7K) electrical probe station for electrical/optoelectronic measurement of devices.
- Single photon level detection and correlation system consisting of timing electronics and single photon detectors.
- CCD camera having single photon detection capability.
- Low temperature (4K) confocal pulse (few 100 ns) Raman/PL setup with different excitation wavelengths.
- Set- up for thermal mapping with 50 ns time resolution and 500 nm spatial resolution. It can be mounted over any probe station as well as over an ultra-low vibration CC-LHe cryostat (in the same lab).
- Deep-level transient spectroscopy (DLTS) set-up to study deep-level defects in quantum materials.
- Fully automated RF (0-70 GHz) probe station.
- Semi-automated L-N2 probe station with RF (up to 4 GHz) capability.
- Room temperature STM, SCM, CFM, SSRM, SThM & KpFM.
- Lock-in amplifier-based set-ups for 1/f noise and thermal characterizations.
- Glove-box-based set-up for 2D material device engineering (having integrated thermal evaporator, stamping stage with a high-resolution microscope, and another dark field microscope with high magnification.
- Dilution fridge 10 mK with suitable microwave cabling, and related RF electronics such as Vector Network Analysers, signal generators, Arbitrary Waveform Generators, Digitiser, Scope.
- Another station for superconducting qubit (up to six) characterization and measurement is expected to be ready by April 2021.
- Low temperature (15 mK) dilution refrigerator system for electrical and thermal transport and noise measurements in field effect devices, single crystals, and thin films.

• Variable temperature optoelectronic measurement set-up for single photons in a magnetic field.

• Material and device engineering set-up with 2D materials for studying novel superconductors, and structural and topological phases, which may be useful in quantum communications as well as novel qubit platforms.



Deposition system for thin film and heterostructures of quantum materials



Schematic of Synchrotron X ray diffraction

Source: Prof. Srimanta Middey's group, Dept. of Physics, IISc.

To find more information about the Ongoing projects, please visit the IQTI website's page.
Here is the link to the page: https://iqti.iisc.ac.in/ongoingprojects

Team of IQTI

To find more information about the team members, please visit the IQTI website's member page.
Here is the link to the page:
https://iqti.iisc.ac.in/IQTImemberspage

Meet our Team

MTech in Quantum Technology

The program will train students in quantum technology for advanced research and industry. The elective part of the program will equip students to acquire training in allied technology areas as well.

M. Tech. Program in Quantum Technology

Motivation

- Quantum Technology is a rapidly growing field worldwide. There is a recent push in this direction by the Government of India. The National Quantum Mission (NQM) is being set up, and it urgently requires a trained workforce. The central government budget (2020) announced a support of Rs. 6000 crores over five years to this field.
- Govt. of India has declared a clear intention to develop the Quantum Technology Ecosystem
- Various govt organizations/departments have begun diverse activities in this area
- Several start-ups have come up in the field
- IISc is leading the first fully funded project on Quantum computing supported by MEITY
- Various groups at IISc already working in areas of Quantum Tech
- IQTI brings together around 50 faculty from different departments of IISc
- IISc has a vibrant community of researchers working in this field, spanning both science and engineering faculty, and across many departments. Several faculty members offer courses related to quantum technologies in their individual capacity, and the M.Tech. program will bring them under one umbrella.
- The program will train students in quantum technology, for both advanced research and advanced industry. The elective part of the program will equip students to acquire training in allied technology areas as well. The Entrepreneurship Seminar will encourage students to initiate start-ups in the field and help build a sustainable ecosystem.

Highlights of the Programme

- First full-scale Masters' program in all areas of Quantum Technology in India – one of the few in the world.
- Four verticals under the program
- Core courses in all four streams
- Lab courses teaching state-of-the-art techniques in RF engineering, Optics, Quantum Circuits, and Algorithms
- Emphasis on industrial internships after the second semester
- M.Tech project to give scope for tackling advanced open research problems

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Goals of the program

- To establish a multidisciplinary program for a multidisciplinary field
- To train skilled quantum engineers for academia and industry alike
- To prepare indigenous manpower for the National Quantum Mission
- To provide hands-on training in the full spectrum of fields within quantum technology

Admission

- **Duration of the program:** 2 years (4 semesters), as per IISc rules.
- Admission Qualification: B.E/B.Tech./equivalent degree in any engineering discipline, or 4-year B.S./M.Sc./equivalent degree in any science discipline. In all cases, a valid GATE score and strong mathematical background will be required.
- **Entry mode:** GATE qualification in Engineering or Science, followed by an interview.
- **Preferred GATE disciplines** are AE, BM, BT, CE, CH, CS, CY, EC, EE, GG, NM, IN, MA, ME, MN, MT, PH, PI, XE, ST, and GE.
- Scholarships and fees: These will be as per IISc rules. http://www.iisc.ac.in/admissions/fees-and-scholarships/
- **Host department:** This multi-disciplinary program will be formally hosted by the Department of Instrumentation and Applied Physics. A program coordination committee (PCC) will look after the courses, the admission process and the interviews, and the student performance.

Current Status of students

- August 2021 admissions – 8
- August 2022 admissions – 11
- August 2023 admissions – 13
- Students from Electrical, Electronics, Physics, Computer Science, Mechanical Engineering backgrounds have so far joined the program. We also have students from ISRO and defence forces.

Areas of Study

This is a 2-year (4 semesters) course-based multi-disciplinary program, as per IISc rules, including a project at the end.

The program will have the following four thrust areas:

- **Quantum Computation and Simulation**
- **Quantum Communications**
- **Quantum Measurement and Sensing**
- **Materials for Quantum Technologies**

The students will opt for their area of interest after the first semester of common coursework. Depending on their selected areas, they can choose softcore and elective courses to consolidate their knowledge and expertise.
The courses will also be elective options for the students of the IISc Undergraduate Program.

Total Credits: 64
Project Credits: 20
Hardcore Credits: 23
Softcore + Elective Credits: 21

- Students will be encouraged to pursue an internship with an external organization (public or private) during the summer term after the second semester.
- Students in the M.Tech. program may convert to a Ph.D. program as per IISc rules.

SEMESTER-WISE COURSE STRUCTURE

Semester 1 (16 credits)
Survey of Quantum Technologies (1:0)
Sensing (3:0)
Math Foundations of Quantum Tech (3:0)
Phys/Engg Foundations of Quantum Tech (3:0)
(1:0)
Intro to Quantum Computation (3:0)
Intro to Quantum Communication (3:0)
Basic Quantum Tech Lab (1:2)

Semester 2 (16 credits)
Intro to Quantum Measurement and

Materials for Quantum Tech (3:0)
Student Seminar (Project preparation)

Soft Core I (3:0)j
Elective I (3:0)
Soft Core Lab I (1:2)

Summer project (recommended)

Semester 3 (16 credits)
Soft Core II (3:0)
Elective II (3:0)
Industry/Entrepreneurship Seminar (1:0)
Soft Core Lab II (3:0)
Project I (6 credits)

Semester 4 (16 credits)
Elective III (3:0)
Project II (13 credits)

HARDCORE COURSES

Semester 1 (Aug-Dec):
•Survey of Quantum Technologies (Seminar) (1:0)
•Mathematical Foundations of Quantum Technologies (3:0)
•Physical and Engineering Foundations of Quantum Technologies (3:0)
•Introduction to Quantum Computation (3:0)
•Introduction to Quantum Communications and Cryptography (3:0)
•Basic Quantum Technology Lab (1:2)
Semester 2 (Jan-Apr)
•Introduction to Quantum Measurement and Sensing (3:0)
•Introduction to Materials for Quantum Technologies (3:0)
Semester 3 (Aug-Dec):
•Industry/Entrepreneurship Seminar (1:0)

SOFT CORE COURSES

Semester 2 (Jan-Apr):

- Advanced Quantum Computation and Information (3:0)
- Quantum Information Theory and Communications (3:0)
- Quantum-Safe Cryptography (3:0)
- NEMS and MEMS devices (3:0)
- Advanced Programming Lab (1:2)
- Advanced Optics Lab (1:2)

Semester 3 (Aug-Dec):

- Solid State Qubit devices (3:0)
- Advanced Quantum Communications (3:0)
- Integrated Photonics (3:0)
- Quantum Optics and Advanced Quantum Measurement (3:0)
- Advanced Micro and Nanofabrication Technology and Process (3:0)
- Advanced Materials Synthesis and Characterisation Lab (1:2)
- Advanced Electronics Lab (1:2)

E9 253 (3:1) Neural Networks and Learning Systems (DESE)

ELECTIVE COURSES

Any soft-core course can be chosen as an elective. Students are also free to choose electives from the existing IISc courses, based on their interests and employment opportunities, and in consultation with their supervisors.

Examples:

Aug-Dec

E0 230 (3:0) Computational Methods of Optimization (CSA)
PH 320 (3:0) Condensed Matter Physics II (PH)
NE 213 (3:0) Introduction to Photonics (CeNSE)
NE 312 (3:0) Nonlinear and Ultrafast Photonics (CeNSE)
E3 238 (2:1) Analog VLSI circuits (ECE)
E0 284 (2:1) Digital VLSI circuits (ECE)
IN 229 (3:0) Advanced Instrumentation and Electronics (IAP)
E3 262 (2:1) Electronic Systems Packaging (DESE)

Jan-Apr

E0 249 (3:0) Approximation Algorithms (CSA)
E0 270 (3:0) Machine Learning (CSA)
E0 304 (3:0) Computational Cognitive Neuroscience (CSA)
PH 359 (3:0) Physics at the Nanoscale (PH)
PH 208 (3:0) Condensed Matter Physics I (PH)
PH 366 (3:0) Physics of Advanced Optical Materials (PH)
E9 207 (3:0) Basics of Signal Processing (DESE)
IN 214 (2:1) Semiconductor Devices and Circuits (IAP)
IN 227 (3:0) Control Systems Design (IAP)
E9 253 (3:1) Neural Networks and Learning Systems (DESE)

Companies that hired our M-tech students for Internship (2021 & 2022 batch)

IBM

Texas Instruments

Capgemini

QUANFLUENCE

QKRISHI
Get Ready for Quantum Advantage

Ansys

TATA CONSULTANCY SERVICES

TATA ELXSI

रक्षा अनुसंधान एवं विकास संगठन
रक्षा मंत्रालय, भारत सरकार
DEFENCE RESEARCH & DEVELOPMENT ORGANISATION
Ministry of Defence, Government of India

DRDO Young Scientist Laboratory (DYSL-QT)

accenture

Companies that hired our 1st batch of M-tech students

Industry support for the MTech Program