Q1 2025

QUANTUM VIBES

A newsletter on
Indian Quantum Technology Activities

International Year of Quantum Science and Technology - 2025

Key Breakthroughs & Milestones

Top Master's Programs in Quantum Technology in India

INSIDE THE MINDS

with
Dr. L Venkata Subramaniam, IBM

QUANTUM SENSING OF MAGNETIC FIELDS WITH SPINS IN DIAMOND

Dr. Phani Peddibhotla

Editor's Note

Welcome to the Q1 2025 edition of Quantum Vibes, launching into the International Year of Quantum Science and Technology with groundbreaking developments, insightful research, and an exciting global momentum that is redefining the frontiers of science and technology.

This edition opens with a compelling contribution under our Insights & Tutorials section: "**Quantum Sensing of Magnetic Fields with Spins in Diamond**" by Dr. Phani Peddibhotla (IISER Bhopal) and his students, Mr. Shashank Kumar and Mr. Pralekh Dubey.

Their work beautifully illustrates the versatility of NV-based quantum magnetometry by demonstrating both high-resolution and high-sensitivity magnetic sensing using single and ensemble NV centers, respectively. By leveraging the atomic-scale precision of single NV centers and the enhanced signal strength of dense NV ensembles, the authors effectively highlight the fundamental trade-off between spatial resolution and sensitivity. The team's ongoing efforts to build a diamond spin microscope for nanoscale magnetic imaging mark a promising leap forward in quantum sensing technologies.

In our **Inside the Minds**, we sit down with **Dr. L. Venkata Subramaniam from IBM**, who shares his perspective on the challenges and rewards of working at the cutting edge of quantum computing. From IBM's strategic roadmap to hybrid quantum systems, Dr. Subramaniam offers a thought-provoking look into the engines driving quantum innovation at scale.

We also take a closer look at the **Global Quantum Sensing Market -** a space witnessing rapid growth powered by advancements in defense systems, healthcare diagnostics, and the evolution of autonomous vehicles. This segment maps the key drivers, emerging players, ongoing challenges, and what the road ahead may look like.

As we celebrate 2025 - the **International Year of Quantum Science and Technology -** this issue highlights some transformative announcements shaping the future of the field. Major players are making transformative strides in quantum technology. Google's Willow has improved quantum error correction with its 105-qubit superconducting processor. Xanadu's Aurora leads in photonics as the first fault-tolerant optical quantum computer. Microsoft's Majorana 1 explores topological qubits for more stable, scalable systems, while Amazon's Ocelot introduces cost-efficient "cat qubits" for better error management. Meanwhile, Andhra Pradesh is planning to establish a Quantum Valley in Amaravati.

The quantum revolution is no longer on the horizon - it's here, growing, and accelerating. We're thrilled to have you with us on this journey. As always, stay curious, stay inspired.

Happy Reading !

DR. S.D. SUDARSAN
Editor

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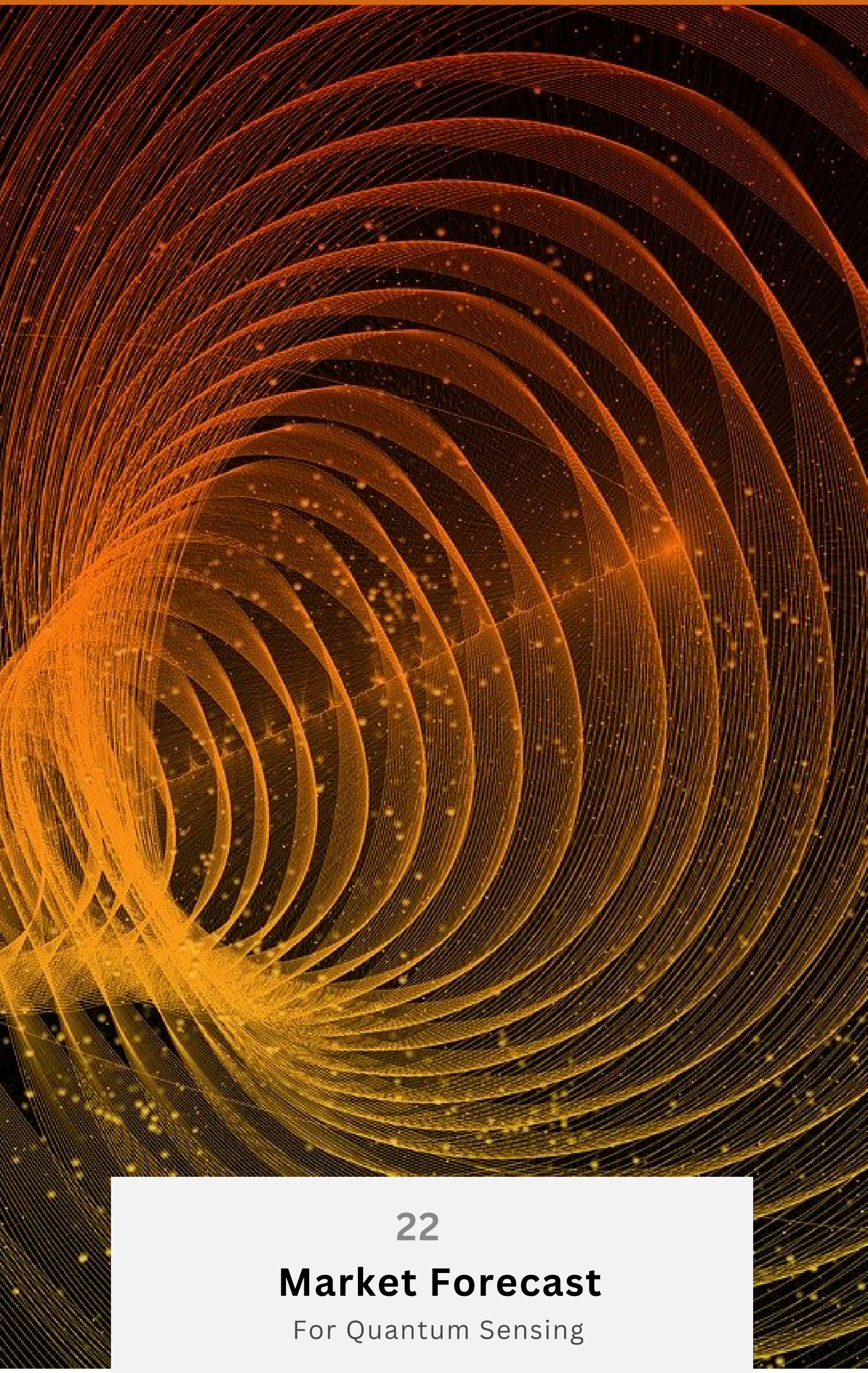
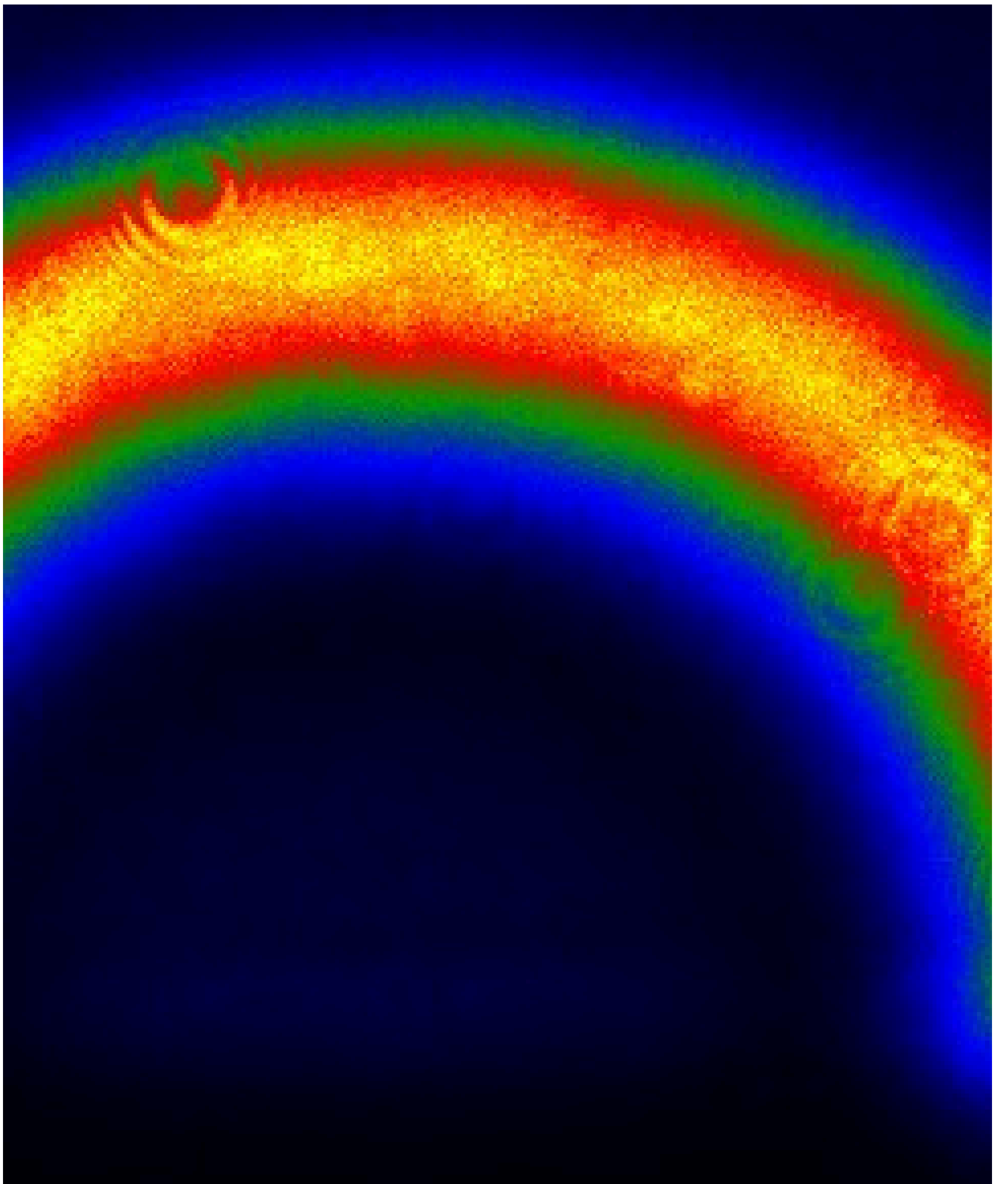
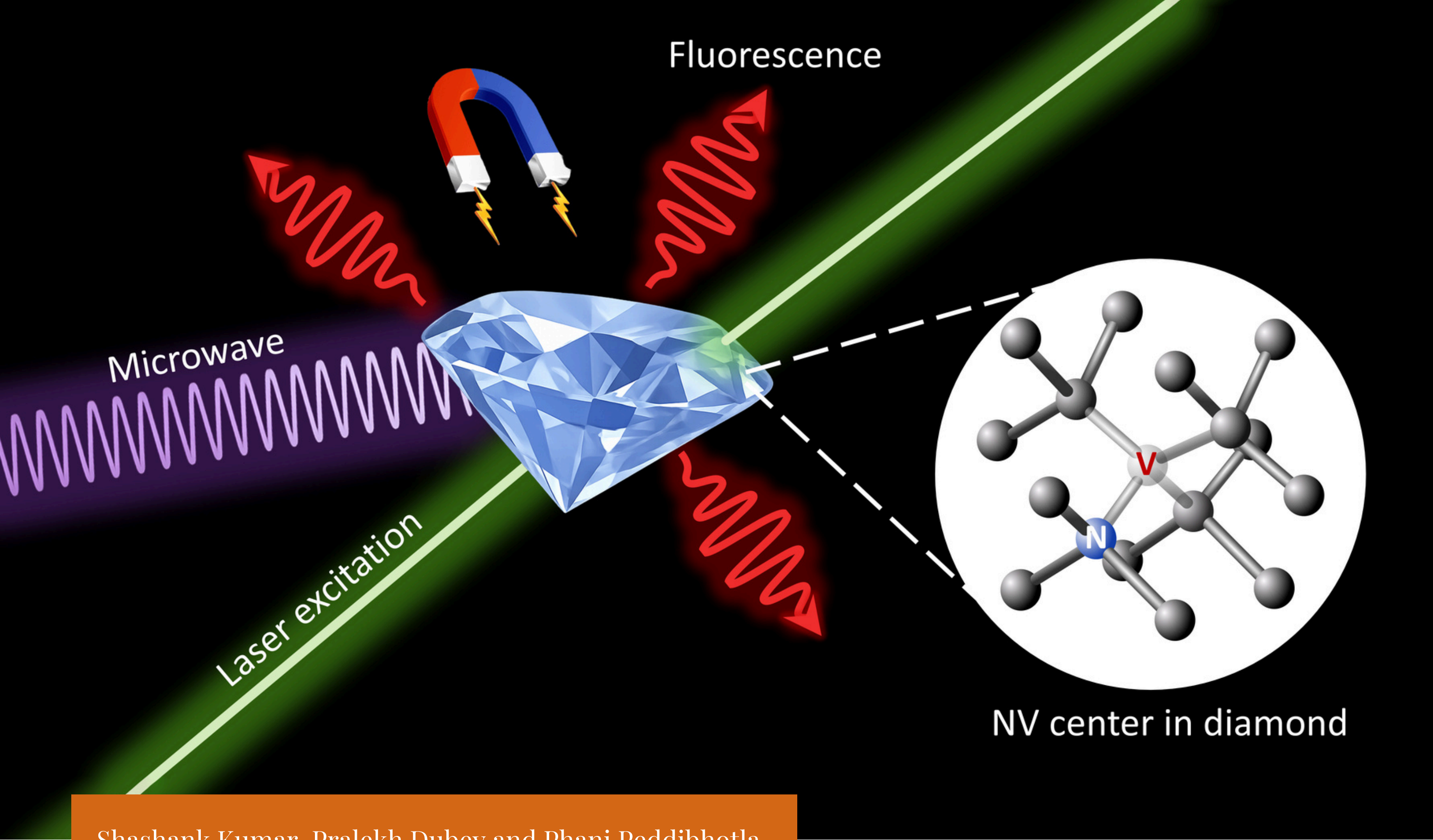


INSIGHTS & TUTORIALS



QUANTUM SENSING OF MAGNETIC FIELDS WITH SPINS IN DIAMOND

Dr. Phani Peddibhotla
Mr. Shashank Kumar
Mr. Pralekh Dubey



Shashank Kumar, Pralekh Dubey and Phani Peddibhotla

Quantum Sensing of Magnetic Fields with Spins in Diamond

Introduction

Quantum sensors utilize quantum phenomena such as superposition and entanglement to achieve exceptional sensitivity and precision. They enable the detection of weak magnetic, electric, and gravitational fields at nanoscopic and macroscopic scales. Nitrogen-vacancy (NV) centers in diamond serve as robust quantum sensors for high-resolution magnetic field measurements at ambient conditions. These sensors have diverse applications in biomedical imaging, precision metrology, and fundamental physics investigations [1, 2].

Diamond magnetometer with picotesla-level sensitivity is based on nitrogen-vacancy (NV) defect ensembles and can be used in various magnetometry applications such as measuring the magnetic fields of a living rat heart [3] and electric vehicle battery monitoring [4], as well as in geological exploration and chemical analysis [5]. Unlike atomic magnetometers which have been around for more than five decades, it is only recently that the solid-state quantum magnetometers based on atom-like NV defects in diamond were shown to offer sub-pT sensitivity [6]. Moreover, these diamond quantum sensors need not be shielded from the Earth's magnetic field while measuring small changes in the magnetic field.

NV magnetometers work by measuring the Zeeman splitting of the $|m_s = \pm 1\rangle$ spin states of the NV electronic ground-state triplet. The interaction between the magnetic dipole moment of the NV spin and the applied microwave (MW) field is exploited to measure the magnetic field of interest. This is typically done by using a green laser which tends to polarize the diamond spin in the $|m_s = 0\rangle$ spin state, while the microwave field induces the $|m_s = 0\rangle \Leftrightarrow |m_s = -1\rangle$ & $|m_s = 0\rangle \Leftrightarrow |m_s = +1\rangle$ transitions which can be detected optically by measuring the fluorescence of the NV center. This technique is known as optically detected magnetic resonance (ODMR). The Zeeman splitting is dependent on the direction of the external magnetic field with respect to the intrinsic quantization axis of the NV defect, which lies along one of the four possible ⟨111⟩ crystallographic directions in the tetrahedral diamond lattice. This orientation-sensitive feature of the NV magnetic sensor can be exploited to extract vectorial information about the magnetic field using a diamond doped with ensemble NV centers.

Magnetic sensing measurements

At IISER Bhopal, we are involved in developing a single NV-based quantum sensor for nanoscale magnetic measurements as well as in developing an ensemble NV-based quantum vector magnetometer for achieving sub-nT sensitivity.

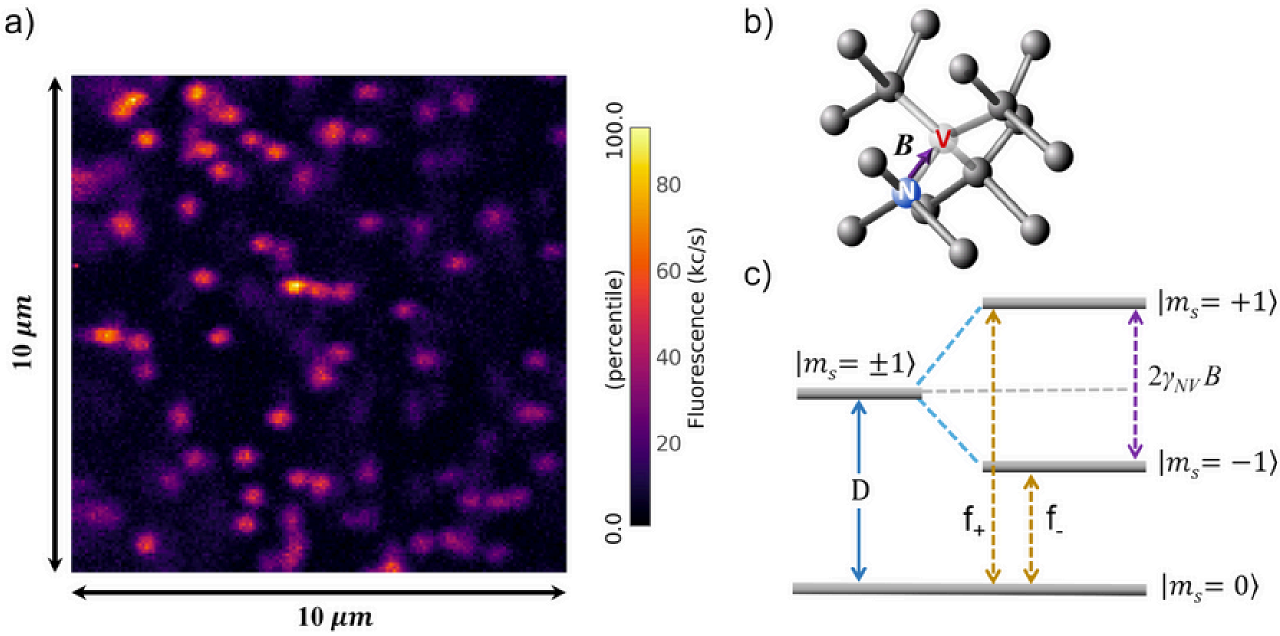


*Figure 1: (a) Confocal scan of the electronic grade single crystal diamond showing single NV centers. (b) A schematic representation of an NV defect in diamond. The gray spheres represent the carbon atoms, while the blue and white sphere together represent the NV center. An external magnetic field **B** acting along the NV axis is also shown. (c) The energy level diagram of the ground-state spin of the NV center. Here, D is the zero-field splitting (ZFS) between $|m_s = 0\rangle$ and $|m_s = \pm 1\rangle$ spin states. With the application of a magnetic field, the degeneracy between $|m_s = \pm 1\rangle$ is lifted due to the Zeeman effect, resulting in spin transition frequencies f_- and f_+ for $|m_s = 0\rangle \Leftrightarrow |m_s = -1\rangle$ and $|m_s = 0\rangle \Leftrightarrow |m_s = +1\rangle$, respectively.*

Measurements on single NV centers

We developed a home-built confocal scanning microscope with optical diffraction-limited spatial resolution, the first of its kind in India deployed for quantum sensing studies on NV centers in diamond. Figure 1 shows a confocal scan of single NV centers in the electronic-grade single crystal diamond, produced using the microwave plasma-assisted chemical vapor deposition (CVD), acquired from Bhathwari Technologies Pvt. Ltd. (BTPL), India. We probe the electronic spin states of single NV centers using ODMR spectroscopy and further measure their coherence properties. Our findings indicate that single NV centers exhibit long dephasing times (T_2^*) making them suitable for nanoscale magnetometry applications.

The first characterization experiment involves driving a single NV spin resonantly using a microwave field to observe coherent Rabi oscillations between the two spin sub-levels. As a result, the population of the $|m_s = 0\rangle$ spin state varies sinusoidally at a rate proportional to the strength of the microwave field. The Rabi oscillation measurement is performed by preparing the NV center in the $|m_s = 0\rangle$ spin state using a laser pulse. A microwave pulse of variable duration (width), tuned to the resonant transition frequency f_- is then applied, followed by another laser pulse for projective spin-state readout. By repeating this pulse sequence multiple times, we obtain time-averaged coherent Rabi oscillations (see Figure 2). The y-axis corresponds to the normalized fluorescence count signal showing a contrast of 35% in the measurement signal between the $|m_s = 0\rangle$ and $|m_s = -1\rangle$ states. The main purpose of this Rabi measurement is to calibrate the microwave pulse duration required to prepare the NV spin in $|m_s = -1\rangle$ spin state (π-pulse) or a balanced (or 50-50) superposition state ($\frac{\pi}{2}$-pulse).

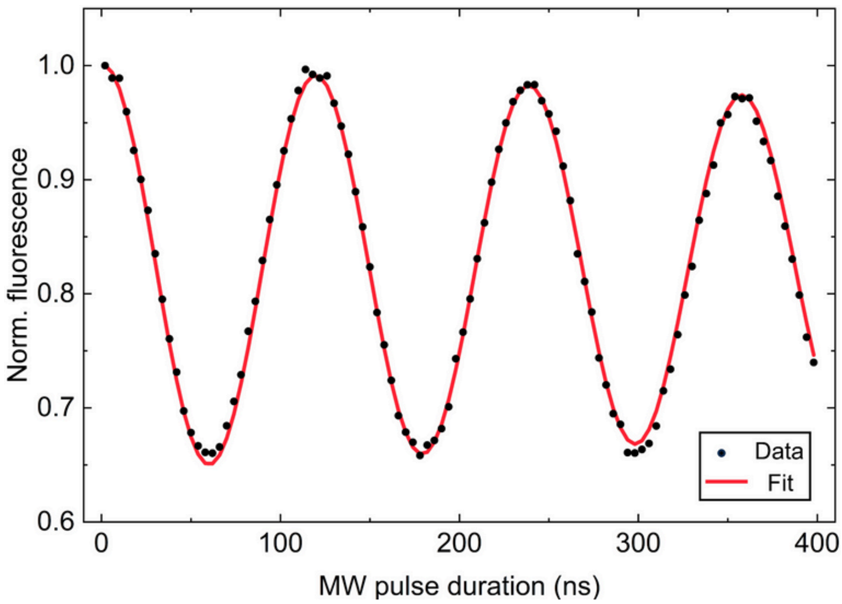


Figure 2: Coherent oscillations of the NV spin state population as a function of microwave pulse width. The time period of the Rabi oscillations is ~120 ns.

With a calibrated $\frac{\pi}{2}$-pulse, we can now measure the spin dephasing time of the NV center using a Ramsey interferometry experiment. This measurement proceeds by preparing the NV spin in the 50-50 superposition state, waiting for some time τ for the relative phase to evolve before inferring the phase by performing a measurement. The measurement procedure involves the application of a second $\frac{\pi}{2}$-pulse to convert the relative phase into a theoretical DC magnetic field sensitivity being 0.72 μT/$\sqrt{Hz}$. Thus, the Ramsey measurement characterizes the magnetic noise affecting the spin coherence properties, and after a sufficiently long time τ (> T_2^*), the NV spin will be in an incoherent mixture of $|m_s = 0\rangle$ & $|m_s = -1\rangle$ spin states.

We note that the true potential of a single NV center as a nanoscale sensor can be

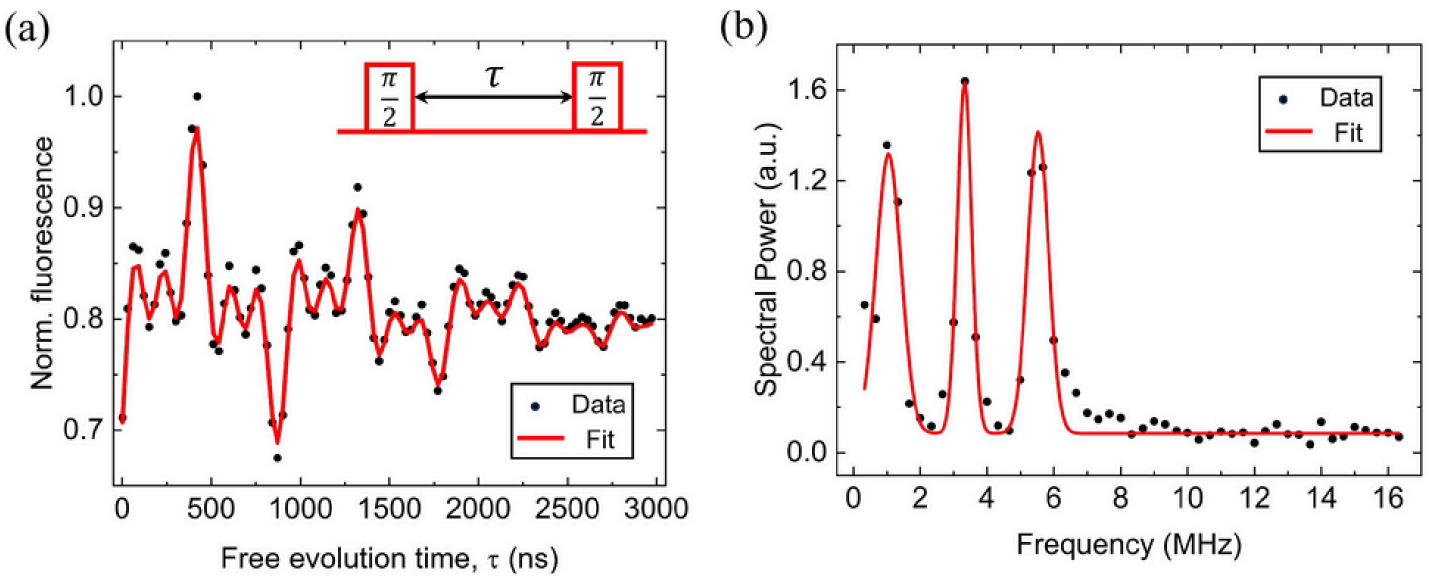


Figure 3: (a) Ramsey interferometry measurement performed to determine the inhomogeneous spin dephasing time T_2^* of a single NV electron spin. (b) Fourier transform spectrum of (a) shows three frequency peaks separated by ~2.33 MHz corresponding to the hyperfine interaction with the ^{14}N nuclear spin.

population difference, and a subsequent laser readout pulse to infer the population difference. We note that the microwave pulse is applied at a slightly detuned frequency $f = f_{-} - \Delta$ so that the relative phase evolves at the detuning frequency Δ in a frame rotating at $\omega = 2\pi f$. The ensemble averaged result of such a measurement is shown in Figure 3. We observe a beating signal between three frequencies resulting from the three ^{14}N hyperfine states with a decay constant of T_2^* ~ 1.9 μs. This implies a slow dephasing of the NV spin due to surrounding bath spins, with the estimated unleashed by developing a NV-based scanning probe microscope. The basic idea is to embed an NV center onto a micronscale diamond probe tip, which is then scanned over the sample of interest to perform local magnetic measurements with a spatial resolution of a few tens of nanometers. Several exciting experiments using a diamond NV-based scanning sensor have already been reported [7, 8]. Keeping the objectives of National Quantum Mission in mind, we are developing a scanning diamond magnetometer that can be used for various nanoscale imaging applications.

Measurements on an ensemble of NV centers

In contrast to single NV center measurements, NV center ensemble based magnetic sensing benefits from an increased signal-to-noise ratio (SNR) due to collective averaging, although at the cost of reduction in spatial resolution. We perform ODMR spectroscopy on a diamond sample with high NV concentration to evaluate its sensitivity to external magnetic fields. We realize enhanced signal strength and faster data acquisition times with the NV-ensemble magnetometer, making it well-suited for real-time magnetic field measurements. The setup used to perform measurements on NV center ensemble is shown in Figure 4.

We use a diamond plate acquired from BTPL to investigate the sensitivity and dynamic range of our NV ensemble magnetometer. The size of the diamond is $3.3 \times 3.3 \times 1\ \mathrm{mm}^3$ and it has a typical NV concentration of 400 ppb - 700 ppb. We conduct magnetic field measurements using a lock-in detection scheme to improve the SNR. A square wave frequency-modulated MW field applied to the NV centers leads to a modulated red fluorescence, which gets demodulated by the lock-in amplifier (LIA).

To enhance the magnetometer sensitivity, we implement the three methods detailed below:

(a) High-efficiency fluorescence collection: The sensitivity of a NV center ensemble magnetometer is primarily limited by the low efficiency of fluorescence collection. Typically, only a small fraction of the fluorescence emitted by the NV centers is collected due to the high refractive index of diamond and total internal reflection at the diamond-air interface. To address this limitation, we employ a compound parabolic concentrator (CPC) lens, which redirects the emitted fluorescence photons towards the detector, thereby allowing us to capture the photons that would have otherwise escaped due to total internal reflection or scattering. Thus, by integrating a CPC lens into our magnetometer setup, we achieve an eightfold improvement in fluorescence collection efficiency.

(b) Balanced detection scheme: We use two identical photodiodes (labelled PD1 and PD2 in Figure 4) to reduce the noise arising from the laser power fluctuations.The photodiode PD1 is used to collect the NV fluorescence and the photodiode PD2 is used to collect a fraction of the green laser excitation. The output from these photodiodes are fed to the differential inputs of the LIA, enabling effective

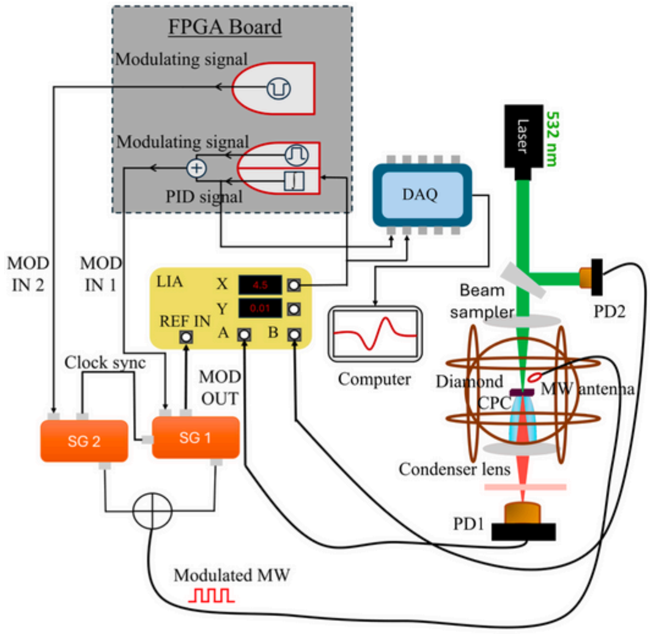


Figure 4: A detailed schematic of the high-sensitivity diamond magnetometry measurement setup.

cancellation of common-mode noise from optical excitation and thereby improving measurement sensitivity.

(c) Orientation of the bias magnetic field: We apply a bias magnetic field along the [100] crystallographic direction using the Helmholtz coil setup. Under this configuration, the resonance frequencies corresponding to all four NV orientations exactly overlap, resulting in a fourfold increase in the overall ODMR measurement contrast.

(d) Dual-resonance magnetometry concept: Here, we use two MW signal generators to strongly drive both ODMR resonances simultaneously. When the MW frequencies are resonant with the $|m_s = 0\rangle \leftrightarrow |m_s = +1\rangle$ and $|m_s = 0\rangle \leftrightarrow |m_s = -1\rangle$ transitions, the spin populations are equally distributed among all the three spin sublevels. As a result, this scheme theoretically predicts an improvement of the ODMR measurement contrast by a factor of 4/3, when compared to the single-resonance approach. Our measurement data (see Figure 5(a)) shows that the lock-in slope is ~1.3 times larger, thereby leading to sensitivity enhancement.

We obtain noise spectral density plots (see Figure 5(b)) by averaging fast Fourier transforms (FFT) of 100 one-second time traces of the lock-in output for three cases: (i) single-resonance magnetometry (MW modulation applied on-resonance), (ii) dual-resonance magnetometry (MW modulation applied on-resonance), and (iii) without laser excitation (to determine electronic noise floor). This analysis suggests that we achieve an average magnetic field sensitivity of ~1.05 nT/$\sqrt{Hz}$ and ~0.680 nT/$\sqrt{Hz}$ in the range of 10 to 100 Hz (without considering the 50 Hz peak) for the single-resonance and dual-resonance modulation protocols, respectively, with the chosen diamond sample using the current configuration of our magnetometer setup. To enhance dynamic range, we also implement a proportional-integral (PI) feedback control loop, in the single-resonance magnetometry mode, on a high speed National Instruments FPGA hardware so that the resonance frequency shifts induced by time-varying magnetic fields can be continuously tracked [9, 10]. This feedback control significantly extended our magneto-meter's dynamic range to 500 μT from its intrinsic value of 35 μT, as shown in Figure 5(c).

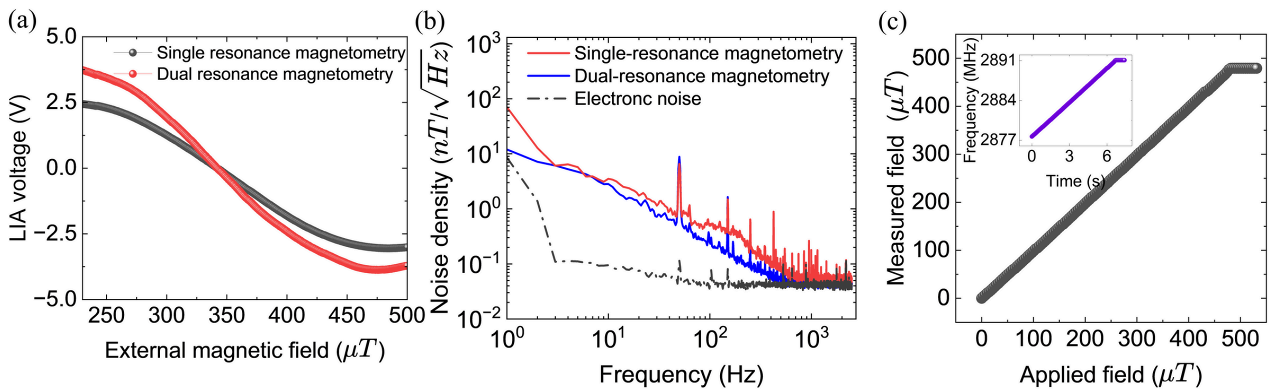


Figure 5: (a) LIA output as a function of external magnetic field for single resonance magnetometry (black) and for dual resonance magnetometry (red) (b) Magnetic noise spectral density for the following cases: single-resonance magnetometry (red), dual-resonance magnetometry (blue) and electronic noise floor (black). (c) Using the Helmholtz setup, the applied magnetic field is linearly varied from 0 μT to 500 μT in steps of 3.59 μT every 50 ms. The magnetometer, working in single-resonance magnetometry mode, reliably and rapidly tracks the magnetic field variations owing to its quick response time. The intrinsic dynamic range of ~35 μT is extended to ~500 μT with the implementation of the PI control feedback loop. The inset shows the change in the resonance frequency induced by time-varying magnetic field.

Conclusion

We demonstrated magnetic sensing capabilities using both single NV centers and dense NV ensembles. Our results emphasize the inherent trade-off between spatial resolution and sensitivity in NV-based quantum magnetometry. A single NV center, being an atomic-sized quantum sensor, is capable of high spatial resolution magnetic field measurements, whereas a macroscopic ensemble of millions of NV electron spins in a larger volume enhance the magnetic detection sensitivity, thereby enabling broad applications such as underwater navigation and biomedical imaging. Currently, we are working towards the development of a diamond spin microscope for nanoscale magnetic imaging as well as on improving the sensitivity of the NV ensemble magnetometer.

Acknowledgement

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Dr. Phani Kumar Peddibhotla is an Assistant Professor at IISER Bhopal, specializing in quantum sensing, nano-magnetometry, and nitrogen-vacancy (NV) centers in diamond. He holds a Ph.D. from the University of Basel and has conducted postdoctoral research at the University of Ulm, NTU Singapore, and DTU Copenhagen. With an academic background from ETH Zurich (M.Sc.) and IIT Madras (B.Tech.), his research focuses on advanced quantum sensing methodologies and imaging techniques.

MR. SHASHANK KUMAR

Shashank Kumar is a Ph.D. student in the Department of Physics at the Indian Institute of Science Education and Research (IISER) Bhopal. His research focuses on nitrogen-vacancy (NV) spins in diamond, quantum sensing, and confocal microscopy. Shashank has co-authored publications, including “High-resolution spectroscopy of a single nitrogen-vacancy defect at zero magnetic field,” contributing to advancements in high-resolution microwave spectroscopy of NV centers in diamond.

MR. PRALEKH DUBEY

Pralekh Dubey is a doctoral student at the Indian Institute of Science Education and Research (IISER) Bhopal, specializing in Quantum Sensing, Quantum Metrology, Quantum Information, and Condensed Matter Physics. His research includes high-resolution spectroscopy of nitrogen-vacancy defects and the development of quantum diamond microscopy for electric current sensing. He is currently pursuing his Ph.D. under the supervision of Dr. Phani Kumar.

2025 International

YEAR OF QUANTUM SCIENCE AND TECHNOLOGY (IYQ)

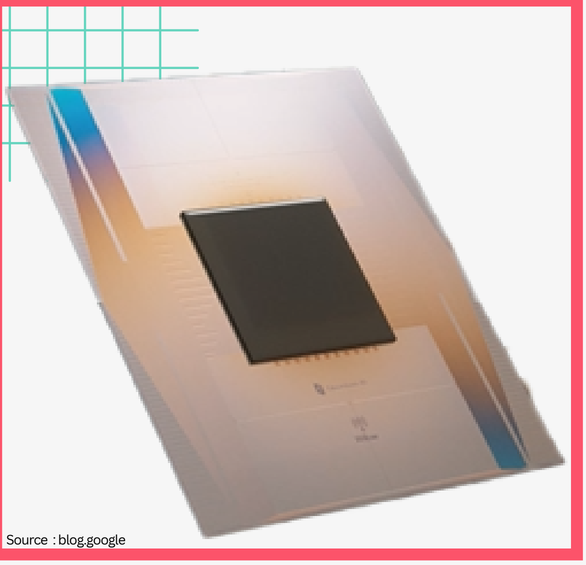
100 YEARS OF QUANTUM IS JUST THE BEGINNING

In recognition of quantum science's significance and its impact, scientific societies worldwide supported the U.N.'s declaration of 2025 as the International Year of Quantum Science and Technology (IYQ). Announced on June 7, 2024, the year-long initiative aims to raise public awareness of quantum science and its applications through global activities. People everywhere can participate by educating others, organizing or attending events, or simply learning more about quantum science.

https://quantum2025.org/

2025

INTERNATIONAL YEAR OF QUANTUM SCIENCE AND TECHNOLOGY



Source : blog.google

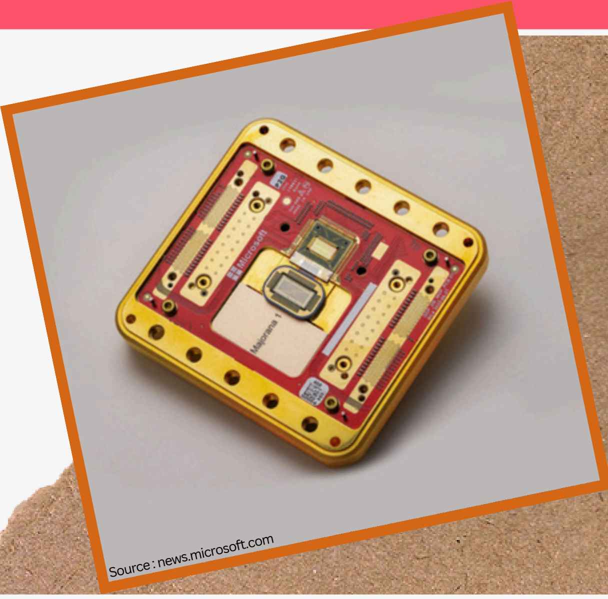
Google Willow

Google's Willow, featuring a 105-qubit superconducting processor, has made significant strides in quantum error correction. This development is a crucial step toward achieving scalable, fault-tolerant quantum computing. However, critics have pointed out the lack of full benchmarking data, which raises questions regarding the reliability of Google's claims.

Xanadu Aurora

Xanadu's Aurora marks a significant advancement in photonic quantum computing with its innovative architecture focused on modularity and networked processors, representing a notable step towards scalable quantum systems.

Source : Xanadu.ai



Source : news.microsoft.com

Microsoft Majorana 1

Microsoft's Majorana 1 utilizes topological qubits, which promise greater stability and scalability—tackling one of quantum computing's biggest hurdles: high error rates. Despite this potential, the approach has faced skepticism, notably from Amazon's quantum team, who question whether Microsoft's topological gap protocol can reliably confirm the presence of Majorana quasiparticles.

Credits: Ms. Kiran (Natashia) Kaur Raina

Amazon Ocelot

Amazon's Ocelot quantum processor incorporates 'cat qubits,' an encoding strategy being explored for its potential to lower the resource overhead associated with quantum error correction, which could contribute to the advancement of practical quantum computing applications.

IBM Qiskit Function: HiVQE & Expanding Functions Catalog

IBM has integrated HiVQE (Hybrid Variational Quantum Eigensolver) into its Qiskit platform, an enhancement designed to improve the efficiency of variational quantum algorithms for simulations in chemistry and materials science, potentially leading to more rapid progress in understanding complex molecular structures. .

India's Quantum Leap

India is drawing attention with the launch of Quantum Valley in Andhra Pradesh. The state government has signed memoranda of understanding (MoUs) with global tech leaders IBM and TCS to set up the IBM Quantum System-2, powered by the 156-qubit Heron processor—set to become the most powerful quantum computer in the country. At the same time, TCS will facilitate quantum computing access across 43 research centers spanning 17 states.

QNodeOS: The First Quantum Network OS

In a major step forward for quantum networking, researchers from institutions like QIA, Delft, QuTech, Innsbruck, Inria, and CNRS have unveiled QNodeOS, the first Quantum Network Operating System. This innovative OS makes quantum networks more programmable and accessible, unlocking new potential for global quantum communication and collaboration.

Credits: Ms. Kiran (Natasha) Kaur Raina

INSIDE

THE MINDS

INDIA HAS A RICH HISTORY OF **SCIENTIFIC INNOVATION** AND WITH THE RIGHT INVESTMENTS, POLICIES, AND TALENT DEVELOPMENT, WE CAN BECOME **A GLOBAL HUB** FOR QUANTUM TECHNOLOGY.

Dr. L. Venkata Subramaniam was born in New Delhi, India. He received the B.E. degree in Electronics and Communication Engineering from Mysore University, the M.S. degree in Electrical Engineering from Washington University, St. Louis, USA, and the Ph. D. degree in Electronics from the Indian Institute of Technology, New Delhi, India. He joined IBM Research India in 1998 where currently leads a team of world class researchers developing the next generation quantum computing algorithms and applications. He has been recognised as an IBM Master Inventor, been awarded 38 patents, and published more than 150 research papers. Recently, his book Quantum Nation made it to the best-seller list on Amazon India.

Exclusive Interview

DR. L VENKATA SUBRAMANIAM

IBM Quantum India Leader

Inside the minds

Exclusive Interview with Dr. L Venkata Subramaniam

Can you share a personal experience or a memorable story that reflects the challenges and rewards of working at the forefront of Quantum Computing?

Quantum computing is at an inflection point—much like classical computing was in its early days. One memorable experience that stands out is the first time I successfully ran a quantum algorithm on an actual superconducting qubit system rather than a simulator. The realization that we were manipulating quantum states—phenomena that defy classical intuition—was exhilarating.

It is thrilling to witness the march towards quantum advantage—the point at which quantum computers outperform classical computers in solving certain complex problems that are infeasible for classical systems. The true reward lies in being part of a global movement that is redefining computation. Seeing India make significant strides in quantum research and talent development makes this journey even more inspiring.

Your book, "Quantum Nation," provides a vision for India's quantum future. What was the primary motivation behind writing it, and what key message do you hope readers take away?

The primary motivation behind writing Quantum Nation was to demystify quantum computing for a broader audience while laying out a roadmap for India's leadership in this domain.

India has a rich history of scientific innovation, and with the right investments, policies, and talent development, we can become a global hub for quantum technology. The key message I hope readers take away is that quantum computing is not a distant dream—it is a present opportunity. The time to act is now, whether as researchers, policymakers, or industry leaders.

Inside the minds

Exclusive Interview with Dr. L Venkata Subramaniam

What is IBM's strategy for advancing quantum computing in India? What are some of the key initiatives that IBM is undertaking in this area?

IBM has been a pioneer in quantum computing, and we view India as a strategic partner in this transformative journey. India has already established itself as a global talent hub and has consistently demonstrated leadership in quantum research and learning.

At IBM, we recognized this potential early when we observed a surge in the usage of our cloud-based Quantum Systems under the open-access plan—real quantum computers, not just simulators. Across multiple metrics—quantum computer usage, engagement with learning materials, and participation in summer schools—India consistently ranks among the top one or two globally.

Our strategy is built on three key pillars

Quantum Workforce Development
In India, we collaborate with universities, research institutions, and government bodies to integrate quantum computing into academic curricula and upskill professionals. IBM Qiskit, our open-source quantum SDK, has seen exceptionally high adoption from Indian users, reinforcing India's strong learning culture in quantum technologies.

Industry Adoption & Co-Innovation: Through the IBM Quantum Network, we partner with industry leaders and startups to explore and develop quantum solutions for real-world applications.

Infrastructure & Research : We are committed to bringing cutting-edge quantum hardware and software to India through cloud-based access to IBM's most advanced quantum systems. For most students and researchers, IBM's quantum systems serve as the starting point for their quantum computing journey. IBM has been actively collaborating with leading academic institutions to foster indigenous quantum research and accelerate India's quantum innovation ecosystem, ensuring that the country remains at the forefront of this technological revolution.

By strengthening these pillars, IBM is committed to empowering India's quantum future and driving the next era of technological breakthroughs.

Inside the minds

Exclusive Interview with Dr. L Venkata Subramaniam

Do you see superconducting qubits integrating with other modalities, such as trapped ions or photonic qubits, to form hybrid quantum systems?

Superconducting qubits currently provide the most scalable and commercially viable path to quantum computing, and at IBM, we are fully committed to advancing this technology. While integration with other modalities remains an area of exploration, the real potential lies in Quantum-Centric Supercomputing—an approach that seamlessly integrates quantum computing with classical high-performance computing (HPC) to solve highly complex real-world problems.

I believe this approach will become increasingly prevalent, with CPUs working alongside GPUs and QPUs to tackle humanity's toughest computational challenges. This integration will drive breakthroughs in optimization, materials science, life sciences, and AI, ultimately unlocking new frontiers in computing and accelerating scientific discovery.

Given the high costs, how soon do you think businesses will start seeing tangible ROI from Superconducting Quantum Computing?

Researchers across industries today are focused on identifying targeted applications in drug discovery, materials design, optimisation, AI, and other high-impact areas. Businesses that invest now will be well-positioned to capitalize on early quantum breakthroughs, gaining a competitive edge in their industries.

While current costs are high, the key is to enter early, drive innovation, and accelerate breakthroughs that will ultimately reduce costs and unlock real-world benefits for humanity. History has shown that early adopters shape the trajectory of emerging technologies, taking the lead and securing market dominance as the ecosystem matures.

With error correction being a significant challenge, how close are we to realizing fault-tolerant quantum computing? Which recent advancements in this area excite you the most?

At IBM, we have always maintained a clear and transparent roadmap for advancing quantum computing. As part of this vision, we are committed to delivering an advanced, error-corrected quantum computer by 2029.

Along the way, we continue to enhance the performance of our quantum systems, making them accessible via the cloud and dedicated quantum hardware for our global network of clients. We firmly believe that real quantum advantage—where quantum systems outperform classical computers in solving practical problems—will be realized even before 2029.

My fervent hope is that India will be at the forefront of this breakthrough, leading the world in achieving quantum advantage by 2027.

QUANTUM CURRENTS

17 December 2024

Workshop on Quantum Accelerated Computing

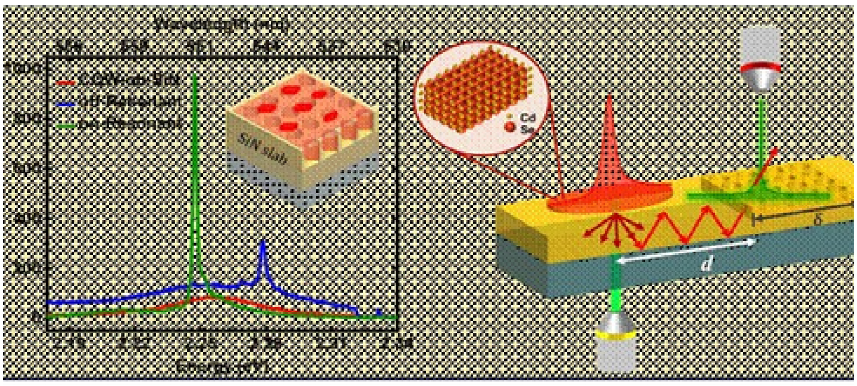
The AI & QT Group from C-DAC Pune organized a workshop on Quantum Accelerated Computing at Rajagiri School of Engineering & Technology (RSET) in Kochi on December 17th, 2024. The event aimed to bridge the gap between emerging quantum technologies and their practical applications. The workshop attracted a diverse audience, including faculty, researchers, and students, who engaged in lectures, demonstrations, and hands-on sessions to understand the transformative potential of Quantum Computing. The workshop played a crucial role in advancing India's leadership in quantum computing.

Source - CDAC

10 January 2025

Quantum Leap: IISc Develops Ultra-Bright, Long-Range Nanoscale Light Platform

Researchers at the Indian Institute of Science (IISc), Bangalore, have developed a groundbreaking platform for manipulating light at the nanoscale, which is crucial for quantum technologies like quantum metrology and cryptography. By integrating two-dimensional semiconductor colloidal quantum wells (CQWs) with dielectric metasurface resonators (MSRs),



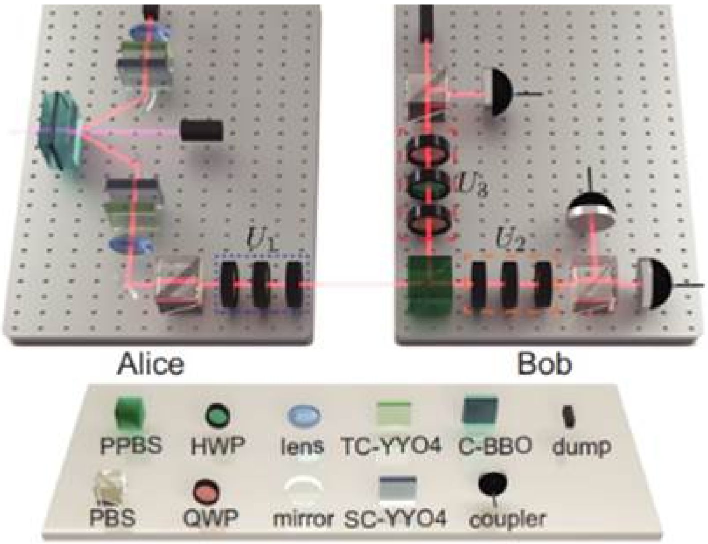
Emission spectrum collected from confocal PL microscope funded by DST FIS

the team achieved remarkable advancements, including a 12-fold increase in brightness, a 97% reduction in spectral line width, and long-range photon transport across a 1 mm chip distance. Led by Prof. Jaydeep K. Basu and Prof. Shankar Kumar Selvaraja, with theoretical support from Prof. Girish S. Agarwal, this work promises to advance quantum information processing. The results, published in Advanced Optical Materials, highlight the potential of nanoscale materials for improving quantum devices, particularly in the fields of quantum cryptography and information processing.

Source - PIB

17 January 2025

Quantum Advantage Unveiled: From Theory to Real-World Demonstration



A groundbreaking study led by Professor Manik Banik from the S. N. Bose National Center for Basic Sciences has demonstrated that even the simplest quantum systems can outperform classical computing methods. The research shows that a single qubit can complete a communication task without relying on shared resources, a feat impossible for classical bits. Published in Quantum and Physical Review Letters, the study provides a real-world demonstration of quantum advantage. The team developed a photonic quantum processor and a novel instrument for precise light polarization measurements to validate their findings. This work, involving international collaboration, marks a significant step towards revolutionizing information processing and communication with quantum technologies.

Source - PIB

19 January 2025

Kick-off Meeting of Quantum Sensing Hub at IIT Bombay Strategizes Way Forward

The Quantum Sensing and Metrology Hub (Qmet Tech Foundation), established by IIT Bombay under the National Quantum Mission, held its inaugural meeting to define its strategic direction. The foundation aims to lead India in quantum sensing and metrology by promoting interdisciplinary collaboration among research institutions and advancing cutting-edge technologies. The meeting was attended by key stakeholders, including Prof. Abhay Karandikar from the Department of Science and Technology, who emphasized the need for India to escalate its quantum research. With 16 institutes and 40 researchers, Qmet is set to bridge fundamental research with real-world applications in areas such as healthcare and national security, positioning India as a global leader in quantum technologies.

Source - PIB

19 January 2025

Prof. Urbasi Sinha Receives Gates-Cambridge Impact Prize for 2025

Professor Urbasi Sinha from the Raman Research Institute (RRI) has been awarded the prestigious Gates-Cambridge Impact Prize for 2025, recognizing her significant contributions to quantum research. She leads the Quantum Information and Computing (QuIC) laboratory at RRI, which was among the first in India to establish the use of heralded and entangled photon sources for quantum communication, computing, and optics. Prof. Sinha also holds leadership roles in India's National Quantum Mission. Her work has earned her numerous accolades, including the Rashtriya Vigyan Yuva Puraskar and the Canada Excellence Research Chair. She was also instrumental in establishing the Open Quantum Institute at CERN.

Source - PIB

30 January 2025

Symposium on Quantum Computing and Artificial Intelligence

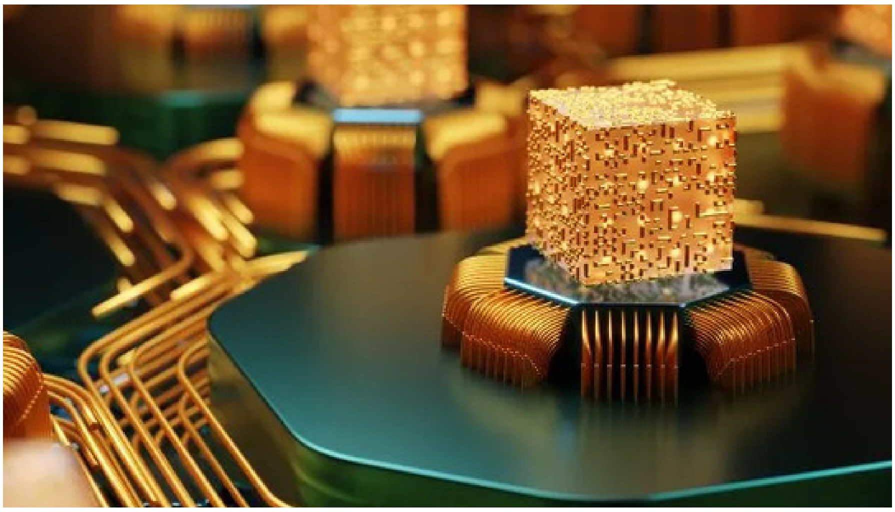
The Symposium on Quantum Computing and Artificial Intelligence, held on January 29–30, 2025, at DIAT Pune, was a landmark event co-organized by C-DAC Pune and DIAT under the MeitY-funded Quantum Accelerator project. It brought together top experts, researchers, and industry professionals to explore the intersection of quantum computing and AI. Inaugural talks by leaders from DRDO, DIAT, and C-DAC highlighted India's strategic

initiatives and collaborative efforts. Across two days, sessions covered quantum hardware, AI ethics, generative AI, silicon photonics, and innovations in qubit automation and algorithm design. A young scientists' session and a panel on hybrid quantum-classical systems underlined the event's focus on innovation and future technologies. The symposium fostered interdisciplinary collaboration and showcased India's growing capabilities in emerging tech, marking a significant step toward real-world applications in defense, finance, and high-performance computing.

Source - CDAC

25 March 2025

Quantum Startup
QNu Labs: India's Quantum Leap in Cybersecurity



Founded in 2016 at the IIT Madras Research Park, QNu Labs is transforming cybersecurity with quantum-safe technologies. It launched India's first QKD system in 2018, putting the country on the global quantum map. Since then, QNu has marked key milestones—winning the iDEX Challenge in 2022, completing Army trials for a 150-km QKD system, and securing a major defence order to build quantum-safe wireline networks.

In 2023, it launched a Quantum Secure VPN (QVPN) for wireless protection, now deployed at critical defence institutions. By 2024, QNu delivered 25 QKD systems to the Indian Navy. Its product suite—Tropos (QRNG), Armos (QKD), and QShield (quantum-secure SaaS)—is widely used across defence and critical sectors. Selected under the National Quantum Mission, QNu aims to build the world's first end-to-end quantum-safe heterogeneous network—Made in India, Made for the World.

Source - PIB

24-26 March 2025

Tech Experts Converge at CDAC's Tech Horizons Conclave to Explore Quantum Computing Frontiers

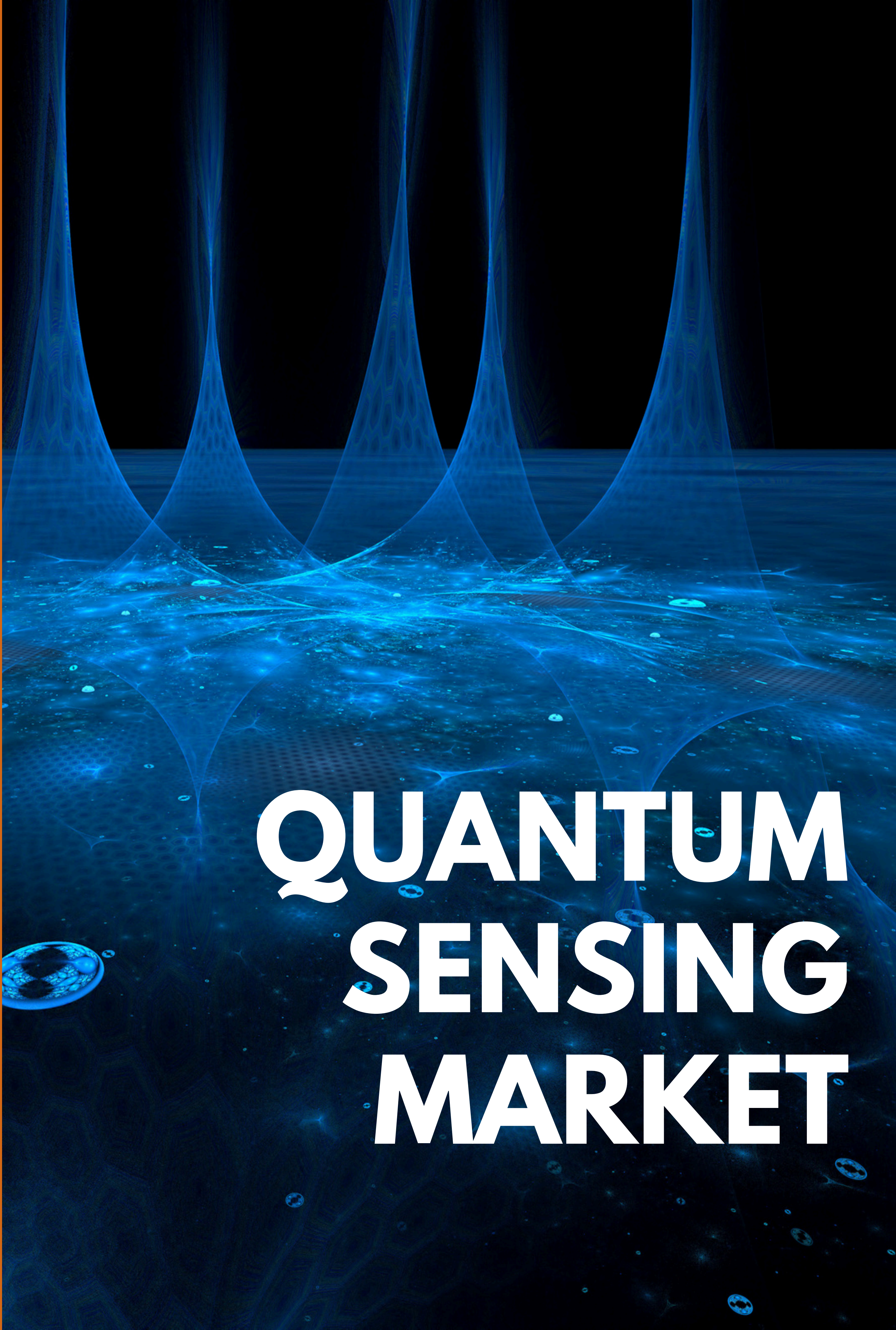
The Centre for Development of Advanced Computing (C-DAC) Bangalore curated its dynamic "Tech Horizons" conclave from March 24–26, 2025, uniting visionary tech leaders and pioneering researchers to delve into next-gen technologies. Staged at Brigade Signature Club Resort, Devanahalli, the symposium also explored transformative fields including IoT, AI, HPC, Hardware Design, and Cybersecurity.

Experts offered deep insights into post-quantum cryptographic protocols designed to withstand quantum-era threats. Dr. Saptarishi Chaudhuri (RRI) presented on ion trap quantum architectures, highlighting advanced techniques for qubit stabilization using charged particles.

Dr. Naresh Raghava of C-DAC Bengaluru delivered an in-depth walkthrough of Quantum Key Distribution (QKD), emphasizing how quantum mechanics ensures secure communication with built-in intrusion detection.

A standout moment was a fireside chat with Prof. Apoorva D. Patel (IISc), who illuminated strategic use cases for quantum computing and stressed the importance of identifying domains where it outperforms classical systems.

The conclave wrapped up with an immersive tour of C-DAC Bangalore, featuring its photonics-based quantum computing lab and the state-of-the-art HPC Param Utkarsh supercomputing facility.



QUANTUM SENSING MARKET

QUANTUM SENSING MARKET

The global quantum sensing market is on track for significant expansion, with projections indicating growth from $550 million in 2024 to $1 billion by 2032. This represents a compound annual growth rate (CAGR) of 7.8%, according to a recent report by Market Data Forecast.

Key Growth Drivers

Military and Defense Applications: Quantum sensing technology is proving invaluable in the defence sector, where it is used for highly accurate positioning and submarine detection. This has led to increased investment in quantum sensing technologies for national security purposes.

Revolutionising Healthcare: Quantum sensors are playing a transformative role in healthcare by enabling early disease detection, particularly in identifying conditions like cancer before symptoms emerge. These sensors achieve this by measuring free radicals, which serve as biomarkers for various diseases.

Automotive Advancements: The increasing adoption of quantum sensors in the automotive sector is fuelling market growth. These sensors are instrumental in enhancing navigation systems by providing precise measurements of motion, acceleration, gravity, and rotation. The rise in autonomous and electric vehicles has driven a surge in sensor integration per vehicle, further propelling market demand.

Source: Market Data Forecast Analysis

Key Industry Players

Several companies are driving innovation in the quantum sensing sector, including:

- Oscilloquartz
- Apogee Instrument Inc.
- GWR Instruments Inc.
- Spectrum Technologies Inc.
- Thomas Industrial Network Inc.
- Adcon Telemetry GmbH
- METER Group
- Microchip
- Impedans Ltd.
- M-Squared Lasers Limited

These industry leaders are at the forefront of developing cutting-edge quantum sensing technologies that are shaping the future of multiple industries.

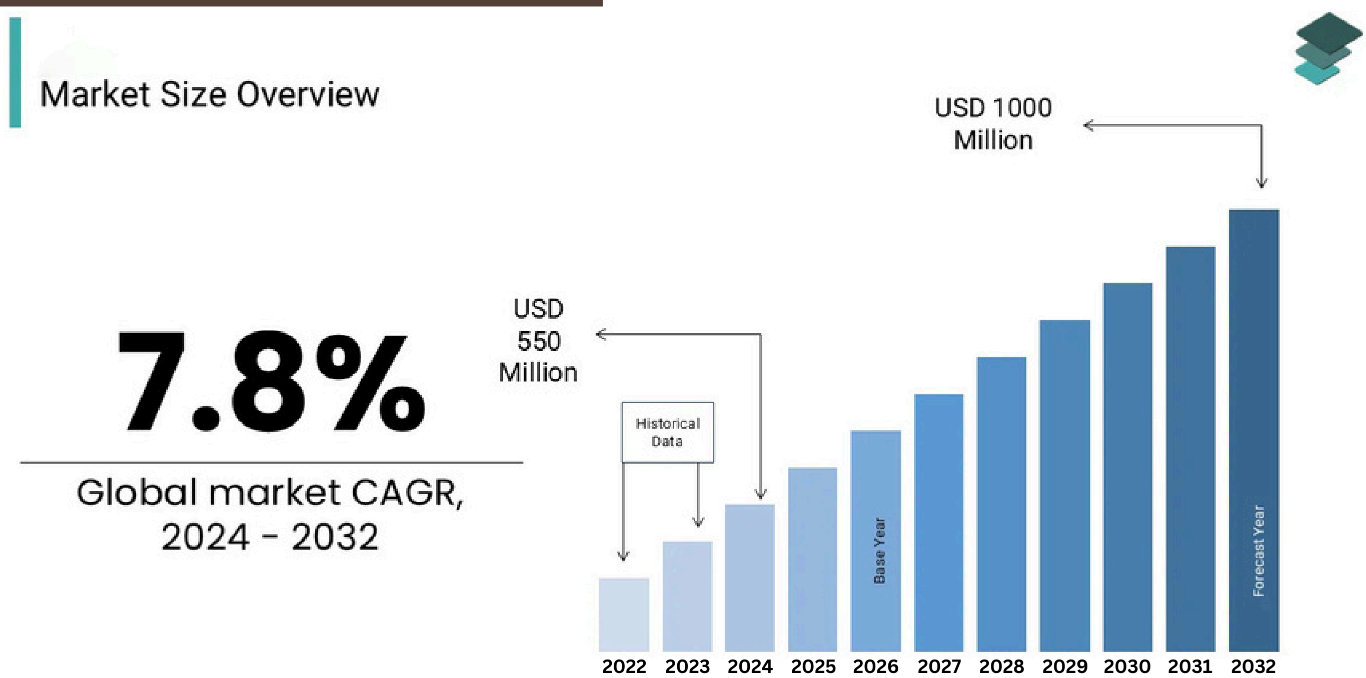
Challenges Facing the Market

Despite its promising outlook, the quantum sensing industry faces significant technical challenges. One of the primary hurdles is maintaining the delicate balance between isolating quantum states from external disturbances and allowing their modification for measurement. Additionally, issues such as spectral errors can impact measurement precision, posing a challenge to further advancements in the field.

Regional Insights

Europe is projected to lead the quantum sensing market, driven by early investments and strategic planning. The United Kingdom, a pioneer in quantum technology, significantly contributed with a GBP 270 million investment through the National Quantum Technologies Programme. Europe's early adoption, particularly in the military and defence sectors, continues to fuel its dominant market position.

Source: Market Data Forecast Analysis



TOP MASTER'S PROGRAM IN QUANTUM TECHNOLOGY

Credits: in Ms. Kiran (Natashia) Kaur Raina

Top Master's Program in Quantum Technology in India

Indian Institute of Science (IISc), Bangalore

MTech in Quantum Technology
Bangalore, Karnataka

Focus Areas : Quantum Computing, Communication, Materials

Highlights :
- Research-rich environment in quantum labs
- Collaborations with industry and academia
- Hands-on training in quantum hardware & simulation

Best for : Research & Deep Tech Careers

Indian Institute of Technology (IIT), Madras

International Interdisciplinary Master's programs in Quantum Science and Technology
Chennai, Tamil Naidu

Focus Areas : Physics, Computer Science, Superconducting Qubits

Highlights :
- Hands-on experience with quantum programming
- Strong interdisciplinary foundation
- State-of-the-art quantum research labs

Eligibility : Only for Non-Indian Citizens

Best for : International Students Seeking Advanced Quantum Training

Indian Institute of Technology (IIT), Jodhpur

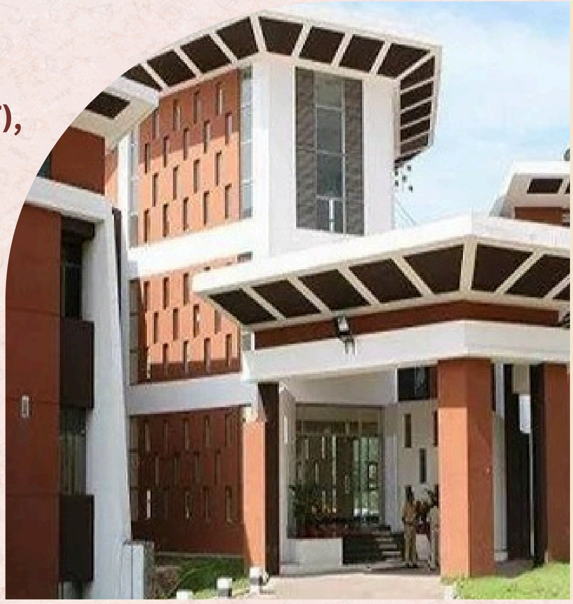
MTech in Quantum Information and Computation
Jodhpur, Rajasthan

Focus Areas : Quantum Computing, Communication, Sensing

Highlights :
- Specialization in quantum algorithms & error correction
- Exposure to experimental physics
- Project-driven curriculum with real-world applications

Best for : Quantum Algorithm Enthusiasts & Researchers

Top Master's Program in Quantum Technology in India



Indian Institute of Space Science and Technology (IIST), Thiruvananthapuram

MTech in Quantum Technology, Thiruvananthapuram, Kerala

Focus Areas : Quantum Optics, Electronics, Satellite Communication

Highlights :
- Integration with space & defense quantum applications
- Research in secure quantum communication
- Strong experimental focus with national relevance

Best for : Quantum Optics & Space Tech Aspirants

Indian Institutes of Science Education and Research (IISER). Pune

Master of Science (MS) in Quantum Technology Pune, Maharashtra

Focus Areas : Quantum Simulations, Computing, Materials

Highlights :
- Research-oriented curriculum
- Projects using real quantum hardware & software
- Strong foundation for PhD and R&D paths

Best for : Academic & Research-Oriented Students

Defence Institute of Advanced Technology (DIAT) - DRDO, Pune

MTech in Quantum Technology Pune, Maharashtra

Focus Areas : Quantum Cryptography, Secure Communication, Quantum Radar

Highlights :
- Specialized in defence-linked quantum research
- Deep industry connections with DRDO
- Security-focused quantum curriculum

Best for : Defence-Tech & Secure Communication Aspirants

Upcoming Events

May 03-25 — 1. Quantum Computing and Quantum Machine Learning (Jointly by CDAC & IIT Roorkee), India (Online - https://tinyurl.com/4t7j6dv8)

May 04 — 2. Conference on Lasers and Electro-Optics, Long Beach, United States

MAY 12-16 — 3. 2nd International Conference on Quantum Computing (ICOQC2025), Paris, France

MAY 13-16 — 4. Quantum Meets & Q-Expo, Amsterdam, Netherlands

MAY 14-15 — 5. Q2B: The Roadmap To Quantum Value, Tokyo, Japan

MAY 20-22 — 6. 5th Quantum Matter International Conference, Grenoble, France
7. IQT Nordics, Gothenburg, Sweden

Upcoming Events

MAY 26-30 — 8. Celebrating 100 Years of Quantum Science, Ottawa, Canada.

JUNE 02-06 — 9. The 3rd International Workshop on the Art, Science, and Engineering of Quantum Programming, Prague, Czechia

JUNE 10 — 10. France Quantum 4, Paris, France

JUNE 10-13 — 11. International Conference On Quantum Software (IQSOFT), Bilbao, Spain.
12. ISC High Performance 2025, Hamburg, Germany

JUNE 15 — 13. Quantum Information, Benasque, Spain

JUNE 16-20 — 14. 2nd Workshop on Quantum Software 2025, Seoul, South Korea

JUN 16 - JUL 04 — 15. Fault-Tolerant Quantum Computing: From Theory to Practice, Stockholm, Sweden

JUNE 17-18 — 16. Quantum Engineering and Technology Conference, London, United Kingdom

Upcoming Events

JUNE 18-20	17. Quantum ChemE 2025: Quantum Computing Applications in Chemical and Biochemical Engineering (QChemE 2025), Lyngby, Denmark
JUNE 23	18. European Conference on Lasers and Electro-Optics (CLEO®/Europe), Munich, Germany
JUNE 24-27	19. World of QUANTUM 2025, Munich, Germany
JUNE 25-28	20. 2025 IEEE International Conference on Quantum Control, Computing and Learning (IEEE qCCL2025), Hong Kong, China
AUG 25	21. Superconducting Qubits and Algorithms, Delft, Netherlands 22. QCrypt '25, Sanya, China
AUG 31	23. IEEE Quantum Week, Albuquerque, United States
SEPT 15	24. The Theory of Quantum Computation, Communication and Cryptography (TQC) at India (Tentative)
NOV 31	25. The International Conference for High Performance Computing, Networking, Storage, and Quantum at St. louis, MO

PUBLICATIONS

List of selected publications in Quantum Technologies during January to March 2025

Exact quantum Fisher matrix results for distributed phases using multiphoton polarization Greenberger-Horne-Zeilinger states *January 2025*	Physical Review A, 111(1), 012414 *Wang, J., & Agarwal, G. S. (2025)*
Thermalization and criticality on an analogue-digital quantum simulator *February 2025*	Nature, 638(8049), 79-85 *Andersen, T. I., Astrakhantsev, N., Karamlou, A. H., Berndtsson, J., Motruk, J., Szasz, A., ... & Molina, S. (2025)*
Quantum coarsening and collective dynamics on a programmable simulator *February 2025*	Nature, 638(8049), 86-92 *Manovitz, T., Li, S. H., Ebadi, S., Samajdar, R., Geim, A. A., Evered, S. J., ... & Lukin, M. D. (2025)*
Hardware-efficient quantum error correction via concatenated bosonic qubits *February 2025*	Nature, 638(8052), 927-934 *Putterman, H., Noh, K., Hann, C. T., MacCabe, G. S., Aghaeimeibodi, S., Patel, R. N., ... & Painter, O. (2025)*
Deterministic photonic entanglement arising from non-Abelian quantum holonomy *February 2025*	Physical Review Letters, 134(8), 080201 *Bhattacharya, A., & Raman, C. (2025)*
Certified randomness using a trapped-ion quantum processor *March 2025*	Nature, 1-6 *Liu, M., Shaydulin, R., Niroula, P., DeCross, M., Hung, S. H., Kon, W. Y., ... & Pistoia, M. (2025)*
Establishing a new benchmark in quantum computational advantage with 105-qubit Zuchongzhi 3.0 processor *March 2025*	Physical Review Letters, 134(9), 090601 *Gao, D., Fan, D., Zha, C., Bei, J., Cai, G., Cai, J., ... & Zhu, C. (2025)*
Tensor networks and efficient descriptions of classical data *March 2025*	Physical Review A, 111(3), 032409 *Lu, S., Kanász-Nagy, M., Kukuljan, I., & Cirac, J. I. (2025)*

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