McKinsey & Company

The Quantum Technology Landscape, Quantum Sensing, and the Path to Maturity

Internet of Things (IoT) Summit at RWW2023

Prof. Dr. Niko Mohr

Quantum Technologies (QT) are comprised of three parts: Computing, Communications, and Sensing

Not exhaustive

☐ Focus today

Number of players[1]

Total raised start-up funding[2]

Estimated market 2040[3]

Quantum computing (QC)

228[1]

$3.0 billion[2]

$9 billion–$93 billion[3]

Quantum sensing (QS)

58[1]

$0.4 billion[2]

$1 billion–$7 billion[3]

Quantum communications (QComms)

111[1]

$0.7 billion[2]

$1 billion–$6 billion[3]

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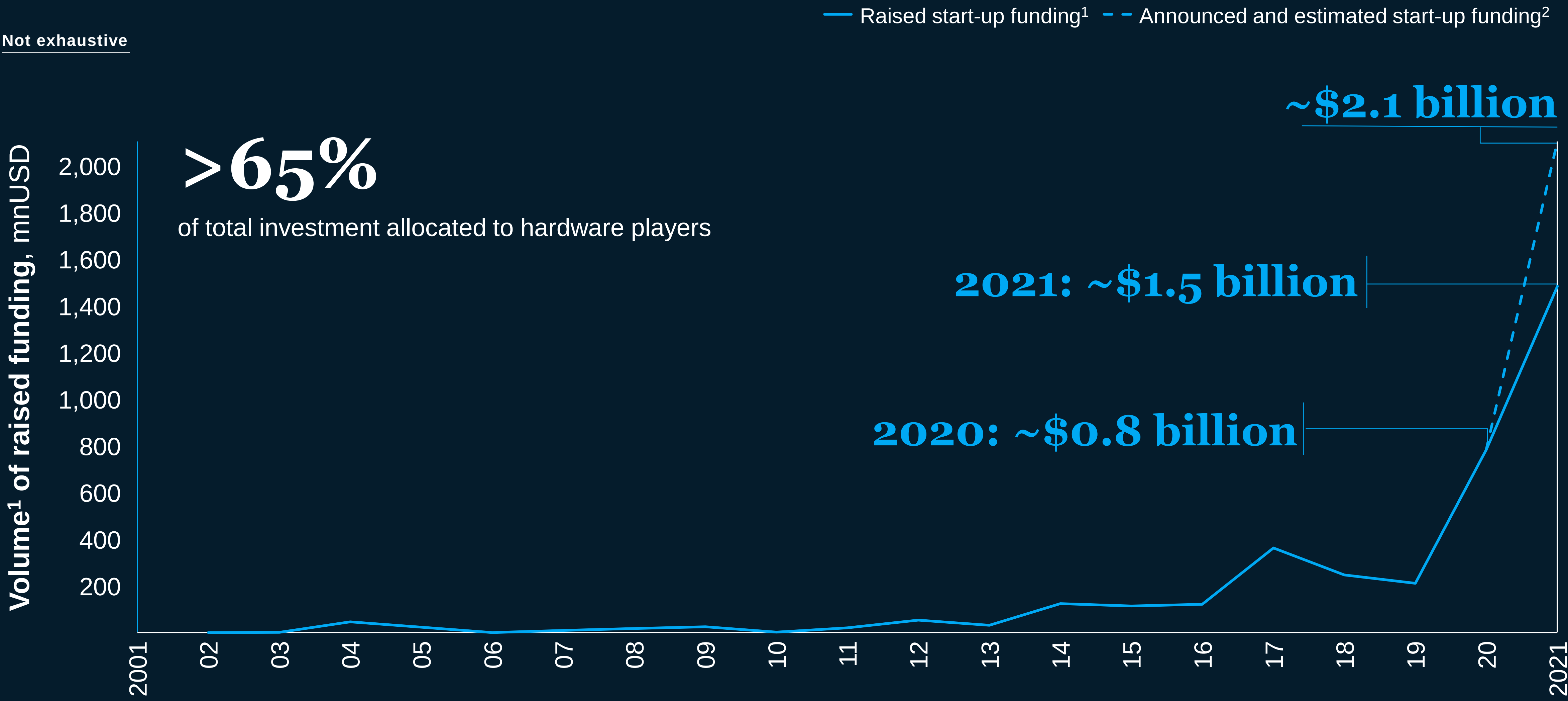
1. Includes start-ups and incumbents that develop or offer QT products
2. Based on public investments in start-ups recorded on Pitchbook and announced deals from 2001 to 2021. Actual investment is likely higher, excludes investments in internal QT departments or projects by incumbents.
3. Exchange rate for market estimates EUR to USD: 1.19.

Source: CapitalIQ; Crunchbase; PitchBook; press search; Quantum Computing Report; expert interviews

Overall, the QT ecosystem has seen a massive influx of capital in recent years

Not exhaustive



>65%

of total investment allocated to hardware players

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1. Based on public investment data recorded in PitchBook; actual investment is likely higher.
2. Public announcements of major deals; actual investment is likely higher as for 7 out of 20 deals done in 2H2021 the deal size was not disclosed.

Source: PitchBook

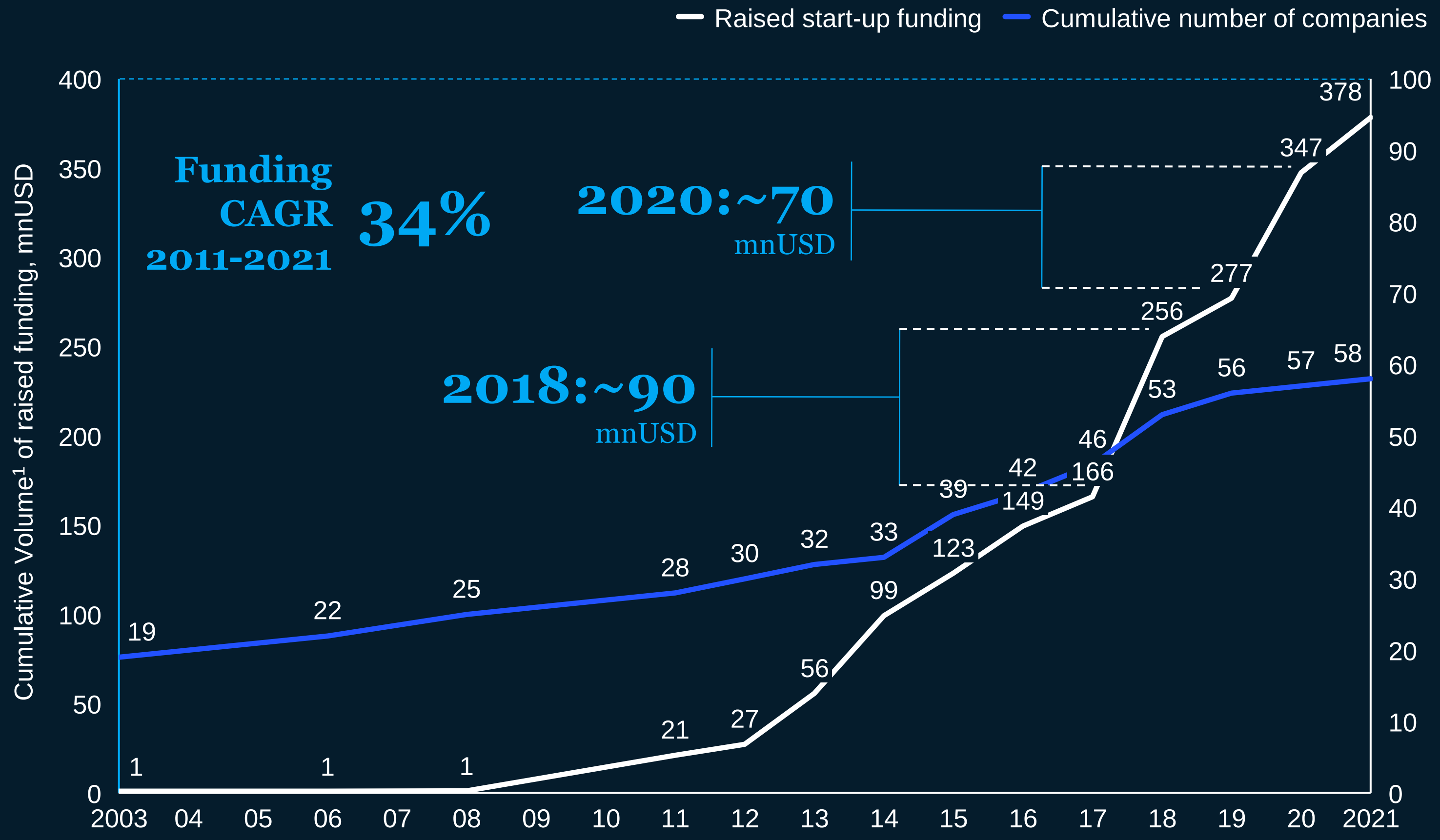
While interest by investors in QS start-ups accelerates, unique to other QT, QS incumbents are important drivers of QS development

Not exhaustive

Use case exploration

Entrepreneurial activity

Activities re QS start-ups



Corporate activities

- Measuring particle size, specific product surface and shape for quality check in plastics production, food industry etc.
- Control of e.g., temperature and pH in bio reactors for improved quality and waste
- 2018: Spin-off Q.ANT with 2021 reinforced xx mnEUR investment
- 2022: Announcement of partnership with Sick

TRUMPF QANT

- Prediction of neurological conditions like Alzheimer's and Parkinson's
- Record of nerve impulses and possibility to control artificial limbs
- Detection of magnetic fields generated by physiological processes
- 2022: Launch of new business unit to commercialize quantum sensors

BOSCH

- Tissue differentiation during surgery
- Detecting and visualizing neuronal signals for life science
- High precision overlay metrology for the semiconductor industry
- 2021: Announcement of Zeiss Quantum Challenge competition

ZEISS

- Use cases for better resolution imaging in healthcare, MRI and CT scanning

SIEMENS

- Dark Ice project re navigation use cases: positioning of aircraft without GPS signal thanks to ultrasensitive magnetic field readings

LOCKHEED MARTIN

- Miniature quantum antennas to detect communication signals over very large portion of radiofrequency spectrum and long range for military purposes
- 2021: Announced investment of 1 bnEUR annually in self-funded R&D for quantum tech

THALES

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1. Based on public investment data recorded in Pitchbook; actual investment is likely higher

Source: Pitchbook; McKinsey analysis

QS is not just about sensors but an ecosystem incl. components, QS systems, orchestration layer, and applications and services layers

Illustrative

■ Applications, services and orchestration ■ Hardware ■ Components

Tech stack, incl. customer		Description	Example
Sales		Market placement of the QS solution to customers	Integration of the underlying sensing technology into the application and service system such as navigation systems
Services		Services around QS solution, e.g., consulting, after-sales device care, product customization, etc.	
Applications		Applications that use quantum sensing information, e.g., finding the best place to drill for oil, navigating a map without GPS signal, etc.	
QS-BUS: Orchestration layer	**Analytics modules**	Process to get useful information from the structured quantum sensor data, e.g., a map of brain activity, geological layer information, etc.	Systems that extract data from each sensor and link with their physical position
	Data platform	Structuring of sensor data from both quantum and classical sensors into a form that is suitable for modeling later	
Quantum sensing system	**Sensor design**	Overall packaging of the quantum sensor and the methods by which the data is read out of it	Interferometers, magnetometers; quantum atomic clocks; quantum radar
	Core sensor software	Low-level embedded software close to the sensor's hardware that does basic signal processing and controls the sensors	
	Core sensor hardware	Finished element that can pick up a signal from the environment and transmit it further	
Components		Different parts of the sensor in their base form, e.g., chips, wiring, superconducting material, etc.	Lasers; detectors; Cryostats; Specialized fibres; NV centre diamonds…

Number of QS players by value chain segment1

In this early stage of this ecosystem majority of funding and players are in the components segment

	Number of players	Share of start-up funding[2]
Component manufacturers	>100[1] suppliers, which are largely not specific to QS hardware; there are a few (37) quantum-sensing-focused component suppliers that figure into the overall company count	51%
Hardware manufacturers	16	21%
Applications, services & Orchestration	13	28%
Total number	56	

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1. Includes start-ups and incumbents that develop or offer QT products; see methodology page for details
2. Based on public investments in start-ups recorded on Pitchbook and announced in the press. Includes announced deals for 2021; excludes investments in internal QT departments or projects by incumbents; actual investment is likely higher

Source: CapitalIQ; Crunchbase; Pitchbook; press search; Quantum Computing Report; expert interviews; McKinsey analysis

Value pools and focus of the QS ecosystem is expected to shift up the stack over time

Illustrative

Insights

Significant value pools move up the stack over time

Historically, initially scarce components get commoditized, making the QS device the bottleneck; with time, value shifts towards analytics and applications

Most valuable plays involve platform approach

Across industries, platform play are highly attractive given multiple monetization models, de-risking approaches and unavoidable role in ecosystem

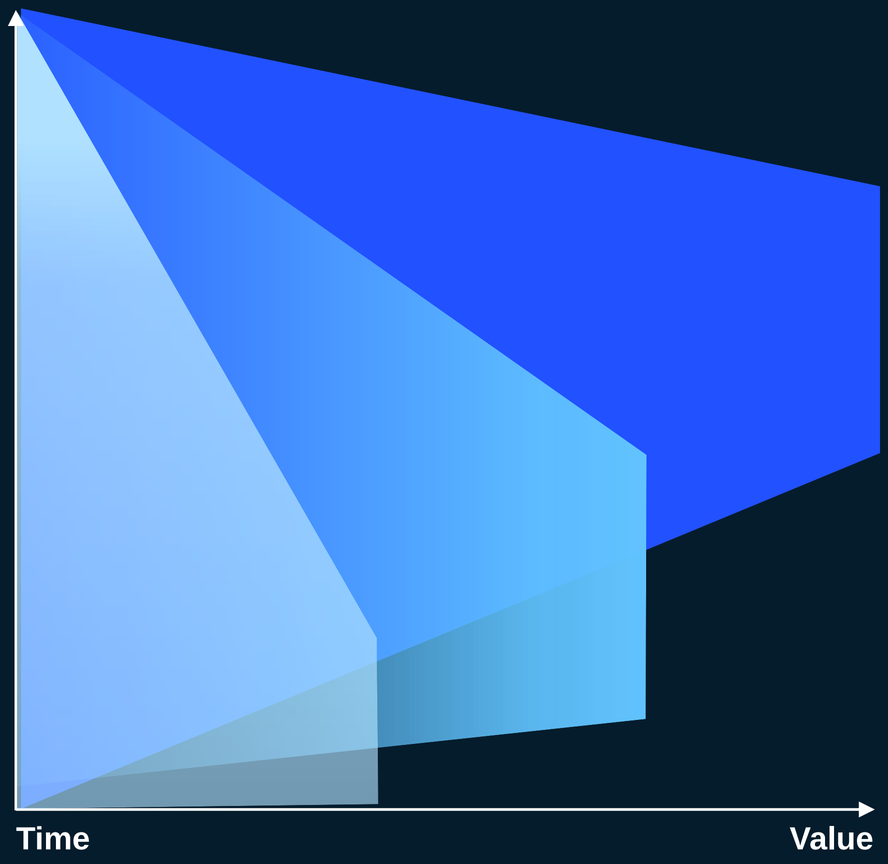
Pull-through effect of software

Software as critical element that drives decision for hardware in long-term

QS stack, incl. customer

Sales	
Services	
Applications	
QS-Orchestration layer	**Analytics modules**
	Data platform
Quantum sensing system	**Sensor design**
	Core sensor software
	Core sensor hardware
Components	

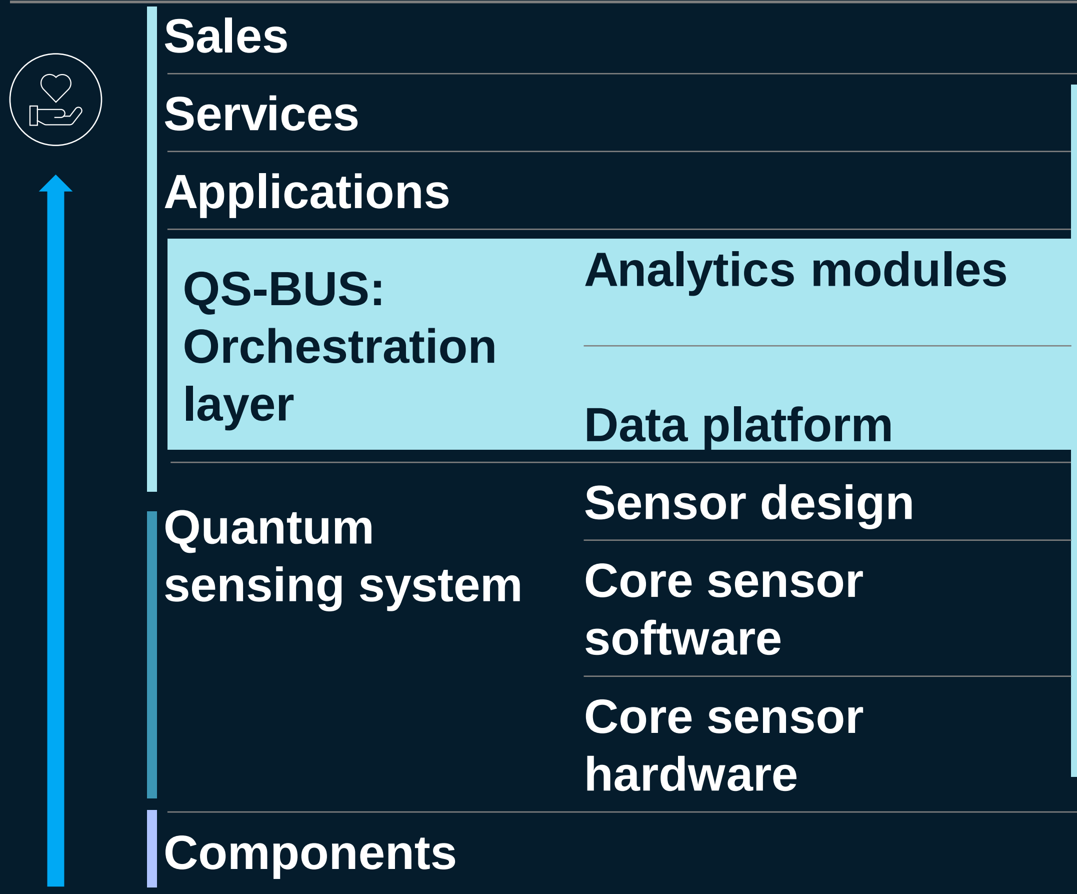
Focus based on value



🟦 Current 🟦 Near-term 🟦 Long-term

An orchestration layer serves as enabler, multiplier and 'spider in the web', enabling much more than pure tech connections

■ Applications, services and orchestration ■ Hardware ■ Components



Tech stack, incl. customer

Sales

Services

Applications

QS-BUS: Orchestration layer

Analytics modules

Data platform

Quantum sensing system

Sensor design

Core sensor software

Core sensor hardware

Components

Insights of the orchestration layer

- Is responsible for **the governance, control, and coordination** of data or applications, incl. (raw) data from sensors
- Ensures **data formatting** between separate services or applications, e.g., time relation between measurements from different sensors
- Optimizes **speed and data rates**
- Exists in cloud and **manages interactions and interconnections between onsite and cloud components**, incl. sensor data, edge layer and data lake
- May include **intelligence for communication between services** through API

Solid state spins and neutral atoms are the most used hardware technologies for quantum sensing, so far

Overview of quantum sensing technologies[1]

Non-exhaustive

○ Theoretical evidence ◔ PoC ◑ Prototype ◕ Commercialized ● Produced at scale

Technology	**Solid state spins**	**Neutral atoms**		**Superconducting circuits**	**Photonics**
Implemen-tation type	**NV[2] center in diamonds**	**Atomic vapor**	**Cold Cloud**	**SQUIDs[3]**	**Interferometer[4]** **Photon counter**
System description	Spin of one electron localized in an insulator defect (e.g., NV center in diamond)	Atoms in the vapor cell sense changes in the environment	Laser cooled atoms sense changes in the environment	Difference in Cooper pairs between two islands of a Josephson tunnel junction	Photon interaction in a material that leads to measurable difference in the interference pattern
Measured properties	Magnetic field, electric field, temperature, pressure, rotation	Magnetic field, rotation, temperature, electric field, frequency, acceleration, rotation		Magnetic field, electric field	Temperature, distance, Refractive index, photon counts
Example players	nami QDTI Quantum Diamond Technologies, Inc. BOSCH LOCKHEED MARTIN QANT ZABRE THALES	ColdQuanta NOMAD ATOMICS	RYDBERG TECHNOLOGIES μQUANS THALES	Terra Quantum chipiron THALES supracon	IDQ SIEMENS QLM Enabling Net Zero TRUMPF QANT
Maturity	◕	◕		◑	◔

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1. Trapped ions are an additional technology at research state
2. Nitrogen-Vacancy
3. Superconducting Quantum Interference Device
4. Minituarization and precision has been improved; not a novel sensing principle

Source: Expert interviews

The advantages of QS are in enhanced sensitivity, increased reliable measurements and miniaturization

Key benefits of QS vs. classical sensors

Higher precision

The enhanced sensitivity of quantum systems to the outside world can be leveraged to reach a **higher precision**

Enhanced access

Quantum sensors provide **new access** to e.g., extremely small ranges in size, high resolution or inaccessible locations

Measured properties

- Magnetic field
- Temperature
- Time
- Rotation
- Force
- Pressure
- Electric field

Source: Expert interviews; McKinsey analysis

QS systems enable new applications in different industries with the potential to materialize in the next two to three years

Non-exhaustive

Applications » Next step: Identification of economically viable use cases vs. conventional alternatives

Bio imaging, including brain scans, imaging of protein structures and real-time metabolic processes

Imaging of molecular structures

(spectroscopy)

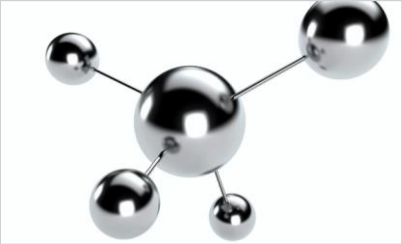
Signal receivers and amplifiers for radar communication

Calibration of electrical standards for new technologies
(e.g., 5G, 6G)

Precise atomic clocks for high-accuracy GPS navigation

Navigation inside buildings and underground

Environmental monitoring: prediction of volcano outbursts



Fundamental research, e.g., High-Energy physics

Quantum Sensing is the application of **quantum metrology** in practical settings.

“You have to do very accurate measurements to compare values, that’s ***metrology****. When you then put this technique into instruments and place them in the field you build up a* ***sensor****.”*

Professor of Quantum Communication, Computing & Measurement at Boston University

Quantum sensing might be the first quantum technology to materialise, short-term

Quantum technology has the potential to revolutionise our everyday life and is receiving huge influx of funding (~$2.1bn) in recent years

Unique to other QT, QS incumbents are important drivers of QS development in addition to QS start-ups

QS **is not just about sensors but an ecosystem** incl. components, QS systems, orchestration layer, and applications and services layers

As value pools and focus of the QS ecosystem is expected to shift up the stack over time, **orchestration layer is becoming critical to the system**

Quantum Sensing systems enable new applications in different industries with the potential **to materialize in the next two to three years**

For more McKinsey insight on quantum technology

SCAN ME