METRICA
METRology Institutional CAtalog

ISTITUTO NAZIONALE DI RICERCA METROLOGICA
Repository Istituzionale

Quantum (sensing) leap: Pushing the technology readiness of Nitrogen-Vacancy sensors in Europe forward

Original
Quantum (sensing) leap: Pushing the technology readiness of Nitrogen-Vacancy sensors in Europe forward / Traina, Paolo; Degiovanni, Ivo Pietro; Gramegna, Marco; Vidal, Xavier; Gil, Guillermo. - In: PHOTONIQUES. - ISSN 1629-4475. - 131(2025), pp. 28-32. [10.1051/photon/202513128]

Availability:
This version is available at: 11696/89240 since: 2026-03-10T10:48:13Z

Publisher:
Société Française d'Optique

Published
DOI:10.1051/photon/202513128

Terms of use:

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

Publisher copyright

(Article begins on next page)

15 May 2026

Quantum (sensing) leap:
Pushing the technology readiness of Nitrogen-Vacancy sensors in Europe forward

Nitrogen Vacancy centers in diamond interact with local magnetic and electric fields, temperature, strain, and pressure. Their ease of operation and exceptional performance has led to the emergence of a first generation of commercial NV-based quantum sensors, as scanning-probe systems, giving them wide recognition as the quantum technology with the most imminent market potential. In recent years, there is an effort to advance the TRL of those quantum technologies through several European initiatives.

https://doi.org/10.1051/photon/202513128

Paolo TRAINA[1,*], Ivo Pietro DEGIOVANNI[1], Marco GRAMEGNA[1], Xavier VIDAL[2], and Guillermo GIL[2]

[1] INRIM, Istituto Nazionale di Ricerca Metrologica. Strada delle cacce 91, I-10135 Torino (Italy)
[2] TECNALIA, Basque Research and Technology Alliance (BRTA). Parque Científico y Tecnológico de Bizkaia. Astondo Bidea, Edificio 700. E-48160 Derio – Bizkaia (Spain)

***p.traina@inrim.it**

In the 1966 sci-fi movie *Fantastic Voyage* a submarine full of scientists is miniaturized and injected into the body of a critically ill diplomat in a rush to selectively destroy an embolus in his brain before his death. Even if scientists' miniaturization remains science fiction territory, there is great interest to investigate in the micro/nano scale and to probe extremely local properties of small systems such as living cells and/or nanodevices.

Among the most prominent new-generation sub-microscale sensors, the Nitrogen-Vacancy (NV) center in diamond [1] has emerged as extremely promising candidate for measuring very small fields (as in the case of bulk sensors) or for detecting signals with high spatial resolution (e.g. with nanodiamonds).

An NV center is a point defect in a diamond crystal where a nitrogen atom replaces a carbon atom next to a vacancy. These defects exhibit unique quantum properties, including long-lived spin states that can be manipulated and measured with high precision, even at room temperature.

NV centers are particularly valuable for detecting magnetic fields [2], electric fields [3], temperature [4], and even pressure at the nanoscale. Their interaction with external fields, such as magnetic or electric, alters the properties of their electronic spins, which can be measured using techniques like Optically Detected Magnetic Resonance (ODMR). This allows NV centers to act as highly sensitive sensors for magnetic resonance imaging (MRI), magnetic field mapping, and even biosensing.

Some of the most significant advantages of NV centers is their robustness and photostability. These properties make NV centers suitable for applications in quantum computing, materials science, biology, and environmental monitoring. Their potential for precise, non-invasive measurements at the nanoscale positions NV centers as a promising tool in advancing both scientific research and practical technologies.

Thermometry

NV sensors have proven to be versatile and game-changing in advanced applications such as magnetometry, thermometry, imaging, electric field and strain sensing. As an example of the potential of those quantum objects, we will describe here a recent experiment of intracellular thermometry performed at Istituto Nazionale di Ricerca Metrologica (INRIM) in Torino (Italy), in collaboration with the Universtiy of Turin and Charles University in Prague (Czechia) [5].

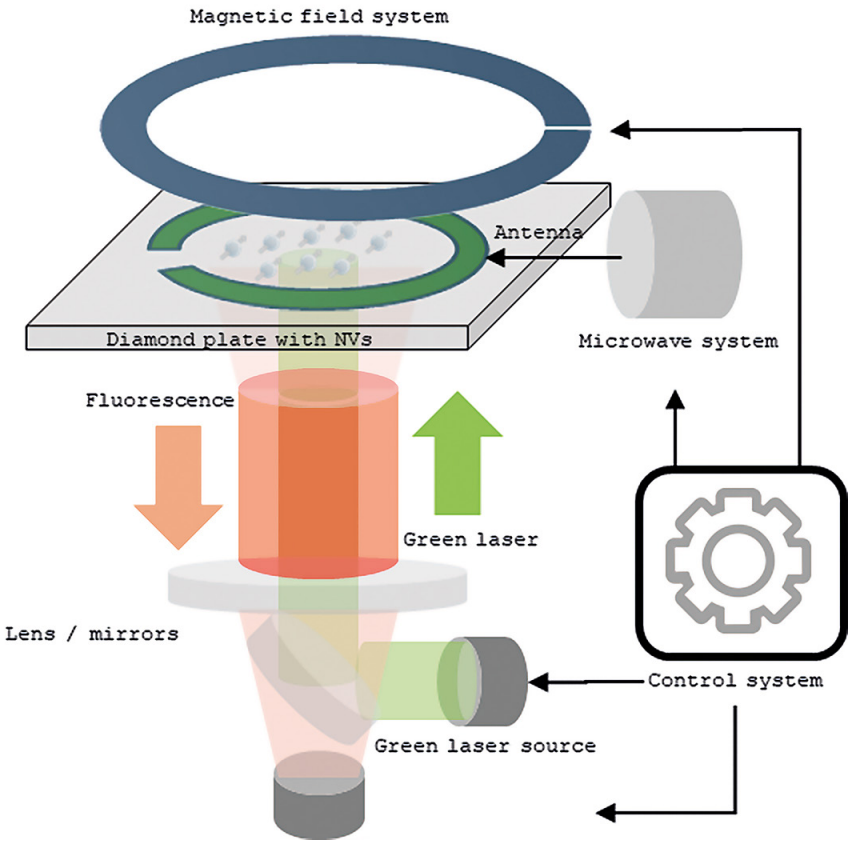


Figure 1. Scheme of the typical setup for the study of color centers in diamond. It includes: diamond sample, detection system, laser excitation, microwave antenna.

Table 1. Overview of NV sensing Companies and SMEs ecosystem.

COMPANY NAME	WEBSITE
QNAMI	https://qnami.ch/
QZABRE	https://www.qzabre.com/
QDTI	https://qdti.com/
QDM.IO	https://qdm.io/
Q.ANT	https://qant.com/
DIASENSE	https://www.diasense.dk/
QUANVIA	https://www.quanvia.com/
QUBIZ.TEAM	https://www.qubiz.team/
QTSENSE	https://www.qtsense.com/
SBQUANTUM	https://sbquantum.com
SQUTEC	http://squtec-tti.com
BOSCH QUANTUM SENSING	https://www.bosch-quantumsensing.com/
SPINFLEX	https://spin-flex.com/
CHINAPROSP QUANTUM	https://en.gshqt.com/
KWAN-TEK	https://www.kwan-tek.com/
DETEQT	https://www.deteqt.com.au/
THALES	https://www.thalesgroup.com/

standa
by OPTON LASER INTERNATIONAL
OPTO-MECHANICS & MICRO-POSITIONING
38 years of expertise in precision engineering
Specializing in opto-mechanics, motion control, & vacuum-compatible products
Custom solutions & OEM development to meet unique customer needs
Fast delivery on in-stock items
Providing high-precision metalworking services (parts production)
Customer-focused, flexible, and committed to innovation
Votre contact :
Baptiste.Callendret@optonlaser.com
www.optonlaser.com

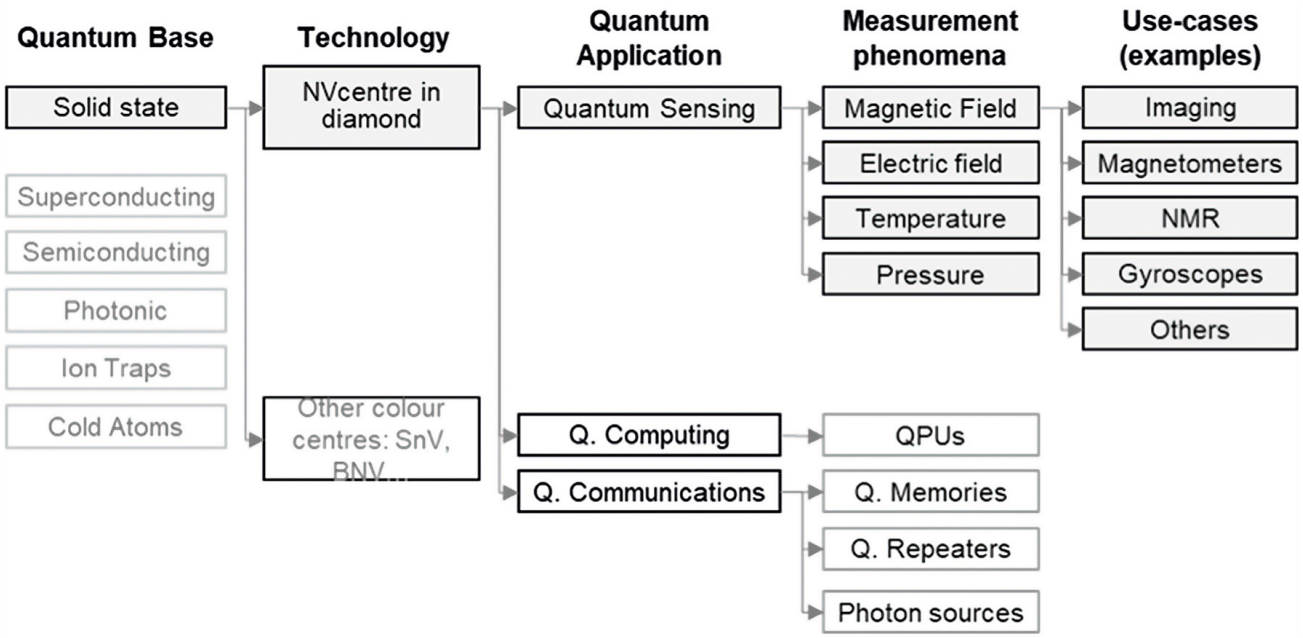


Figure 2. Hierarchy of the quantum-based technologies with particular focus on solid state systems, including NV-based sensors.

Not even the authors of *Fantastic Voyage*, who imagined the above mentioned submarine diving through streams of blood cells and lymphocites, dared conceive a more extreme scenario in which the dimensions of the vessel were reduced to nanometric dimensions to observe the internal mechanism of a single cell. This has been now indirectly realized by probing the temperature variations inside the membrane of a mice neuron by means of a diamond nanosensor, *i.e.* a 100 nm diameter-wide diamond crystal containing the temperature sensitive NV centers. This nanosensor was capable of detecting shifts of the internal temperature of the neuron correlated to different intensity of its signaling activity, stimulated through a protocol consisting of the injection of different doping substances. This multidisciplinary experiment (involving quantum and laser physics, biotechnology, and microwave electronics) not only proves the first ever measurement of a real metabolic process at the single cell scale in mammalians, but also generates further debate as the detected local temperature increase following stimulation is greater than expected, as high as 1°C.

Following the great success in the academic field, it is natural that these NV-based system are nowadays recognized as potential objects of interest also for industrial application and several companies and SMEs have started commercializing products based on this technology (See TAB.1).

For a decisive interest from the industry and a concrete penetration of these devices in the market, two key aspects are expected: the increase of the technology readiness level (TRL) and the development of documentary standards.

Standardization: a global effort

The Development of standards at European level and the harmonization of standards within the European Union are provided by CEN (European Committee for Standardization) and CENELEC (European Committee for Electrotechnical Standardization). The need for standardization of Quantum Technologies was identified as an emerging key requirement for industrial applications by the CEN/CENELEC, which kicked-off a dedicated Focus Group (FGQT) in 2020 [6]. This group of experts developed a roadmap about quantum-technologies and their standardisation needs. This roadmap documents that *there are not standards related to NV-centers based sensors* and *lack of standards for quantum sensor industry is commonly seen as a barrier to market acceptance of new relevant products [...]. The standardisation will help multiple industries in the quantum technologies sector. The existence of a standard that stakeholders can adhere to would therefore significantly de-risk further investments in the market.*

Following the publication of the first release of the Roadmap, the activities of the Focus Group moved in a new entity called Joint Technical Committee 22 "Quantum Technology" (CEN/CLC JTC-22 QT , www.cencenelec.eu/areas-of-work/cencenelec-topics/quantum-technologies/), which kicked off in 2022 and is nowadays active.

Similarly, at the International level, ISO (International Organization for Standardization) and IEC (International Electrotechnical Commission) are two key international organizations that develop and publish global standards. ISO focuses on a wide range of standards across various industries, including quality management, safety, environmental, and technological standards. IEC is dedicated to international standards in the electrotechnical and electronic fields, covering areas like electrical engineering, energy, and telecommunications.

Standardization in the field of quantum technologies is developed by the IEC/ISO JTC 3.

Standardization and Metrology: The QADeT and NoQTeS initiatives

Metrology, the science of measurement, is a building block for an industrialised and increasingly globalised and digital society: Reliable measurements are essential for innovation in industry, research, trade and regulation. New societal challenges and emerging technologies increase the need for accurate, precise, and trustworthy measurements and thus for novel measurement capabilities. The European Metrology Partnership aims to support the competitiveness, and economic growth of the European quantum industry.

Among the European metrology projects funded in the field of quantum technologies, INRIM is coordinating the European Metrology Partnership project "Normating colour-center-based quantum sensing technology towards industrial application and standards" (NoQTeS), kicking off in 2024, which is the follow-up of the previous EMPIR project "Quantum Sensors for Metrology based on single-atom-like Device Technology" (QADeT, 2021-2024). Both projects are closely connected to the strategies of the "Quantum Photonics" sector of the "European Metrology Network for Quantum Technologies" (EURAMET EMN-Q), a network that provides an active coordination of metrology research to support the competitiveness of the European industry in the field of quantum technologies.

QADeT project, targeting the development of NV quantum sensors of industrial interest, was notably successful in terms of output and impact, having led to more than 30 peer-reviewed publications, above 90 contributions to international conferences, several connections with stakeholders and Quantum Flagship consortia. Furthermore, experts of QADeT consortium were involved since the starting of FGQT and JTC22.

NoQTeS project is intended to move forward from QADeT and have a lead in the development of standards for color center-based quantum sensors.

The objectives of NoQTeS project are:

- To implement reference methods to produce of NV-based sensors and to develop methods for the standardised characterisation of NV-based sensors.
- To develop and validate reproducible procedures for producing and testing non-NV sensors/single photon emitters (e.g. novel defects in diamond, point defects in Si, SiC, 2D materials (hBN), semiconductor quantum dots (e.g. InAs, etc.).
- To extend current techniques and methods for the production of sensors based on colour centers in diamond, with enhanced performance.

The methods used within the project are controlled ion implantation and advanced photoluminescence microscopy and ODMR, while the sensors to be investigated are Optically active Point defects (NV or otherwise) in diamond, Silicon, quantum dots, etc. The consortium has a strong point of well-established collaboration in color center based quantum sensing (academic & industrial) through previous JRP QADeT and huge availability of ion implanting and characterization facilities.

A TRL sprint: Horizon Europe PROMISE

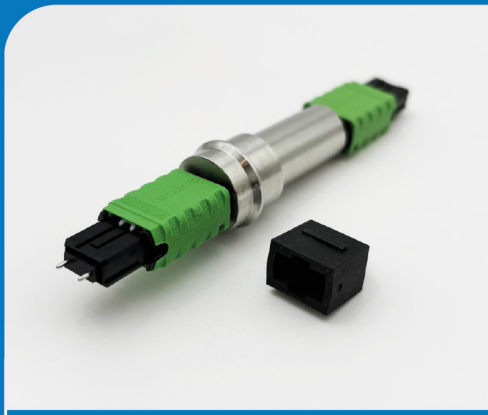
Several projects funded by the European Commission have focused on developing NV centers as quantum sensors to impact the industrial sector through various prototypes and SMEs. Diadems, funded in 2013 for five years, aimed to advance the NV technology. The consortium of 15 partners grew to 23 in Asteriqs from 2018 and 2022. One relevant outcome of those consortia was the commercialization of a single NV scanning system by two Swiss startups, Qnami and QZabre. Their instrument combines the high spatial resolution of atomic force microscopy with the sensitivity of a single NV center at the apex of a tip connected to a scanning tuning fork.

Horizon Europe in its vision and ambition to facilitate market uptake, has moved quantum sensing to pilot lines where NV-sensing technologies are present in Qu-Test and Qu-Pilot. Also, Innovation Action projects such as AMADEUS, ACDC_Q and PROMISE are three of the examples with the aim to reach high TRL.

SEDI•ATI
fibres optiques
by Fiber Optics Group

Ribbon fiber-optic hermetic feedthrough

KTRAV-MTP



Specifications:
- Weldable feedthrough
- MTP®/MPO male or female
- 12-channel ribbon
- SMF28 or GI50/125 µm fibers

Applications:
- Vacuum
- Cryogeny
- Quantum

Available in both in-line and brazed versions on CF or KF flanges.

Phone - 33 (0)1 69 36 64 32
Mail - contact@sedi-ati.com
Web - sedi-ati.com

Scan me!

The expert in extreme environments

Let's take the example of PROMISE (PROtotypes of Magnetic Imaging Systems for Europe); the aim is to develop widefield NV-based magnetometers at TRL7. Currently, this approach is mostly developed in research labs dedicated to NV research, with the only opportunity outside the research lab offered by the US company QDM. Over 44 months, PROMISE will develop a versatile and user-friendly instrument that does not require expertise in quantum sensing or NV technology, but rather an imaging system for magnetic fields. The versatility of the prototypes is addressed from two fronts: research and technology organizations (RTOs) and an SME joining forces to develop the instrument, and from the other front industrial and academic use cases to benchmark and challenge the NV technology. The PROMISE consortium is completed with experts in the standardization of quantum technologies, NV technology in particular, and a business and innovation consultancy for exploitation and dissemination, as well as screening industrial opportunities for the NV widefield approach.

Four use cases will validate the widefield magnetometer prototypes, with implications for the semiconductor industry, materials science, aerospace and biotechnology. The proximity of quantum sensors based on NVs to be integrated into industrial processes and their market potential is evident in PROMISE, where industrial partners are not experts in quantum technologies. The industry, globally, will benefit from a tool that improves its devices, materials, and production processes, deepens understanding of mechanisms at the atomic level, and monitors events and dynamics for more accurate predictions and addressing pressing challenges in various fields. All together PROMISE focuses on technology development supporting industrialization and use case testing.

The NV based widefield magnetometer is an interesting approach where high spatial resolution and high sensitivity need to be combined with dynamic samples. Specifically, the project will show applicability in three fields: Materials engineering, through the analysis of corrosion in alloys; Semiconductor industry, analyzing current flow distribution in electronic chips; and Biotechnology, by monitoring the evolution of tumoral cells. Additionally, the technology will benefit from innovations of the different components of the instrument. The most obvious is the engineering of the NV layer on the diamond surface, requiring a combination of NV layer depth, thickness, and concentration beneficial for the entire NV technology field. An optimized rf controller will be developed to vastly reduce weight, volume, power consumption and cost compared to commercial solutions. This will enhance the user-friendliness of the instrument but mainly pave the way for future commercialization facilitating a reduced final price and commission. Although commercial scientific cameras have different high-performance functions, they are not fast enough to detect single NV spin events. Therefore, a pixel array sensor will be integrated into the instruments for faster and lower signal detection, adapting to various acquisition protocols available for NVs. The exploitation of the results may come not only from a refined prototype that can achieve higher TRLs but also from the exploitation of the individual components relevant in the quantum field.

Machine learning experts will optimize data acquisition and analysis by leveraging their knowledge of the physics of NV centers. Additionally, as mentioned above, standardizing designs and methods will be considered for an easy industrialization.

During the 44 months, PROMISE will operate in two cycles. The second cycle will refine specific details of the prototypes, components, and test with more complex use case samples. The goal is that at some point in the second cycle a potential manufacturer will consider commercialization of the widefield magnetometer in the future. Ideally, the manufacturer will advise the consortium on appropriate testing for future commercialization. However, this is a difficult path, so all partners will protect their designs and methods through patents and IP repositories. They themselves have several commercialization options: licensing the various component designs to instrument manufacturers; creating spin-off companies; using a mixed approach in which the technology is licensed for specific fields and commercialized through spin-off companies for others; and potentially forming a joint venture between the partners. The path chosen will depend on market penetration and certification requirements.

Thus, the NV-based sensing technology has evolved from academic research to actual industrial interest in roughly fifteen years, and it has now already entered in a phase of maturity that reflects in a global effort for standardization of the techniques and in a dash of the technological readiness. A *fantastic voyage* indeed!

Acknowledgement

This article has been prepared in the context of the activities of: the projects 23NRM04 NoQTeS (23NRM04 NoQTeS has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States) and PROMISE project (funded by the European Union, Grant Agreement 101189611).

REFERENCES

[1]L. Rondin, et al. Reports on Progress in Physics **77** (5), 056503 (2014)

[2] J. M. Taylor, et al., Nature Phys. **4** (10), 810 (2008). doi:10.1038/nphys1075

[3] F. Dolde, et al., Nature Phys. **7**, 459 (2011)

[4]G. Kucsko, et al., Nature **500** (7460), 54 (2013)

[5] G. Petrini, et al., Adv. Sci. **9**, 2202014 (2022)

[6] O. van Deventer, et al., EPJ Quantum Technol. **9**, 33 (2022)