Quantum Technologies Flagship

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Ambition

In general industrial technologies are constrained by the laws of nature, in particular, physics. In the 19th century technological limits were set by thermodynamics and classical mechanics. In the 20th century quantum mechanics shattered these limits, leading to the age of transistors, lasers, computers and information technology as we know it.

Quantum physics has now become the driving force behind new and powerful technologies. Recent advances in atomic, molecular, optical as well as solid state physics enable precise control at the quantum level, which in turn allows for the exploitation of the full potential of quantum mechanics in information technology. We can now control quantum dynamics and engineer quantum behavior of physical system at unprecedented level which allows to bypass the constraints of semi- classical approximations of the 20th century technology, and allowing for a host of new possibilities: quantum technologies.

The proposed QUantum TEchnologies FET Flagship (QUTE-F) will allow Europe to play a key role in this new market where the quantum limits will define the performance of industrial applications. It builds and expands on the recent efforts in exploring the use of quantum degrees of freedom to perform complex calculations and tasks unattainable by systems behaving classically. Through the novel combination of quantum physics with information science, this research has already lead in the past ten years to new and unprecedented means for communicating and computing, thus creating a new conceptual platform for a family of potentially disruptive (quantum) technologies, adding a new stage to the already staggering impact of conventional information technology. QUTE-F will focus on these technologies with the purpose of bringing them from the lab to the real world. It will ensure a constant progress in the field through the integration of the scientific base built up to now, in order to conceive novel and powerful technological applications of quantum coherence and entanglement. The new technological paradigms explored within QUTE-F have the potential to lead in the mid- to long-term to entirely new fields of economic activities in the high-tech sector, and at the same time could have an impact on everyday concerns like, e.g., security and privacy of information, data protection, health care and energy efficiency.

Europe’s large stake in all these potential applications warrants a cohesive international effort to strengthen the leadership in this rapidly emerging field, and QUTE-F will allow Europe to play a key role in the future markets they promise to open up. The highly ambitious objective to respond to the major global technological challenges that the full exploitation of quantum technologies entail can only be achieved through the large unified international effort ensured by QUTE-F. The reason is the enormous breadth of the field, which makes it impossible to advance it with only the participation of national researchers. The field is truly multidisciplinary by nature, with scientists coming from theoretical and experimental physics, computer science, mathematics, material science and engineering. Thus, it takes the best expertise in all these scientific areas from different Member States to maintain Europe at the forefront of research in this very competitive international environment. In addition, quantum technologies are an emerging research area that will require sustained, focused attention if Europe is to maintain its position as global leader. European and national agencies that fund basic research in the physical sciences must work together to ensure that all promising avenues are addressed, priorities are set and the results of scientific breakthroughs are properly shared. QUTE-F will encompass the most competitive research on quantum technologies in Europe, which is a big fraction of the best research in this field worldwide. It

will provide sustained support and adaptive structures that will allow scientific breakthroughs to move effectively from research institutions to technological applications and ultimately to industries. In this way, quantum technologies will be developed based on European competence, without the need to rely on extra- European expertise for future commercial exploitation. QUTE-F will also ensure the training of the future scientists who will be actively forging this field, thus ultimately guaranteeing the European competitiveness in the long run.

Impact

Quantum technologies can be roughly split into two main categories: either technologies that represent genuine applications of quantum effects (e.g., quantum metrology, entanglement assisted magnetometry and quantum imaging; quantum simulation, computation and communication; spintronics, etc.), or technologies instrumental in developing such devices (e.g., single- and entangled- photon/atom/ion sources and/or detectors; chips for ion and atom traps, etc.). Currently both of them are at an early pre-application stage, but possess a novelty and a richness that suggests an equal or even greater impact than the one of the transistor and the laser.

For instance, quantum metrology and sensors can be used to overcome the classical limits in various kinds of measurements for example in ultra-high-precision spectroscopy, or in procedures such as positioning systems, ranging and clock synchronization via the use of frequency-entangled pulses. Entanglement of atoms in clocks can be used to improve the precision of state-of-the-art atomic clocks, leading to the next generation of GPS. Nanometer sized rods and cantilevers can be used as sensors for the detection of extremely small forces and displacements. Quantum imaging allows increasing the optical sensitivity beyond the wavelength limit with applications in pattern recognition and segmentation in images, and optical data storage where it is now envisioned to store bits on areas much smaller than the square of the wavelength. Sub-micron biomedical imaging can be achieved using frequency entangled photon pairs. Quantum simulators could provide answers to problems that are fundamentally beyond classical computing capacities, such as the study of microscopic properties of materials permitting free variation of system parameters, an accurate description of chemical compounds and reactions, or even find out why free quarks are not found free in Nature. New quantum communication protocols will guarantee the absolute security of all kinds of commercial transactions including the ones performed through the future (quantum) Internet. Quantum computers will allow unprecedented computing power with which the simulation and understanding of complex systems and phenomena (such as protein folding, genome decoding and possibly the simulation of biological systems) might become feasible.

The time-scale varies with the first applications being ready in the short- to mid- term, and the most demanding ones (such as a fully fledged quantum computer) in the long-term (at least 20 years from now). Quantum technologies will thus clearly have important implications for the future European economic competitiveness in areas ranging from wholly new and innovative technologies to improvements in everyday concerns like, e.g., security and privacy of information, data protection, and could have a broader impact on further fields such as health care and energy efficiency. QUTE-F will strive for turning these promises into reality, strengthening at the same time the industrial dissemination of quantum technologies and thus helping in bootstrapping the market for their commercial exploitation.

Integration

For the first time in history, the (European) scientific community has achieved a sufficient control over single quantum degrees of freedom that realistically allow the design of new technologies that fully exploit this power. The planned European efforts that address various aspects of the manipulation of quantum effects (e.g., the FET Proactive Initiatives Quantum Information Foundation and Technologies, NANO-ICT and Molecular Scale Devices System) constitute an excellent basis on which Europe can build a programme specifically aimed at significantly advancing the field of

quantum technologies. QUTE-F aims at merging all these ongoing initiatives, including possibly initiatives addressing spintronics, single nano objects and similar topics, with the final objective of creating the next level of scientific foundation and community. All of the outstanding scientific communities working on quantum technologies (from experimental and theoretical physics to chemistry, nanoscience, computer science and mathematics) will be federated under the common QUTE-F initiative, forming an unprecedented critical mass that would be needed to ensure to Europe a leadership in the IT field for the next decades, that is when the quantum limit on the building blocks of current electronics will be hit. In addition to outstanding scientific communities in all the areas addressed by QUTE- F, such a flagship can rely on an impressive infrastructure, including specialized labs and cleaning room facilities for nanotechnologies that could be used to develop enabling technologies such as atom and ion chips.

QUTE-F builds on fundamental purpose-driven technology-oriented research, which truly is of transformative nature, in the sense of leading to exceptional and unprecedented outcomes (the nurturing of this type of research representing clearly the FET mission). The most radical and promising ideas and approaches to continue the progress granted until now by the fulfillment of the so-called Moore’s law will be thoroughly addressed. For example, on the one hand quantum information processing can exploit coherence effects as a technological resource for applications to find solutions to go beyond Moore’s law (More Than Moore); on the other hand atomic scale systems and devices can use decoherence to make the system behave classically as soon as possible pushing back the quantum wall (More Moore). QUTE-F will seize these opportunities, thereby building a new connection between the science of quantum effects manipulation and quantum enabled and enabling technological applications.

Plausibility

The European and national funding agencies that perform or sponsor research in the field of quantum technologies have looked at the roadmap document “Quantum Information Processing and Communication: Strategic Report on the current status, vision and goals for research in Europe” as a basis for establishing their research agenda. All the steps and timelines identified on the roadmap has been met, and its constant update has turned it into a primary instrument for identifying research gaps, highlighting results, and addressing the challenges that lies ahead. This has allowed many branches of the quantum technologies area to go past the proof-of-principle phase; further advancements however can only be ensured by the integration of the scientific base in order to encompass the full range of quantum information processing from conception to development of devices and from computation and communication to other technological applications of quantum effects. And this can only be achieved through a leap in resources and the long- term commitment coming with it.

In fact, with the limited resource available, the quantum technologies community has been able not only to elaborate a common European research strategy, but also to meet all the timelines identified for the various goals and proof of principle. From this track of record it is to be expected that the leap in invested effort that QUTE-F would ensure, will have an extremely high return on investment, with a new wealth of quantum technologies capable of unprecedented tasks being thought, developed and finally commercialized for the benefit and wellness of the whole European society.

Backing from different experts and/or organizations

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An up-to-date list of industrial stakeholders is available here.

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