Delft University of Technology
Friday, 26 May 2023

Focus session 'Quantum'

Speakers:

- Philippe Bouyer (UvA): Quantum Sensing research line within Quantum Delta NL
- Miriam Blaauboer (TU Delft): The new multidisciplinary *Quantum Information Science and Technology* (QIST) Master program
- Florian Kaiser (Luxembourg Institute of Science and Technology): The prospects of using color defects for carrying quantum information
- Menno Veldhorst (TU Delft): Fault-tolerant quantum computation platforms based on silicon and germanium

Session leader: Sander Otte (TU Delft)

Summary of the session

Quantum mechanics has immensely changed our understanding of nature over the past century. We often don't realize it, but its effects can already be found all around us in everyday technology: from chemistry to lasers to semiconductor electronics. These direct effects of quantum mechanics are collectively referred to as the *First Quantum Revolution*.

We now find ourselves in the age of the *Second Quantum Revolution*: the phase where we start to use our ability to control the quantum degrees of freedom to design and develop fundamentally new forms of technology: quantum computation, quantum cryptography, quantum internet and quantum sensing are just some of the possibilities. It is no surprise that quantum science takes an ever-larger role in our education and in the public debate.

In this focus session we will strike a balance between on the one hand showcasing some of the beautiful quantum research that happens in and around the Netherlands and on the other hand highlighting recent initiatives that help shape the landscape for fostering quantum education and innovation.

To start with the latter, we are happy that Philippe Bouyer (UvA) has agreed to speak about his role as leader of the Quantum Sensing research line within Quantum Delta NL. On the topic of education, Miriam Blaauboer (TU Delft) will talk about the new *Quantum Information Science and Technology* (QIST) Master program that she is leading, which will start in Delft this coming September.

These contributions will be complemented by two research talks. First, Florian Kaiser from the Luxembourg Institute of Science and Technology (LIST) will speak about the prospects of using color

defects for carrying quantum information, in particular focusing on exciting developments in silicon carbide. Finally, Menno Veldhorst (TU Delft) will talk about his efforts to develop fault-tolerant quantum computation platforms based on silicon and germanium.

Abstracts:

Philippe Bouyer (UvA): Quantum Sensing research line within Quantum Delta NL

The remarkable success of atom coherent manipulation techniques has motivated competitive research and development in precision metrology. Matter-wave sensors – accelerometers, gyrometers, gravimeters, clocks, magnetometers ... – based on these techniques are all at the forefront of their respective measurement classes. Atom inertial sensors provide nowadays about the best accelerometers and gravimeters and allow, for instance, to make the most precise monitoring of gravity or to device precise tests of general relativity.
The outstanding developments of laser-cooling techniques and related technologies allowed the operation of these sensors outside the laboratory in boats, planes, rockets, the space station … They are now reaching a point where they can be commercially available, and operated to monitor water resources, volcanoes, …I will introduce the recent progress in this field, and present the perspectives and opportunities arising from the recent initiatives, such as the Quantum Delta KAT-3 catalyst program.

Miriam Blaauboer (TU Delft): The new multidisciplinary *Quantum Information Science and Technology* (QIST) Master program

Quantum Science and Technology is a rapidly developing field at the intersection of physics, mathematics, electrical engineering and computer science. How do you educate students so that they are best prepared and can successfully contribute to the growing quantum-technological industry? In this talk I will introduce the new multidisciplinary master programme on *Quantum Information Science & Technology (QIST)* that Delft University of Technology and Leiden University have developed together and that will start in September 2023. I will also briefly discuss related programmes that are being developed in The Netherlands and abroad, at university, applied university ('hbo') and vocational college ('mbo') level.

Florian Kaiser (Luxembourg Institute of Science and Technology): The prospects of using color defects for carrying quantum information

Color centers are defects in solid state crystals, which constitute of highly coherent optically active electron spins. These implement atom-like two-level systems, in which the built-in electron spin is a stationary quantum system, and the photon emission provides an interface to the surrounding for control and readout.

These features have allowed to implement a teleportation quantum network [1], and quantum computing with a few 10 nuclear spin qubits, both in Delft [2].

In this talk, we outline a pathway towards upscaling the technology by integrating color centers into a CMOS compatible semiconductor platform, silicon carbide (SiC). Our latest work investigated silicon

vacancy color centers in SiC, for which we showed state-of-the-art spin-optical coherences [3], and the possibility to perform optical interference experiments in the perspective of quantum networks [4]. Crucially, we and other groups recently demonstrated that the excellent spin-optical properties of silicon vacancy centers remained (almost) unaltered after integration into scalable nanophotonic structures [5-7]. From here on, we detail the next steps to be made towards industry processing of quantum chips based on color centers in SiC.

Bibliography:
[1] S.L.N. Hermans et al., Nature 605, 663 (2022)
[2] M.H. Abobeih et al., Nature 576, 411 (2019)
[3] R. Nagy et al., Nat. Commun. 10, 1954 (2019)
[4] N. Morioka et al., Nat. Commun. 11, 2516 (2020)
[5] C. Babin et al., Nat. Mater. 21, 67 (2022)
[6] D. Lukin et al., Phys. Rev. X 13, 011005 (2023)
[7] D. Lukin et al., Nat. Photon. 14, 330 (2020)

Menno Veldhorst (TU Delft): Fault-tolerant quantum computation platforms based on silicon and germanium

Quantum computers may be able to provide answers to problems that are classically impossible to address. However, building quantum computers is a formidable task and it may require millions of qubits that can interact with each other in a precise manner. Our approach toward scalable quantum technology is based on the transistor, the most replicated structure made by mankind. We define qubits on the spin states of electrons and holes in silicon and germanium quantum dots.

In this talk I will present the challenges in the opportunities in the field and highlight some of our results. These include the ability to confine individual electrons and holes and to use their spin states as qubits. We find that qubit operations can be with errors less than 1 in 10.000, and we can couple spin qubit to construct small quantum processors comprising four qubits. Furthermore, I will discuss our vision toward scaling to larger systems, motivated by experimental results and proven scalable concepts.