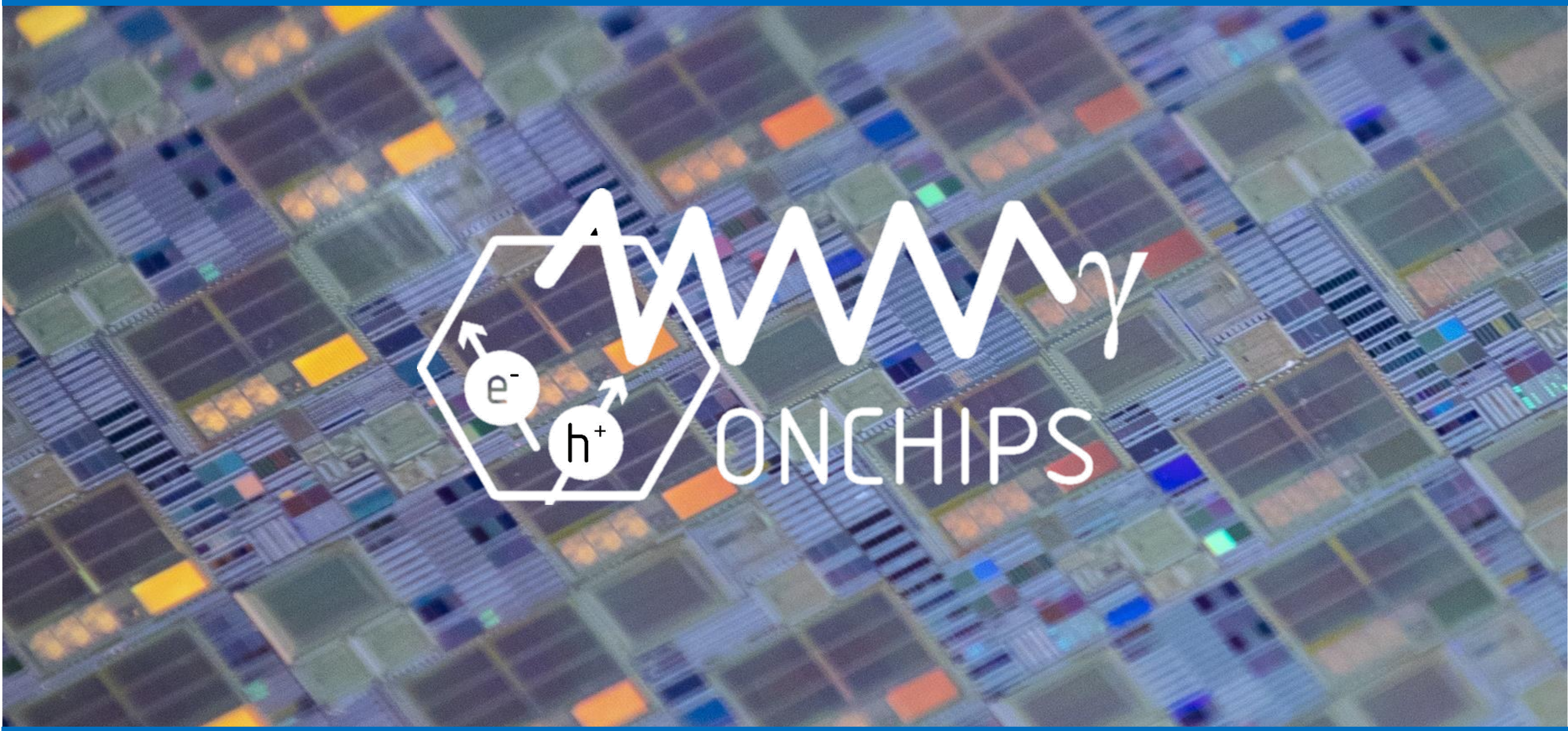


# ONCHIPS 1st year bulletin

December 2023

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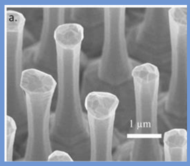

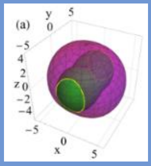

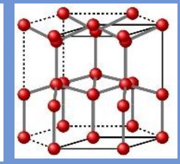

### Highlights from the first year of ONCHIPS

**- Note from coordinator Floris Zwanenburg & project manager Gabi Maris, University of Twente**

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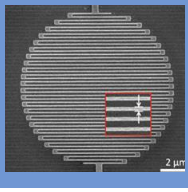


### Superconducting nanowire single photon detector system

**- by Eitan Oksenberg, research engineer at Single Quantum**

The ONCHIPS project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101080022

# Interplay of electronics and photonics for next generation of quantum devices -

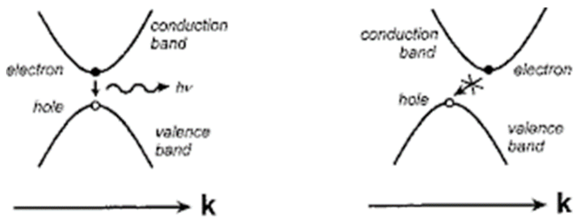
Press release introducing ONCHIPS – Wiebe van der Veen, science communication officer, University of Twente

For building quantum computers, making use of both electronics and photonics technologies on one and the same chip is promising. Thanks to silicon technology that we know well from today's electronic devices, quantum devices can be scaled up to larger systems. Another advantage is that they could be better protected from influences from the outside world. Unfortunately, light and silicon are not the best friends. That is, unless you add germanium to it in a fully new hexagonal crystal structure. In that case, electronic and photonic quantum bits can indeed be combined. The European research project ONCHIPS, led by the University of Twente, works on this 'best of both worlds' technology.

Making predictions about the best manufacturing technology for quantum computers is not easy: all approaches have their pro's and con's. Some of the quantum bits (qubits) are quite large, need extreme cooling and are very sensitive to their surroundings: there's only a short time in which you can benefit from their specific quantum properties. Others are more robust and less sensitive to disturbances, but can't easily be upscaled to hundreds or even thousands of qubits. What you, in fact, would like to do, is benefit from the industrial scale and highly standardized processes used for 'regular' semiconductor chips (CMOS). In the combination of silicon and germanium, recently invented, many of the advantages potentially may come together on one chip. This material, having a hexagonal crystal structure, was named breakthrough of 2020 by Physics World. The inventors of the material, from the Technical University of Eindhoven, are members of the ONCHIPS consortium.

The hexagonal structure of silicon-germanium has a major advantage: it enables silicon to send and absorb light. In this way, photons can be coupled to electrons that owe their quantum qualities to their 'spin': the direction in which they toll around their own axis.

This opens whole new possibilities, for example in combining the superior quantum communication properties of photons and the local quantum calculation power of electron spins. And all this on the same CMOS electronics chip. One of the challenges to be addressed is creating the hexagonal structure in an easier way than is feasible right now. What silicon on its own cannot do, and the combination of silicon and germanium can, is associated with the 'direct band gap' that is created in this way. An electron can directly recombine with a hole across the band gap and send out a photon by doing so. Silicon in itself does not have this direct 'crossing': the top of the valence band and bottom of the conduction band are not directly above each other, so silicon in itself is not a good light source.




*Energy levels, bands, at which an electron can exist. The conduction band is responsible for conducting electric current. In between the conduction band and the valence band, there are forbidden energy levels - the so-called band gap. An electron may cross this bandgap, releasing a photon, in the case of the direct band gap (left). In the situation on the right, the electron cannot simply cross because of the indirect band gap.*

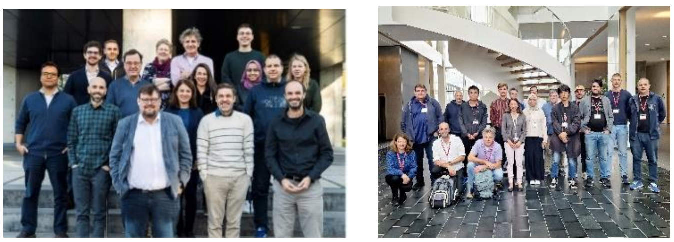
The 'best of both worlds' approach may lead to exciting new perspectives in quantum computing, although it is still a challenging task, project leader Professor Floris Zwanenburg says. "*Each of our ideas have never been realized in this way. The ambition is understanding more about the best conditions for crystal growth. Furthermore, we have to create the first spin qubits and shape interfaces of these spin qubits and photons. Thorough understanding of the germanium silicon crystal structure is key.*" And all that with the future integration of electronics and photonics in mind, on one and the same silicon platform.

**ONCHIPS partners: University of Twente, TU Eindhoven, TU München, CNRS Paris - Saclay, Single Quantum, Universität Konstanz and Budapest University of Technology and Economics**

# Highlights from the first year of ONCHIPS

Note from coordinator Floris Zwanenburg & project manager Gabi Maris, University of Twente

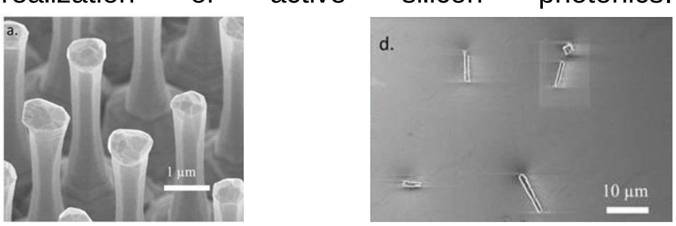
ONCHIPS kicked off on 14-15 November 2022 in an inspiring meeting at the University of Twente. The consortium aligned its ambitions and challenges and laid the fundamentals for an efficient collaboration. Updates on the latest developments and plans are regularly discussed in our progress meetings. Our CNRS partner hosted the consortium meeting in Paris-Saclay in October 2023, an excellent occasion for fruitful discussions and informal exchanges. The first year has been marked as well by the building of an enthusiastic and closely collaborative team of Ph.D. students and postdocs and by 3 publications.



*ONCHIPS kick-off meeting in Enschede (November 2022) and consortium meeting in Paris-Saclay (October 2023).*

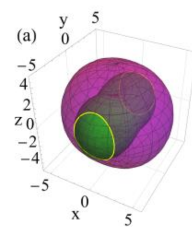
**Publications**

In a recent article, authors from TU Eindhoven report on polarization properties of hex-SiGe nanowires from photoluminescence spectroscopy experiments. The simulations investigating the influence of the dielectric contrast of nanowire structures confirm the polarization selection rules of the lowest optical band-to-band transition in hex-SiGe. The understanding of the selection rules is important for creating light detection devices from hex-SiGe and for developing silicon-based light sources for the realization of active silicon photonics.



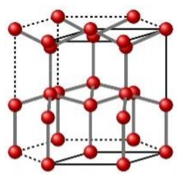

*Scanning electron microscopy images of (a) as-grown hex-SiGe and (b) of the nanowires transferred to the substrate.*

A theoretical work from TU Budapest [2] shows that the spin-orbit-coupled double quantum dots can be categorized in six classes determining the physical characteristics of the dot in transport, spectroscopy, coherence measurements, as well as in qubit control, shuttling, and readout experiments. The spin physics is highly simplified whenever the external magnetic field is pointing to "magic directions". The number of such special directions is determined by the class. These results represent an important step toward the precise interpretation and efficient design of spin-based quantum computing experiments in materials with strong spin-orbit coupling.




*Dimensionless Zeeman splitting of the two dots (violet and green). The 'magic loops' (yellow closed curves) in a spin-orbit-coupled double quantum dot are defined as the intersection curves of the two surfaces.*

A preprint manuscript from University of Konstanz [3] presents a $k \cdot p$ model that captures important features of the 2H-Ge and shows that physical parameters like the g-factor of the electron and holes can be found using the Hamiltonian at hand. In the future the authors will investigate how the optical selection rules are affected by the symmetry breaking caused by the defects present in real samples.



*Hexagonal diamond (2H) structure (dashed lines). The atoms (red balls) are arranged in a hexagonal stacking. The gray lines represent the bonds between atoms. Solid black lines indicate the unit cell.*

**Conferences and outreach activities**

The consortium shared the project's objectives and its first results with our stakeholders through participation at conferences and events such as the Nanowire week (Atlanta), European Quantum Technology Conference (Hannover) and the Gordon Godfrey Workshop (Sydney). As part of our effort to reach out and educate non-scientists about our work, we developed introduction and tutorial videos and participated in various outreach activities as the Girls' Day, high school visits, lab tours and trainings.

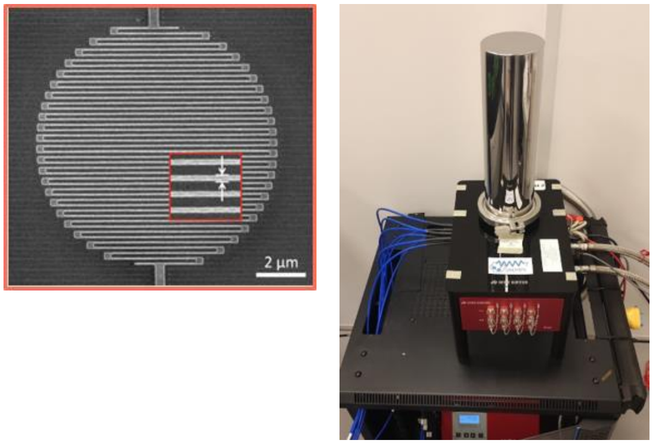
[1] M.A.J. van Tilburg *et al*., J. Appl. Phys. 133, 065702 (2023).
[2] A. Sen *et al*., Phys. Rev. B 108, 245406 (2023).
[3] Y. Pulcu *et al*., https://arxiv.org/abs/2310.17366 (2023).

# Superconducting nanowire single photon detectors system

- by Eitan Oksenberg, research engineer at Single Quantum

To unleash the potential of the exciting hex-$Ge_xSi_{1-x}$ material platform, including spin-photon interfaces, we develop new, dedicated supporting technologies. More specifically, light detection in the 2.3-3.4 µm range is notoriously challenging. Standard Si-based detectors are completely usable in this wavelength range while off-the-self alternatives for mid-IR detection such as i:Sb impurity bands, HgCdTe, and InGaAs, suffer, generally speaking from low efficiency, high dark count rates, and poor time resolution compared with visible detection counterparts. One fundamental reason for the underperforming mid-IR detection technologies is that mid-IR photons carry less energy and therefore are intrinsically more challenging to detect compared with visible and near-IR photons.

Magneto-optical measurements will experimentally determine the electron and hole g-factors and intrinsic spin relaxation dynamics in hex-Ge and hex-$Ge_xSi_{1-x}$. To do so, especially with nanoscale emitters, a detection system with superior performance compared to available alternatives must be developed. More specifically, working with standard silica-based fibers provides advantages. Superconducting nanowire single-photon detectors (SNSPDs) have emerged as the gold standard in light detection in the visible to near IR range offering approaching unity detection efficiencies, unprecedented timing precision, and low dark count rates. However, this amazingly high level of performance has been achieved so far mostly at wavelengths below 2 µm. Extending the spectral window of high-performance SNSPDs into the mid-IR is expected to have far-reaching implications beyond characterizing hex-GexSi1-x in astronomy, environmental monitoring, LIDAR and fundamental studies of molecular behavior.




*(a) Scanning Electron Microscope image of a superconducting single photon detector (SNSPD). The detector consists of a thin, superconducting wire formed into a meander structure for optimal coupling to the mode of a single mode infrared optical fiber. (b) Image of the 2.3 µm ONCHIPS SNSPD system.*

To experimentally determine the electron and hole g-factors and intrinsic spin relaxation dynamics in hex-Ge and hex-GeSi, tailored magneto-optical measurements will be carried out at our partner at Technical University of Munich. These polarization-resolved photoluminescence measurements rely on efficient and fast detection of the emitted light from hex-GeSi structures in the 2.3-3.4 µm range (depending on the stoichiometric composition of the hex-GeSi alloys). We have designed superconducting nanowire single-photon detectors with optimized superconducting film, detector geometry, and optical cavity to achieve superior light detection at 2.3 µm. A single-photon detection system has been built, benchmarked, and shipped to our partner at Technical University of Munich to provide adequate detection efficiency for initial hex-GeSi bulk measurements. Future upgrades would provide unprecedented single-photon detection capabilities for realizing the challenging characterization of spin dynamics in hex-GeSi nanowires and quantum dots.