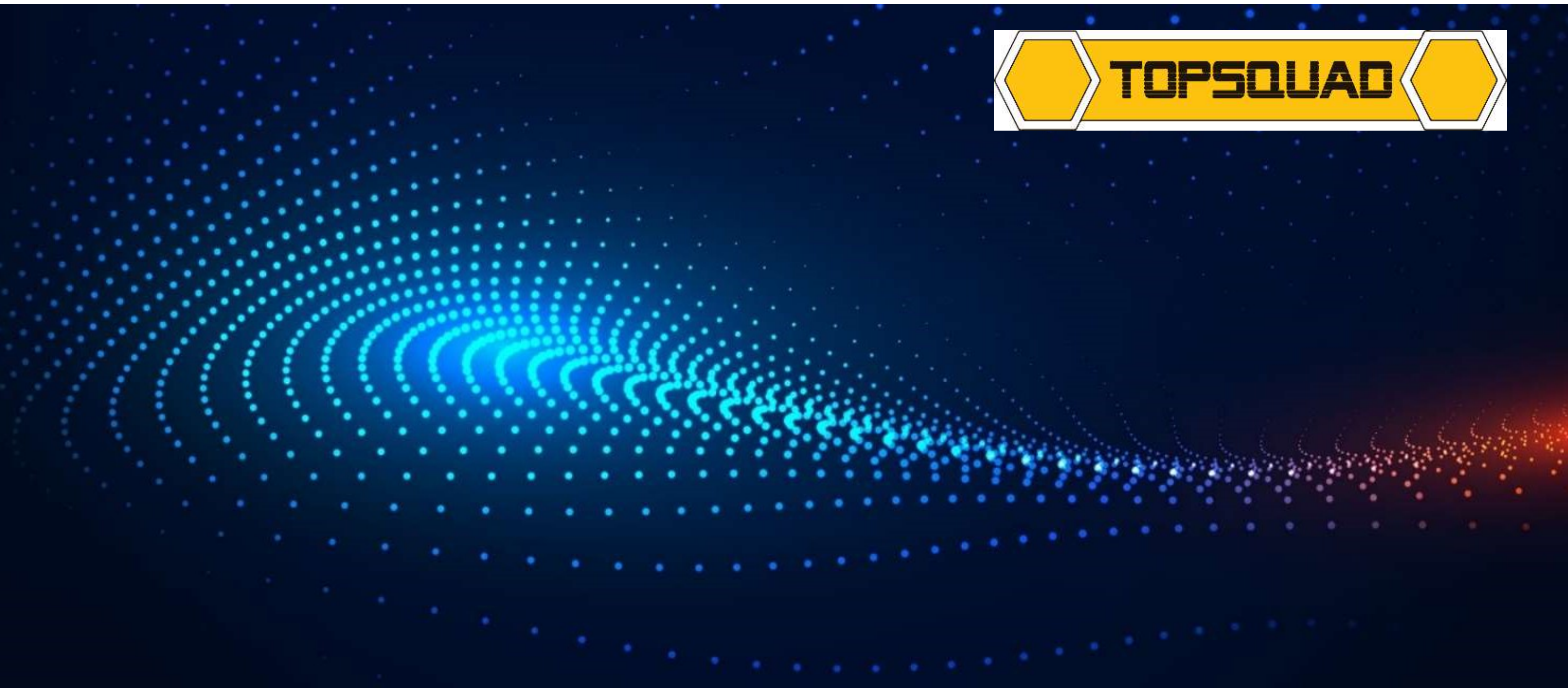
THE TOPFORCE



The official bulletin of TOPSQUAD January 2021

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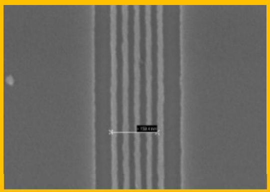
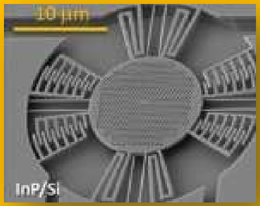


Gate Tunable Spin-orbit Coupling and g-factors
Dominik Zumbühl's group highlights the relevance of Gate Tunable Spin-orbit Coupling and g-factors in TOPSQUAD



Spotlight on nanoPHAB
Our partner, Francesco Pagliano highlights the unique aspects of his SME

The TOPSQUAD project has received funding from the European Union's Horizon 2020 research and innovation programme. Grant agreement: 862046. Funded under: H2020-EU.1.2.1. - FET Open.

A TOP-start for TOPSQUAD

- by project coordinator, Floris Zwanenburg (UT)

TOPSQUAD has gotten off to a flying start with fantastic results from a smoothly cooperating consortium. We aligned our ambitions and challenges at the **kick-off meeting in February 2020** in Twente. The first year has delivered publications in the journals Nature Reviews Materials, Nano Letters and Advanced Materials. The latter concerned the self-controlled growth of highly uniform Ge/Si hut wires for scalable qubit devices, which is at the heart of TOPSQUAD. In the same system we observed the zero-field splitting of heavy-hole states in quantum dots. Our Ge-Si nanowire experiments resulted in topological Josephson junctions with a hard superconducting gap, important for the observation of topological states. On top of that, we have demonstrated strong spin-orbit interaction and g-factor renormalization of hole spins these nanowires, crucial to open the topological gap. The recent success on the selective growth of in-plane Ge/Si nanowires on silicon substrates is promising for scalability. The quality of these wires will be assessed in transport measurements in the near future. All these results bode well for our ambition to demonstrate that strongly interacting holes in Ge wires with a Si shell are a compelling platform for scalable and topologically protected quantum bits.

The first year was marked as well by the building of an **enthusiastic and closely collaborative team of Ph.D’s and postdocs**. In addition to the strong scientific commitment, the entire consortium is actively involved in outreach activities including introduction and tutorial videos and assuring a strong visibility and awareness of the project. Our **introduction video stood out in a contest organized for the EIC Pathfinder FET projects** and has been featured during the European Commission’s Research and **Innovation Days 2020**. We are highly motivated to continue this path and to further expand our communication activities in the years to come.

The Kick-off meeting of TOPSQUAD on February 13 and 14 2020 at the University of Twente assured a solid start of the project. During the first day of the meeting the coordinator and the work packages leaders presented the project’s objectives, deliverables, and tasks. The presentations were accompanied by inspiring discussions of all the consortium members. The presentations of the roles and the interactions for the different tasks stressed on the importance of frequent internal communications and close collaborations between the partners.

In the spotlight - 1: Gate Tunable Spin-orbit Coupling and g-factors

- **by the group of Dominik Zumbühl**

In order to observe Majorana Fermions, one requires a platform that combines a high g-factor, strong spin-orbit coupling and strong hole-hole interactions. For TOPSQUAD, we aim to demonstrate these key properties in Ge/Si core/shell nanowires, which are highly promising due to the presence of a particularly strong direct Rashba spin-orbit interaction that can be controlled by applying an electric field to the nanowires. In a recent work of our research group which focused on a **gate-tunable spin-orbit switch** in Ge/Si nanowires [1], we were able to drive a Ge/Si hole spin qubit and strongly tune its properties by changing the voltage applied to the center gate of the device. As part of this work, we were also able to extract the g-factor and the spin-orbit length -- a measure for the strength of spin-orbit interactions -- in dependence of the center gate voltage (Fig. 1). We have extracted extremely small spin-orbit lengths down to 3 nm (assuming a heavy-hole mass), demonstrating exceptionally strong spin-orbit coupling.

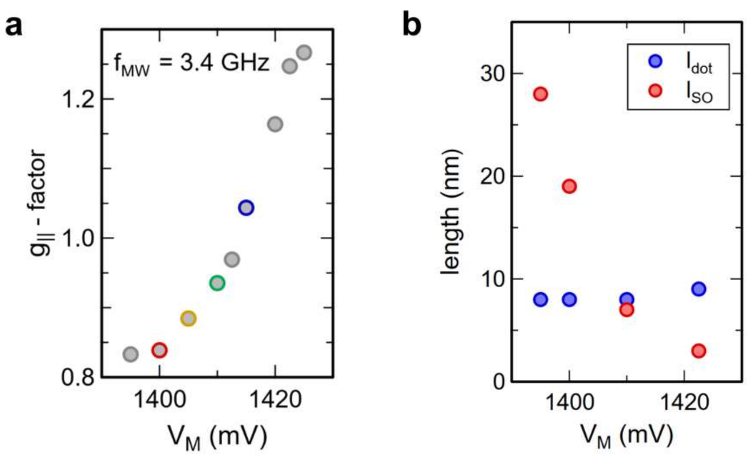


Fig. 1: Dependence of the g-factor (a) and the spin-orbit length (b, red circles) on the center gate voltage. [1]

To gain further control and knowledge over our nanowire devices, we aim to reach the regime of the last hole in transport. To do so, we are currently fabricating devices with a reduced bottom gate pitch (periodic gate distance) of 40 nm (Fig. 2), on which the nanowires are then deposited using a micromanipulator. For better control over the electric field, we are also aiming to add top gates to future devices. We plan to investigate the singlet-triplet anti-crossing and hole-hole interactions in the improved devices.

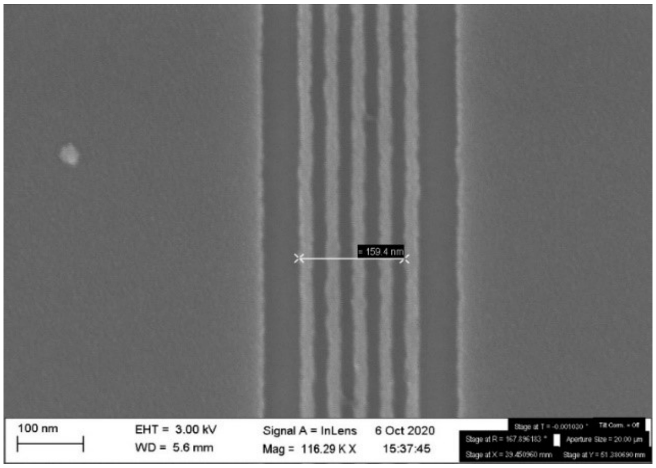


Fig. 2: Scanning electron micrograph close-up of our devices with a bottom gate pitch of 40 nm.

Source:

[1] F. Froning, L. Camenzind et al.: Ultrafast Hole Spin Qubit with Gate-Tunable Spin-Orbit Switch, Nature Nanotechnology (2021).

Read more about our research and interest at : https://zumbuhllab.unibas.ch/en/home/

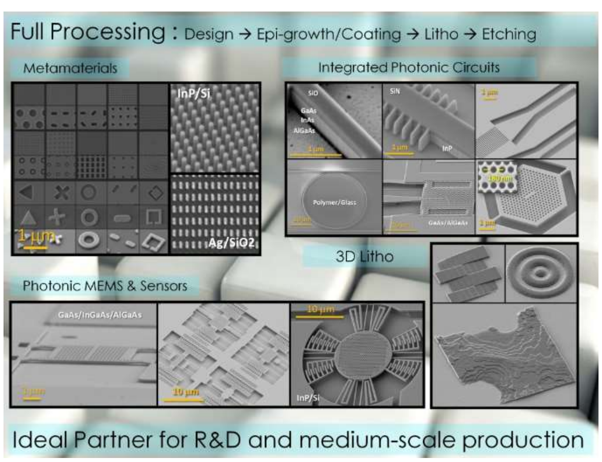
In the spotlight - 2: nanoPHAB B.V.

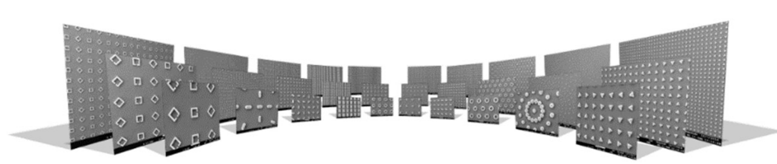
- by Francesco Pagliano

nanoPHAB B.V. is an advance pure play foundry in the field of nanophotonics, able to serve international Academic and Commercial customers with a strong Research and Development approach, providing them with custom oriented nanofabrication and prototyping up to middle scale production. Many years of expertise and a broad portfolio of technologies in a wide range of material platforms make nanoPHAB B.V. a unique player in the semiconductor industry recognized for its high-quality services, flexible customized process development, prototyping and scale-up, as well as its cost effective and fast time to market capabilities. The customers of nanoPHAB can benefits from tailored optimizations and developments and fast reaction times, without the constraints on material type, wafer size, minimum quantity, and long waiting list typical of shared general purpose fabrication campaign. An average complexity process can be design, set up and accomplished in an average time of 1-3 months instead of the usual 10-24 months of a generic integration foundry. Being nanoPHAB a pure-play foundry is an added value for the customers since they can fully retain ownership of their own intellectual properties, being able to introduce new products on the market without the hassle of extra IP's managing.

The unique benefits of nanoPHAB in a nutshell

- Long nanofabrication and nanophysics expertise.
- Nanotechnologies and nanofabrication made cost-effective and accessible using cutting edge technology and dedicated full fabrication facilities.
- Wide portfolio of already developed fabrication processes to speed up custom development.
- Custom, flexible and tailored development, optimization and prototyping.
- Many materials available from III-V, II-IV, standard semiconductors, to dielectrics, metals and polymers.
- From single wafer prototyping to several wafers medium-scale production.
- No minimum quantity required and open available processing sizes from 10 mm x 10 mm to 4-inch.
- Fast reaction time from 2-3 weeks to 2 months.
- Faster time to publication for Academic groups, faster time to market for Companies.
- Pure Play Foundry so the intellectual properties remain with the customers





Find out more about us on: http://www.nanophab.com/nanofabrication

Publications

1. Froning, F. N. M. *et al.* Strong spin-orbit interaction and *g*-factor renormalization of hole spins in Ge/Si nanowire quantum dots. (2020).
2. Froning, F. N. M. *et al.* Ultrafast Hole Spin Qubit with Gate-Tunable Spin-Orbit Switch. Nature Nanotechnology (2021).
3. Gao, F. *et al.* Site-Controlled Uniform Ge/Si Hut Wires with Electrically Tunable Spin–Orbit Coupling. *Adv. Mater.* **32**, 1906523 (2020).
4. Katsaros, G. *et al.* Zero Field Splitting of Heavy-Hole States in Quantum Dots. *Nano Lett.* **20**, 5201–5206 (2020).
5. Ridderbos, J. *et al.* Hard Superconducting Gap and Diffusion-Induced Superconductors in Ge–Si Nanowires. *Nano Lett.* **20**, 122–130 (2020).
6. Scappucci, G. *et al.* The germanium quantum information route. (2020) doi:10.1038/s41578-020-00262-z.
7. Aggarwal, K. et al. Enhancement of Proximity Induced Superconductivity in Planar Germanium. (2020).

TOPSQUAD in numbers

In year 1, TOPSQUAD has achieved several milestones, despite the hindrances faced by all our partners due to the ongoing COVID-19 pandemic.

- 6 partner universities, institutes, and SME's
- 3 live conferences attended
- Spanning across 3 EU countries
- 7 deliverables submitted this year
- 7 publications accepted or in review
- More than 2000 views of project website
- 6 training sessions and education videos
- More than 250 followers on social media

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the bulletin of TOPSQUAD

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Topologically protected and scalable quantum bits

www.top-squad.eu