THE TOPFORCE ISSUE #3

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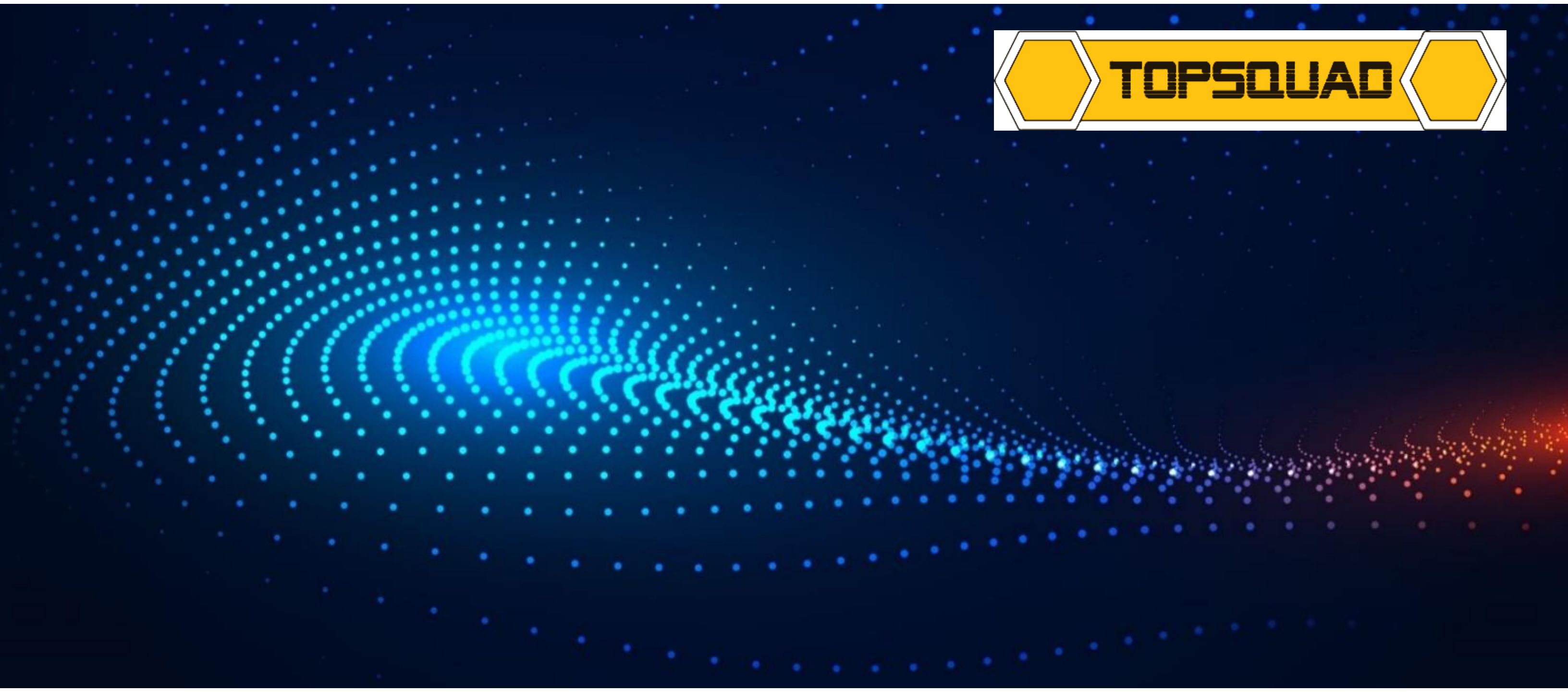

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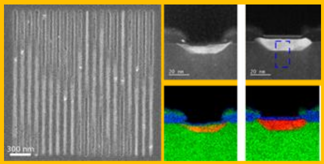

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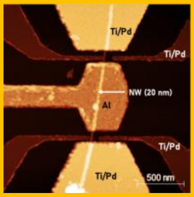

New contacting method allows creation of superconducting island devices

by Joost Ridderbos, University of Twente

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On the way to a TOP finish for TOPSQUAD

- by project coordinator Floris Zwanenburg

In the past year, TOPSQUAD has been productive and collaborating efficiently with regular interactions. Our physical work package meeting in Basel in May 2022 deserves specific mention: meeting in real life was very dear to our consortium after a long period of online meetings and absence of physical conferences. Scientifically we have made significant progress and disseminated our work through conferences, workshops, publications.

TOPSQUAD work package meeting in Basel, May 2022.

Our partner at Institute of Science and Technology Austria has realized Josephson field-effect transistors in the Ge quantum wells, the new platform studied in TOPSQUAD, promising for scalability and suitable for investigating topological superconductivity. In the out-of-plane Ge-Si nanowire system we have attained high g-factor values and strong hole-hole interactions, and we have achieved gate-tunable supercurrent and studied the proximity effect as function of protective shell thickness. We have made some progress towards the search for the fractional Josephson effect which arises in topological Josephson junctions with Majorana end states.

Our partners at TU Eindhoven and nanoPHAB made progress in the selective-area growth of in-plane Ge/Si core shell nanowires and accomplished Molecular Beam Epitaxy (MBE) growth of nanowires with Ge cores and a Si shell showing anisotropic strain. Further investigations opening paths to applications will be pursued in the coming period.

Our SME partner BASPI has enjoyed collaborating with some of the world's top experts to develop instrumentation matching the needs of TOPSQUAD's challenging experiments. As a result of this collaboration, BASPI has realized prototypes for the low-noise high-resolution DAC voltage source and the voltage preamplifier.

Our consortium continued to reach out to many non-scientists with both physical and online interactions. We have developed online tutorial videos, on e.g. nanowire growth by TU Eindhoven, and on superconductivity by University of Basel. The partners have been actively involved in several events on women in science and technology, such as the NCCR women campaign in Basel, and a high school girls day in Twente. Dominik Zumbühl (University of Basel) has been interviewed several times for newspapers and television. Floris Zwanenburg (University of Twente) has given an outreach talk and given a lab tour to secondary school pupils visiting the University of Twente in March 2022. Zwanenburg and Alexander Brinkman (University of Twente) both performed for a wide audience at the Mañana Mañana festival in June 2022.

Floris Zwanenburg at the Mañana Mañana festival (June 2022).

For more news, visit our website: https://top-squad.eu

More flexibility and control of the nanowire growth

- by Orson van der Molen, TU Eindhoven

Many of the predicted promising properties of Ge/Si core/shell nanowires have been verified via quantum transport experiments. However, these experiments were carried out using only out-of-plane vapor liquid solid (VLS) grown nanowires [1-2]. Because they need to be transferred from their vertical orientation on the growth substrate, they are not scalable and limit the complexity of the devices to single nanowires. Therefore, an alternative in-plane selective area growth (SAG) process is being developed. Previously, metalorganic vapor phase epitaxy (MOVPE) was used. This year, a switch was made to molecular beam epitaxy (MBE). This enables growth of nanowires with more flexibility and control over temperature and growth rate. Additionally, the system produces samples of much higher purity, thanks to the ultra-high vacuum in the growth chamber.

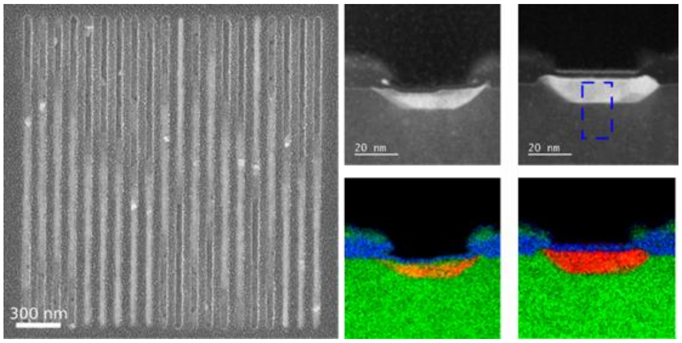

Figure 1 *MBE grown Ge/Si core/shell nanowires.*

[1] S. Conesa-Boj, A. Li, S. Koelling, M. Brauns, J. Ridderbos, T. T. Nguyen, M. A. Verheijen, P. M. Koenraad, F. A. Zwanenburg, and E. P. A. M. Bakkers, Nano Letters 2017 17 (4), 2259-2264

[2] Froning, F.N.M. et al. Ultrafast hole spin qubit with gate-tunable spin–orbit switch functionality. Nat. Nanotechnol. 16, 308–312 (2021).

Using silicon and germanium e-gun evaporators in an MBE system, in-plane core/shell wires have been grown, but the composition of their cores remains a challenge. The growth temperatures required for selective growth led to significant interdiffusion between the cores and the substrate, reducing the Ge content to 60%. The homogeneity also remains a challenge. The wire thickness can vary up to 75% over the length of single wires. Geometric phase analysis was applied to the scanning transmission electron microscopy (STEM) data enabling the extraction of the local lattice constants (Fig. 2). This analysis reveals anisotropic strain exceeding 1%, achieving a major milestone, as anisotropic strain enables the high mobilities and strong spin orbit interactions that make this material platform appealing for quantum applications. The source of the inhomogeneities has been identified and low temperature growth has been explored. By improving processing and adjusting the temperatures, the remaining challenges will be tackled leading to a new generation of quantum materials.

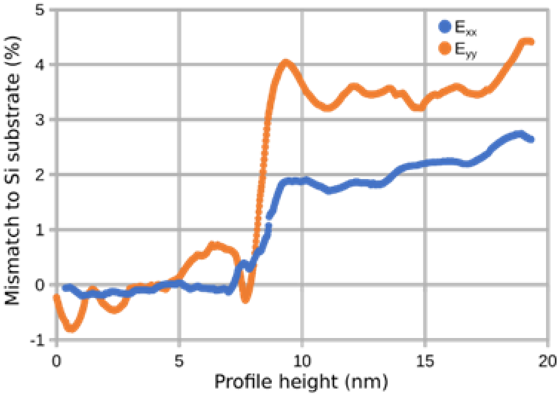

Figure 2 *The anisotropic strain in the blue rectangle area of Fig.1 characterized by the difference in horizontal and vertical lattice constants.*

Read more about our research and interest at:

https://www.tue.nl/en/research/research-groups/advanced-nanomaterials-devices/

New contacting method allows creation of superconducting island devices

- by Joost Ridderbos, University of Twente

A new method of contacting the Ge-Si nanowires was developed at the University of Twente together with the University of Basel, which allowed us to create a new type of devices. In contrast to previous methods, the Si shell and Ge core remain intact by introducing a normal metal interlayer between the Ge-Si nanowire and the superconducting Al electrodes, which was confirmed by an energy dispersive X-ray analysis by the team at the Eindhoven University of Technology. Since the intact Si shell has no free charge carriers and now acts as a barrier, we can now control the superconductor-semiconductor coupling by using nanowires with a different Si shell thickness. This obtained control over the coupling is an essential development that allows us to induce a finite superconducting gap while we retain the semiconductor spin-orbit interaction and Landé g-factor that are needed to reach the topological phase. To be able to exploit this newfound expertise we are currently focusing our efforts to move from Josephson junction devices to superconducting island devices. This architecture will be used to perform tunnel spectroscopy at both ends of the island, to investigate the Andreev states and the induced superconducting gap and, if they exist, to probe zero-bias conductance peaks. In addition, we are developing ultra-thin superconducting films that can withstand much higher magnetic fields so that we can reach higher Zeeman energies before we lose superconductivity.

For the Ge quantum wells investigated at the Institute of Science and Technology Austria, it was demonstrated that superconductivity can be reliably induced. In this architecture, the top GeSi spacer controls the magnitude of the superconductor to semiconductor coupling and shows a similar level of control as is obtained for the GeSi nanowires devices.

For both the GeSi nanowire devices, as well as for the Ge quantum wells, all developments are now culminating towards experiments with magnetic fields. We therefore have good hopes to obtain fruitful results in the last year of the project.

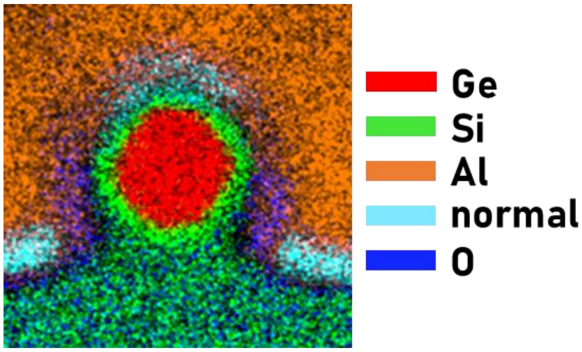

Figure 1 *Energy dispersive X-ray analysis of a Ge-Si nanowire device cross-section. Al remains well separated from the Si shell and the Ge core of the nanowire.*

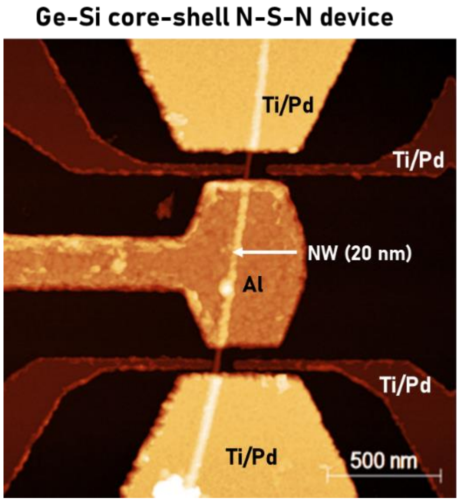

Figure 2 *Superconducting island device with cutter gates at the top and bottom of the island.*

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