communications physics

MEETING REPORT

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When matter and information merge into "Quantum"

Despite only being its 3rd edition, the QUANTUM MATTER international conference & expo (QUANTUMatter) has already become a reference event for communities involved in the study of quantum materials, quantum information and quantum technologies at large. This article reports on this meeting, which took place in Madrid, in June 2023, with 420 participants and keynote speakers from all areas of quantum technologies and quantum materials.

In recent years, major advances in the fabrication and integration of a large number of quantum bits (qubits) have brought quantum computers closer to reality offering new tools for researchers, engineers and students to engage in the emerging quantum computing world. Demonstrations of the long-range transfer of quantum information combining various possible hardware platforms and the joint progress in quantum software are paving the way towards revolutionary technologies in quantum communication, quantum memory (internet) and sensing.

Adding to this already prolific landscape, the new generation of quantum materials carries the promise to marry topological physics with strong correlations. The integration of such materials in quantum technologies advances the forefront of quantum technologies and supports the development of highly energy-efficient computing devices, advanced metrology platforms and topological quantum qubits as alternatives for error-resilient quantum computing protocols.

However, pioneering a rapidly evolving field means advancing without a compass and the purpose of QUANTUMatter is to provide directions in both the known and the unknown to push the exploration further without getting lost.

QUANTUMatter2023 united 420 participants from all over the world (30 countries represented) during a three-day event, during which plenary sessions were complemented by parallel workshops on focused topics (quantum matter, quantum information theory, etc.) and a one-day industrial forum, organised with Quantum Spain, a national initiative with a strong focus on developing a quantum computing ecosystem in Spain[1]. As shown in Fig. 1, the conference was attended by many participants, and it figured many and very relevant contributions from keynote and invited speakers in the fields of quantum technologies and quantum materials.

Starting with an enlightening presentation by Prof. Daniel Loss (Basel University, Fig. 2) on the developing field of semiconductor spin qubits for quantum computation, the conference hosted a series of plenary talks covering a large variety of qubit platforms (superconducting qubits, programmable atomic arrays) and materials (silicon and germanium-based planar heterostructures, hybrid semiconductor/superconductor systems), with an emphasis on their large-scale integration[2]. The questions and challenges faced in optimising the design of materials and interfaces to integrate performant qubits at large-scale have been widely discussed during the conference. The discussion highlighted the drawback of a rapidly evolving field attracting researchers and companies with different backgrounds and aims, namely the lack of a systematic link between growth, characterisation and simulation of materials and devices. Establishing the key building blocks for quantum technology and identifying the most promising avenues toward scalable quantum information processing is of paramount importance to accelerate further progress.

Prof. Mikhail Lukin (Harvard University, USA) provided a fascinating plenary talk on the exploration of new scientific frontiers with programmable Rydberg atom arrays, including the solution of the maximum independent set problem with quantum optimisation, quantum simulation of strongly correlated molecules, as well as the control of entanglement of many

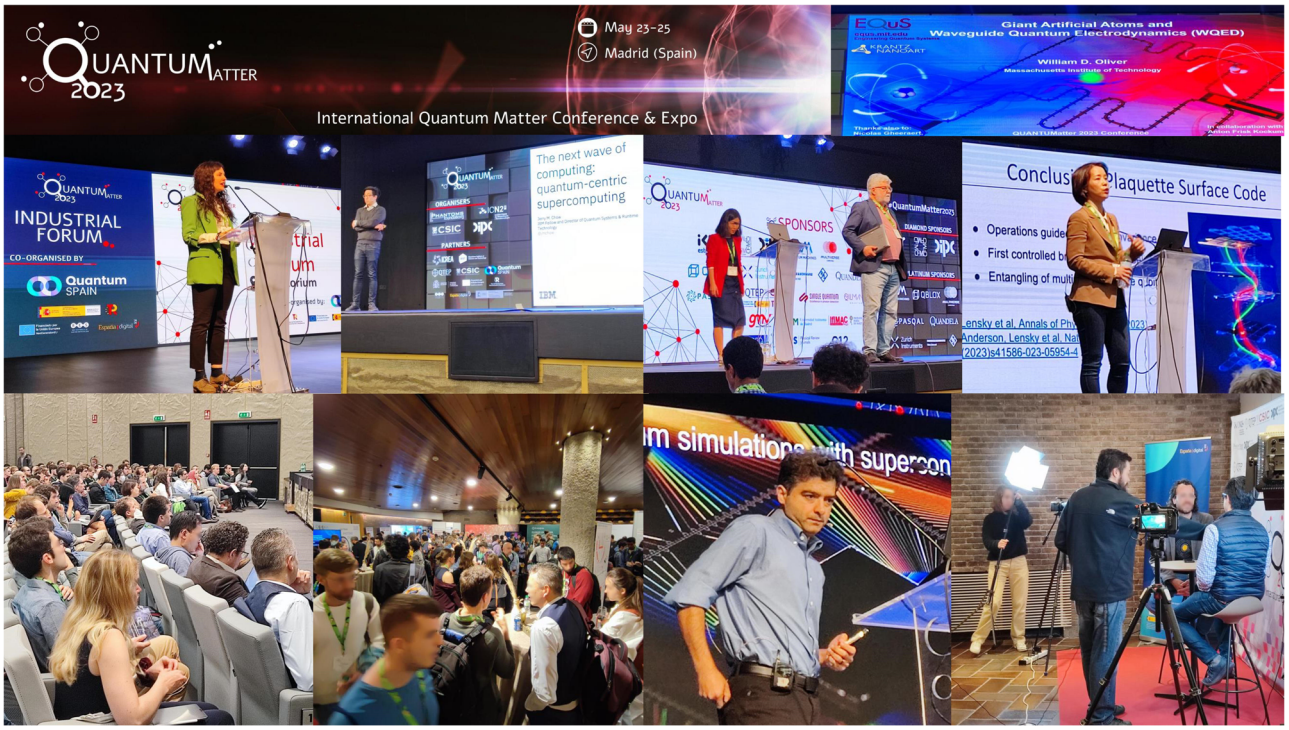

Fig. 1 Highlights of QUANTUMatter2023. The conference featured talks by academic international speakers complemented by an industrial forum and one-on-one interviews, highlighting the promising directions in the fields of quantum materials, quantum information and quantum technologies.

hundreds of atoms. Prof. Lukin also argued the possibility of controlling 10,000 atoms in the coming years and 100,000 more in the future[3,4]. Similarly, Prof. Ana Maria Rey from NIST and the University of Colorado discussed how spin interactions can be manipulated to control correlated pair-production processes in different quantum platforms, such as arrays of neutral atoms, Rydberg atoms, magnetic atoms and polar molecules[5,6].

Prof. William Oliver from MIT reported the first demonstration of "*giant artificial atoms*" realised with superconducting qubits in a waveguide Quantum Electrodynamics (wQED) architecture, as well as "an artificial molecule" comprising two qubits to demonstrate directional photon emission with 97% fidelity (a chiral waveguide). Such waveguide QED technologies are used to create quantum links between quantum computers, enabling architectural modularity[7]. The relevance of a wQED platform is not only technological, as it provides a practical platform for the demonstration of fundamental quantum science[8], also discussed during the conference. In this context, Prof. Pascale Senellart-Mardon (C2N-CNRS-Université Paris Saclay, France) presented novel tools of cavity QED and semiconductor nano-processing, quantum dots as efficient single photon emitters with unprecedented efficiency and near-perfect quantum purity, as well as a first generation of photonic cluster state chains of entangled photons[9].

To broaden the perspective of academic research in quantum technologies, QUANTUMatter2023 also secured quality contributions from several representatives of quantum industries. Dr. Jerry Chow from IBM and Dr. Pedram Roushan from Google provided informative and exciting views about the capabilities of superconductor-based quantum computing implementations, which are already in use for fundamental studies and, to a certain extent, accessible to public users. Providing insight into the development of topological qubits, Dr. Chetan Nayak from Microsoft Quantum presented their proposed protocol to identify the regimes of topological superconductivity in hybrid superconductor-semiconductor one-dimensional systems[10]. The topic was also the focus of later discussions on the possibility of bottom-up engineering of topological superconductivity and Majorana fermions using hybrid quantum dots[11].

The industrial forum gathered many representatives from spinoff companies actively engaged in the development of quantum hardware: Quantum Machines, Qilimanjaro, QBlox BV, Zurich Instruments, Pasqal, C12, Kiutra and Quandela. Their equipment is enabling the scientific community to explore the potential of new materials and applications for quantum technologies, as illustrated by other participating spinoff companies such as Multiverse Computing. Two round tables have brought into the discussion the big challenges that the industry is facing to bring quantum technologies to the next level. Topics such as best practices, practical experiences, standardisation, talent search and benchmarking were discussed together with representatives from spinoff companies and big corporations such as Orange, BlueSpecs and Mahou-San Miguel, Qureca (startup about quantum resources and career) and Quside (quantum random number generation). The dominant presence of European companies and startups, together with the participation of a representative from the European Quantum Industry Consortium (QuIC)[12], sent the clear message that Europe is betting on the development of quantum technologies and its industry ecosystem is flourishing. All participants stressed out that collaboration between industry and academia is crucial, as well as the need to forge alliances between companies worldwide. Developing quantum technologies is a big technological challenge that must be addressed in collaboration.

QUANTUMatter2023 also featured an Industrial exhibition, with more than 20 companies/institutions leaders in their field represented, showcasing cutting-edge advances in Quantum research and developments.

During the conference, several interviews of keynote speakers were recorded and can be viewed at https://www.youtube.com/watch?v=Uq_wjImLIDA as well as at the ICN2 Youtube channel https://www.youtube.com/@ICN2cat.

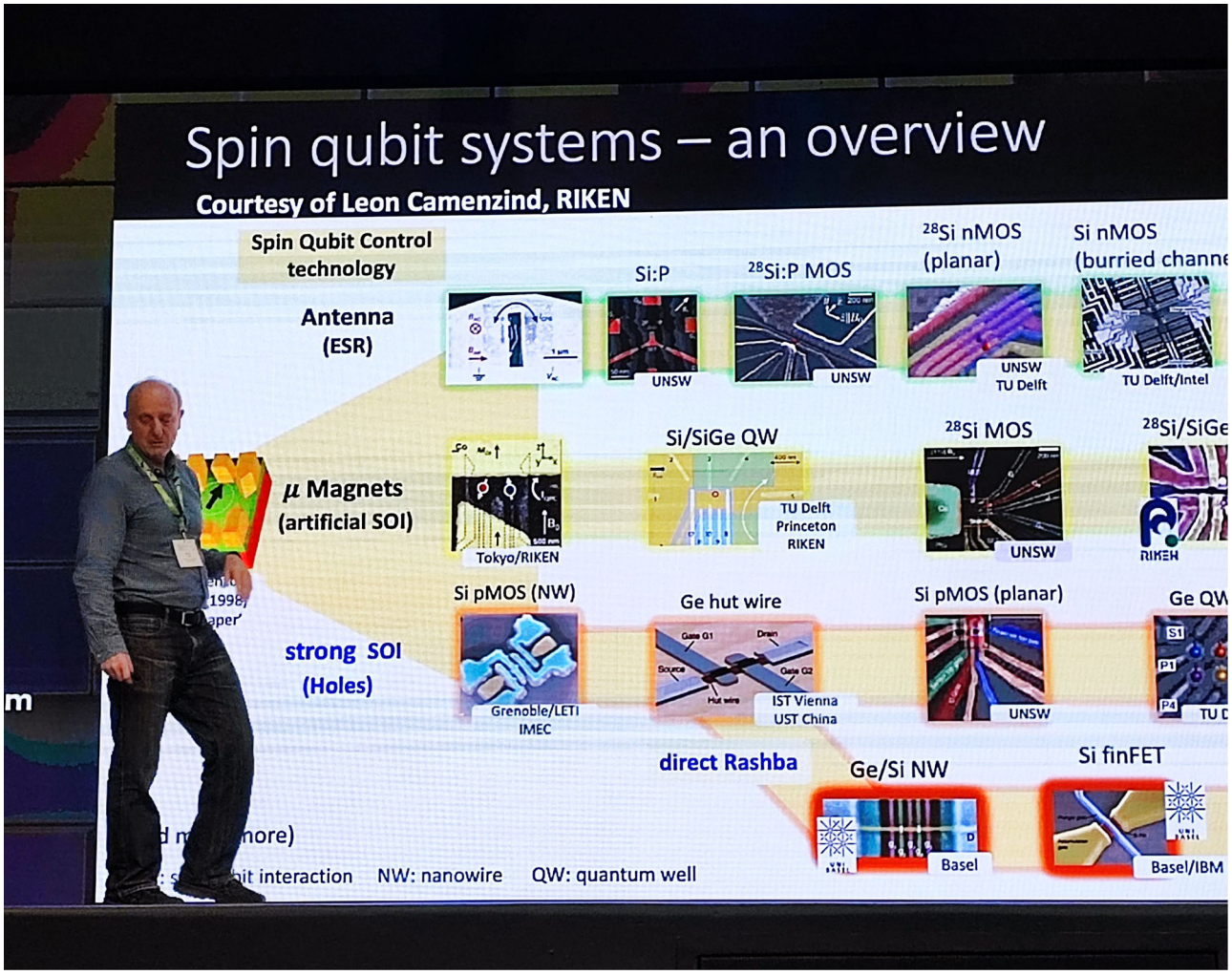

Fig. 2 Overview of spin qubit systems. Professor Daniel Loss (Basel University) reviewed the recent advances and most promising directions in the development of spin qubits for quantum computation.

The next edition QUANTUMatter2024 will move to San Sebastian (May 7–10) and take place at Kursaal (https://www.kursaal.eus/en/) in spectacular surroundings. With an extended programme of four days, it will welcome researchers from across the globe to showcase their scientific and technological findings. QUANTUMatter2024 will be a cornerstone outreach event and a formidable platform for developing partnerships, collaboration and alliances (more information soon at www.quantumconf.eu).

The authors affirm that informed consent for publication of the images in Figs. 1 and 2 were obtained from identifiable individuals.

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References

1. Quantum Spain. Quantum Spain project, financially supported by the Ministry of Economic Affairs and Digital Transformation of the Spanish Government through the QUANTUM ENIA project call—Quantum Spain project, and by the European Union through the Recovery, Transformation and Resilience Plan —NextGenerationEU within the framework of the Digital Spain 2026 Agenda. URL: https://quantumspain-project.es/en/quantum-spain/.

2. Stano, P. & Loss, D. Review of performance metrics of spin qubits in gated semiconducting nanostructures. *Nat. Rev. Phys.* **4**, 672–688 (2022).
3. Nguyen, M. T. et al. Quantum optimization with arbitrary connectivity using Rydberg atom arrays. *PRX Quantum* **4**, 010316 (2023).
4. Ebadi, S. et al. Science 376, 1209–1215 (2022)
5. Bilitewski, T. & Rey, A. M. Manipulating growth and propagation of correlations in dipolar multilayers: from pair production to bosonic Kitaev models. https://doi.org/10.48550/arXiv.2211.12521 (2022).
6. T. Bilitewski et al. Momentum-selective pair creation of spin excitations in dipolar bilayers. https://arxiv.org/abs/2302.09059 (2022).
7. Kannan, B. et al. On-demand directional microwave photon emission using waveguide quantum electrodynamics. *Nat. Phys.* **19**, 394–400 (2023).
8. Storz, S. et al. Loophole-free Bell inequality violation with superconducting circuits. *Nature* **617**, 265–270 (2023).
9. Coste, N. et al. High-rate entanglement between a semiconductor spin and indistinguishable photons. *Nat. Photon*. https://doi.org/10.1038/s41566-023-01186-0 (2023).
10. Aghaee, M. et al. InAs-Al hybrid devices passing the topological gap protocol. *Phys. Rev. B* **107**, 245423 (2023).
11. Dvir, T. et al. Realization of a minimal Kitaev chain in coupled quantum dots. *Nature* **614**, 445–450, https://doi.org/10.1038/s41586-022-05585-1 (2023).
12. European Quantum Industry Consortium. https://www.euroquic.org/.

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Competing interests

The authors declare no competing interests.

Additional information

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