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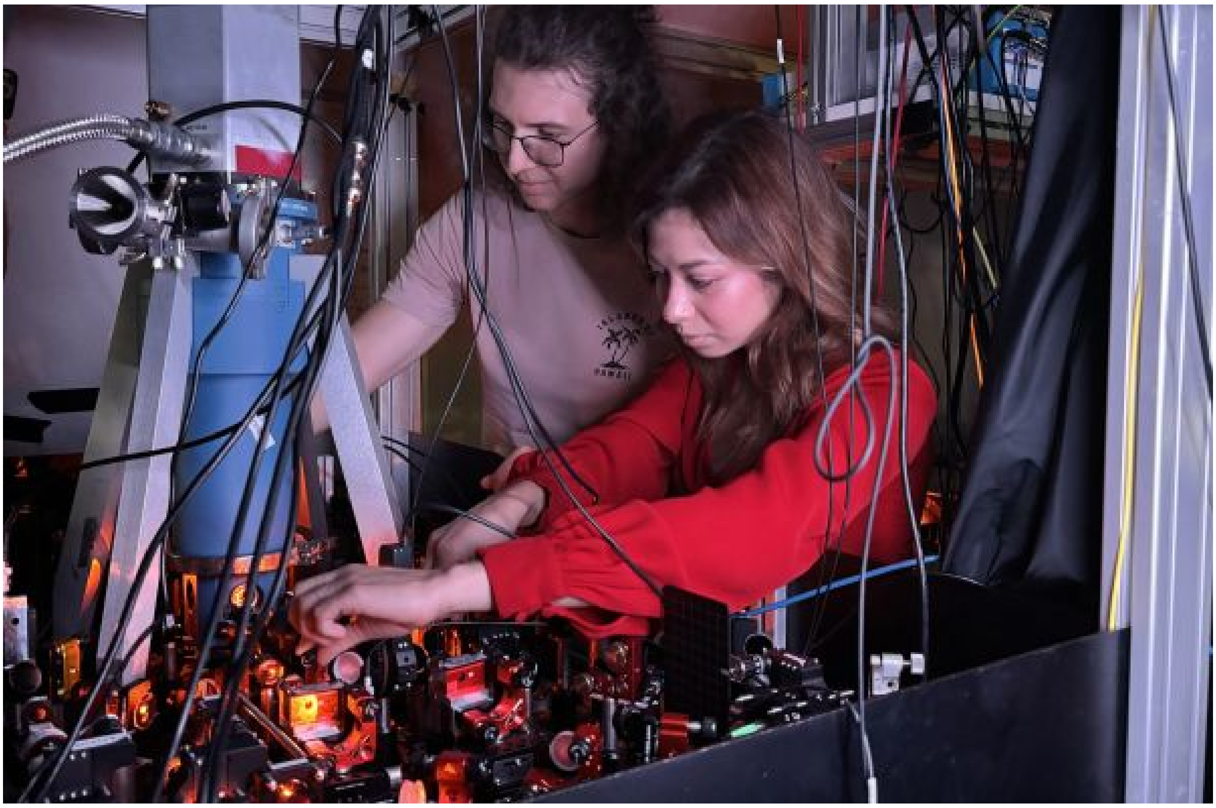

Quantum memory array at ICFO brings us closer to a quantum RAM

**In a major step toward realizing memory systems that works as flexibly as the random-access memory (RAM) in today's classical computers, researchers at ICFO have developed an array of ten individually controllable quantum memories that can store multiple qubits simultaneously and recall them when needed. This solid-state system, reported in Physical Review X, is based on a previous configuration that held 250 available i¿½slotsi¿?
to potentially store a photon -the current world record for a so?lid state device with on-demand retrieval. The system brings us closer to the quantum equivalent of a RAM, and could serve as a building block for generating large-scale entangled states -a key resource for quantum computing- or dramatically boost the efficiency of entanglement distribution across long distances -a foundational task for future quantum communication networks.**

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The internet, social media, and digital technologies have completely transformed the way we establish commercial, personal and professional relationships. At its core, this society relies on the exchange of information that is expressed in terms of bits. This basic unit of information can be either a 0 or a 1, and it is usually represented in electrical circuits, for instance, as two voltage levels (one representing the bit in state 0 and the other representing state 1).

The ability to store and manipulate bits efficiently lays the basis of digital electronics and enables modern devices to perform a variety of tasks, ranging from sending emails and playing music over to numerical simulations. These processes are only possible thanks to key hardware components like random-access memories (RAM), which offer temporary storage and on-demand retrieval of data.

In parallel, advances in quantum physics have led to a new kind of information unit: the qubit. Unlike classical bits, which are strictly 0 or 1, qubits can exist in a superposition of both states at once. This opens up new possibilities for processing and storing information, although its practical implications are still being explored.

Future quantum computers and a quantum internet will likewise require quantum memories (in particular, random-access quantum memories) to store and retrieve qubits. Despite several approaches exist to encode qubits and to implement quantum memories, no single i¿½gold standardi¿½ has yet emer
ed. Now, ICFO researchers **Dr. Markus Teller**, **Susana Plascencia**, **Cristina Sastre Jachimska**, **Dr. Samuele Grandi**, led by **ICREA Prof. Hugues de Riedmatten**, have achieved a major milestone in the development of solid-state quantum memories -one of the most promising platforms for quantum information storage. In a recent Physical Review X article, they use an array of ten individually-controllable memories to store qubits in arbitrary combinations of memory cells and retrieve them on demand. These results build on an earlier npj Quantum Information publication, where they first introduced the array.

Their work focuses on two qubit encodings widely used in photonic quantum technologies: path encoding, where the qubit is defined by which memory the photon enters, and time?bin encoding, where the qubit is encoded in the photon's arrival time (at an earlier or later time interval). For the latter, the team used a unique feature of their approach: the possibility to store photons in multiple time-slots in each memory cell.

Ten cells, one crystal: advancing quantum communications and computing

In the npj Quantum Information paper, the team created an array of ten quantum memories by using a praseodymium-doped crystal cooled to 3 Kelvin inside a cryostat. Within this crystal, they allocated 250 storage i¿½slotsi¿½, or spatio?temporal modes, each potenti
lly storing a photon -the current world record for a solid?state device with **on-demand retrieval**. Such an achievement is really remarkable, because on-demand capabilities are technically very difficult to implement, and yet they are essential to synchronize quantum networks.

The team then employed a similar configuration -ten individually addressable memory cells but with less modes available- to actually store several qubits and retrieve them on-demand, which ultimately resulted in the PRX article. To do so, acoustic?optical deflectors steered laser pulses to write and read qubits in arbitrary combination of memory cells. Posterior analysis of the recovered photons showed that the quantum memory array preserved the original quantum states with reasonable fidelity.

To showcase their configuration's potential, the team stored two time-bin qubits and recalled both at the same time. **These capabilities bring us one step closer to a random-access solid-state quantum memory**, with applications in quantum computing and communications. ï¿½We envision combining this platform with a source of photonic cluster states **for light-based quantum computing**,ï¿½ shares Dr. Markus Teller, first co-author of the stud . ï¿½In this scenario, the quantum memory array would store more and more photons unt l a large entangled quantum state is formed. Then, quantum operations could begin ï¿½ The system could also advan **quantum repeaters**, the backbone of the future quantum internet. These devices aim to extend quantum communication over vast distances by distributing the quantum resource of entanglement across successive segments. ï¿½Previo s experiments with solids had to pause after only a few tens of entanglement attempts, waiti g for a success signal to return,ï¿½ explains Susana Plascencia, ICFO researcher and co-au hor of the study. ï¿½With our ar **we no longer need to wait for the success signal** (at least, up to a certain distance). Instead, we can switch to another memory cell and keep trying.ï¿ ? Filling that idle time with new attempts could boost the rate at which entanglement -a d therefore quantum information- is transferred over long distance . To fully exploit the potential of time-multiplexed quantum memory arrays, the ne t challenges will be to increase the performances (for example, in terms of efficiency a d storage time), to increase the number of memory cells and to be able to store entanglemen . Overall, this study represents a significant step toward the quantum equivalent of a RA , whose implications in quantum communications and computing remain open-ende

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From left to right, Hugues de Riedmatten, Samuele Grandi, Markus Teller, Susana Plascencia, and Cristina Sastre Jachimska outside ICFO?s main building. ©ICFO.