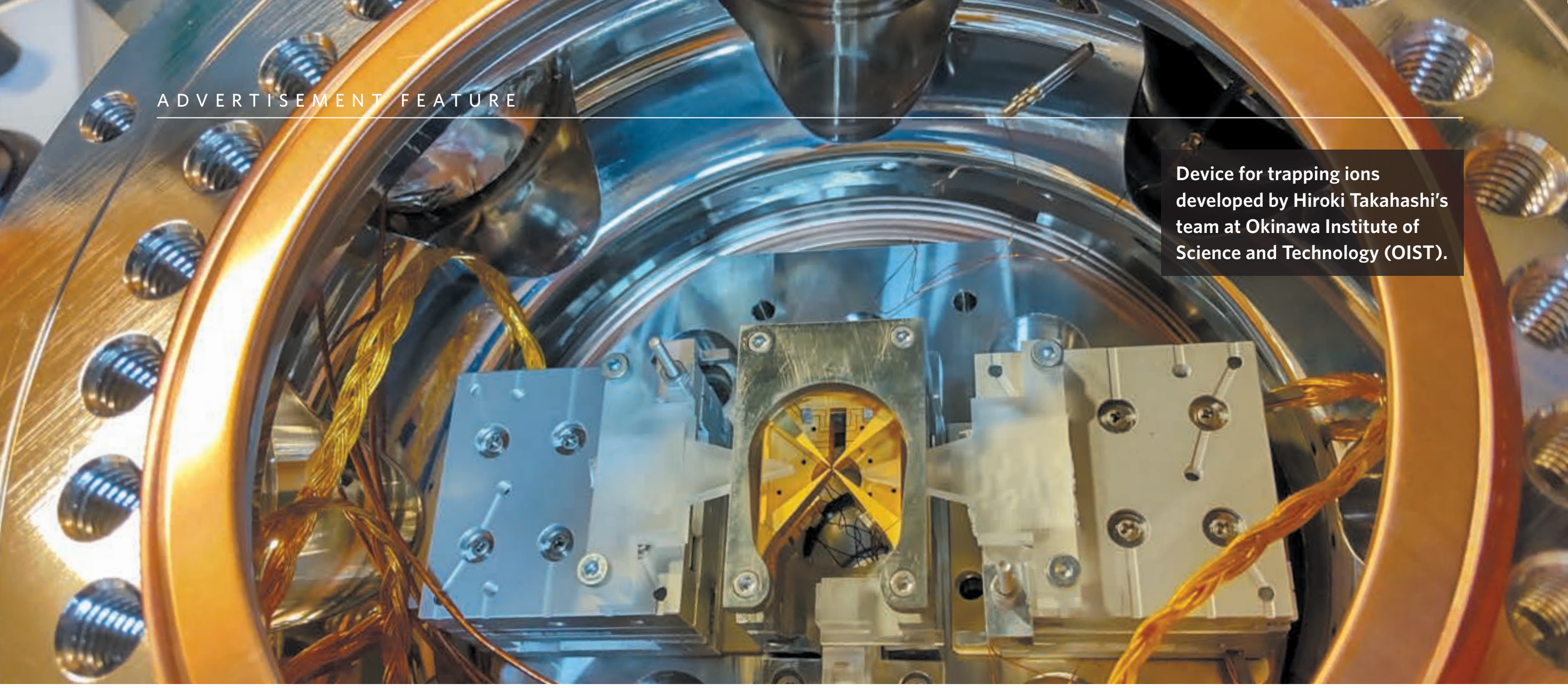

Device for trapping ions developed by Hiroki Takahashi's team at Okinawa Institute of Science and Technology (OIST).

SCALING UP TRAPPED-ION QUANTUM COMPUTERS

NEW TECHNOLOGIES FOR TRAPPED IONS promise to realize large-scale quantum computers.

"Quantum computers are going to revolutionize everything that relies on computers, which is basically all fields of science and technology," predicts Hiroki Takahashi, assistant professor in experimental quantum information physics at the Okinawa Institute of Science and Technology (OIST) in Onna. "They will crack problems that cannot be solved using classical computers, including some of the most important problems in various fields of technology."

Five main platforms are being explored for their potential to build quantum computers: superconducting circuits, silicon quantum dots, light, neutral atoms and ion traps. Projects involving all these platforms are being pursued under the sixth goal of the Japanese government's Moonshot programme, which is seeking to develop "a fault-tolerant universal quantum computer that will revolutionize the economy, industry and security by 2050."

While all five platforms use qubits — the quantum equivalent of bits — Takahashi is convinced that charged atoms (ions) trapped in electric fields offer the best qubits. "The ion trap can achieve the best qubit," he says. "It's just one atom floating without anything around it, so it's a pure quantum state. That's why the very first quantum computers were based on trapped ions."

SCALING UP

But the challenge with trapped-ion qubits is linking many of them together. The conventional approach is to add more ions to a trap. "Problems occur when you try to connect more than about ten trapped ions together," explains Takahashi. "Manipulation of the ions' quantum states becomes more and more difficult due to the complexity of their motional patterns in the trap."

Takahashi's team is exploring an alternative approach. "Since this scalability problem happens when we increase the number of ions inside a single trap, the obvious solution is to use many traps," says Takahashi. "By connecting the traps in quantum way, we can increase the size of the system while not making the traps too complex. This idea has been around for more than two decades, but it's never been fully implemented."

Takahashi's team is using light to connect the traps. "The ions naturally emit photons by fluorescence and so you can connect ions in that way," he says. "The theory is simple, but implementation is really difficult."

IMPROVING EFFICIENCY

The tricky part is that the photons are emitted in all directions, making it difficult to collect and channel them. Typically, the collection efficiency is less than 10%, typically 1–2%. To overcome this problem, Takahashi is looking at confining photons in a cavity created by two mirrors. He believes that, in principle, it should be possible to increase the collection efficiency to about 90%.

Takahashi's team is pursuing a long-term strategy that involves advancing individual components of an ion-trap quantum computer while simultaneously working on the bigger picture of the overall system.

"We're investigating individual technologies that could change the future landscape of ion-trap quantum computers, while also developing a blueprint of a future ion-trap quantum computer by integrating suitable technological elements," says Takahashi. "In this way, we hope to showcase a novel scalable ion-trap device."

Takahashi is seeking to bring researchers together through the Moonshot project and grow the trapped-ion community in Japan. "While the ion-trap community in Japan has tripled in size over the past few years, it's still small," says Takahashi. "And so it's important that we nurture this community to become a global leader in quantum-computing technologies."

MOONSHOT RESEARCH & DEVELOPMENT PROGRAM

www8.cao.go.jp/cstp/english/moonshot/top.html