Aluminum-based low-loss interconnects for superconducting quantum processors

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Five quantum modules linked together by newly developed, low-loss quantum interconnects. Credit: Yan Qiu

Quantum processors are computing systems that process information and perform computations by exploiting quantum mechanical phenomena. These systems could significantly outperform conventional processors on certain tasks, both in terms of speed and computational capabilities.

While engineers have developed several promising quantum computing systems over the past decade or so, scaling these systems and ensuring that they can be deployed on a large-scale remains an ongoing challenge. One proposed strategy to increase the scalability of quantum processors entails the creation of modular systems containing multiple smaller quantum modules, which can be individually calibrated and then arranged into a bigger architecture. This, however, would require suitable and effective interconnects (i.e., devices for connecting these smaller modules).

Researchers at the Southern University of Science and Technology, the International Quantum Academy and other institutes in China have recently developed low-loss interconnects for linking the individual modules in modular superconducting quantum processors. These interconnects, introduced in *Nature Electronics*, are based on pure aluminum cables and on-chip impendence transformers.

"Our recent paper was based on core ideas from my postdoc research at the University of Chicago, which was published in Nature two years ago," Youpeng Zhong, one of the researchers who carried out the study, told Tech Xplore. "In that study, I used a niobium-titanium (NbTi) superconducting coaxial cable to connect two quantum processors."

In one of his previous works, Zhong tried to connect two distinct quantum processors using NbTi superconducting cables, which are commonly used to engineer cryogenic/quantum systems. To reduce the connection loss (i.e., the loss of energy that inherently occurred while energy traveled from one processor to the other through the cables), he tried to wire-bond the quantum chips directly to the connecting NbTi cable.

"I found that this was quite difficult, so I came up with the idea of trying new cables made of different superconducting metals, such as aluminum, the same material as our quantum circuits," Zhong explained. "Coaxial cables made with pure aluminum are not readily available on the shelf, because aluminum is more lossy and difficult to solder than copper, making it unsuitable for normal cabling applications. Moreover, its superconducting transition temperature is below the liquid Helium temperature. Other than quantum interconnection applications, it's rare to find scenarios where a pure aluminum coaxial cable is needed."

To create his new low-loss interconnects, Zhong custom ordered pure aluminum coaxial cables and integrated them with on-chip impedance transformers. The resulting interconnects exhibited significantly less loss (i.e., one order of magnitude lower) than routinely used interconnects based on NbTi cables, and were also easy to wire-bond to quantum chips.

"Pure aluminum cables turned out to be the perfect choice for quantum interconnects," Zhong said. "Our interconnects include the custom developed aluminum coaxial cable, wire-bond connection between the cable and the quantum chip and a quarter-wavelength transmission line on the quantum chip, which serves as an impedance transformer. The impedance transformer in the team's interconnect converts the wire-bond connection point to a current node of a standing wave mode that is used to transfer quantum states. This significantly minimizes the resistive loss at the point of connection between different quantum processors.

"Our findings remind us of how much potential improvement we could attain if we think outside the box," Zhong said. "For example, the work of Charles Kao laid the foundation to optical fibers as we all know today: with record loss of 0.2 dB/km they have become the backbone of the modern global communication network—indispensable to short and long-haul communications. The transformative impact of this highly technical and almost neglected material science research was awarded a half of the

2009 Nobel Prize in Physics. Another example is the use of stainless steel for Elon Musk's Starship Mars Rocket."

The recent work by this team of researchers highlights the huge potential of aluminum cables for developing effective interconnects to link processing modules in modular quantum systems. The low-loss interconnect created by Zong and his colleagues could soon be integrated in other modular systems, contributing to ongoing efforts at developing more scalable quantum processors.

"Among my future research plans, one is to explore quantum entangling gates across different quantum processors," Zhong added. "Another is trying to scale up the size of quantum processors by connecting multiple modules together."

More information: Song Liu, Low-loss interconnects for modular superconducting quantum processors, *Nature Electronics* (2023). DOI: 10.1038/s41928-023-00925-z.
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