QUANTUM COMPUTERS MOVE INTO THE LIGHT

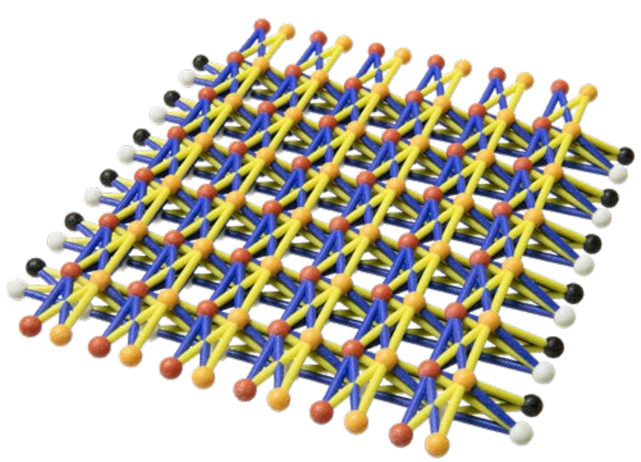
Light offers many powerful advantages when it comes to producing QUANTUM COMPUTERS.

Despite working in quantum computing for decades, Akira Furusawa, a professor at the University of Tokyo in Japan, has no idea what the quantum-computer era will look like. "It's going to transform society, but it's very hard to predict how," he says. "It's a similar situation to the internet, which has radically altered many aspects of life, but often in ways we couldn't have imagined beforehand."

That's because quantum computers won't just be faster and more powerful than current computers — they will be fundamentally different. "Unlike conventional digital computers that perform processing using ones and zeros, quantum computers can use a continuous range of numbers. And quantum computers employ complex numbers, effectively adding another dimension," explains Furusawa. "So we're talking about a very different beast."

Although Furusawa doesn't know how quantum computers are going to impact society, he is convinced that the quantum computers of the future will be powered by light.

"The ultimate goal is to develop quantum computers that are ultrafast and ultralarge scale," says Furusawa. "I believe that optical computers are the most promising way to realize that goal."



A model of a 'quantum lookup table' that will be used to perform calculations in light-based quantum computers.

BETTING ON LIGHT

Five main technologies are currently being pursued for developing quantum computers, platforms based on superconductors, semiconductors, ion traps, quantum dots, and light. Superconductors have got off to a flying start and are the basis for the largest quantum computers built to date. Semiconductor quantum computers also have an impressive head start in that they can exploit current manufacturing technologies.

But Furusawa is convinced that, in the longer term, the advantages of using light for quantum processing are so overwhelming that optical quantum computers will eventually win out.

"I BELIEVE THAT OPTICAL COMPUTERS ARE THE MOST PROMISING WAY TO REALIZE THAT GOAL."

THE SPEED OF LIGHT

For a start, light can perform operations much faster than other technologies. Because light oscillates at much higher frequencies than those used in electronic circuits, it should be possible to achieve processing speeds that are around 10,000 times faster using light.

Based on this speed advantage, Furusawa predicts there will be a wholesale shift towards light-based technologies. "I believe we're entering an age of optical technology," says Furusawa. "Everything will become optical to take advantage of the speed it offers."

"Currently, the way to make fast supercomputers is to use parallel computing with many processors," explains Mamoru Endo, a lecturer at the University of Tokyo and a member of Furusawa's team. "But that consumes a lot of energy, which is a major problem."

But the situation will be vastly different with optical quantum computers. "The basic unit operation has a minuscule energy cost, which means it will be possible to use many processors," says Endo. "Imagine if we could use 100 times as many processors compared to today's supercomputers and take advantage of the 10,000 times faster clock frequencies of optical processes — that's potentially a million times faster."

Another advantage of light-based computers is that they remove the need to convert a light signal, which is used to transport data, into signals, which other quantum platforms use to process data. Thus, both data transport and processing can be performed using the medium.

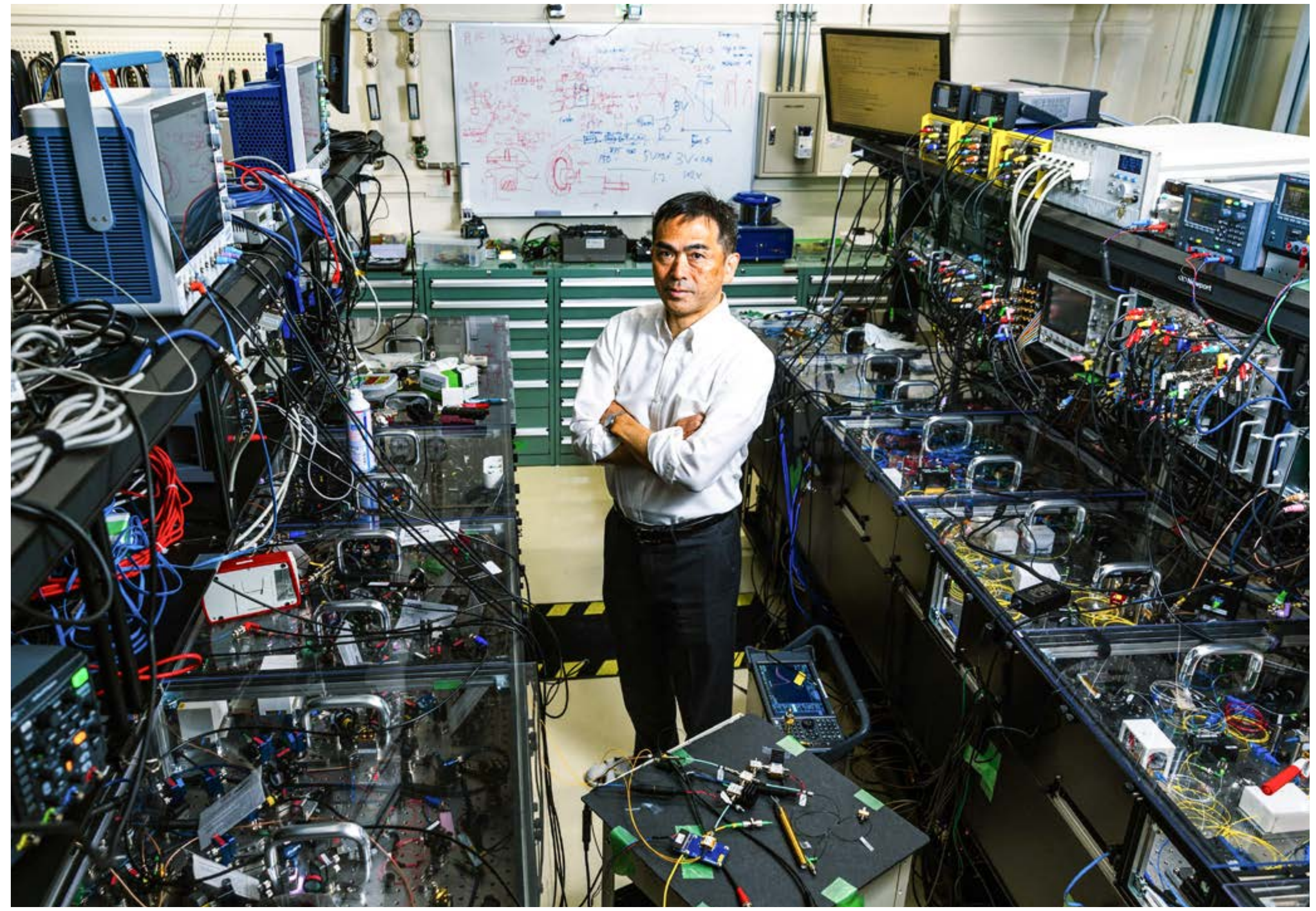
QUANTUM LOOKUP TABLES

To implement an optical quantum computer, Furusawa and his team are employing an original method that involves a form of quantum teleportation.

To perform quantum computations, they set up what they dub a 'quantum lookup table' — a superposition of the relationships between all possible inputs and outputs. They then make single measurements from the table.

Since the measurement results are random, the team incorporates a feedforward mechanism to remove the randomness. In this way, they achieve teleportation between two entangled qubits. "We did the first experiment in the world using this type of transportation," says Furusawa[1].

The University of Tokyo



Akira Furusawa of the University of Tokyo is developing quantum computers based on light.

Importantly, this method uses an original method of multiplexing — a way of combining multiple signals into one — which involves slicing and combining signals in time rather than in space. This is critical because it provides a scalable way of creating large quantum computers. "Since we don't need to use chips for multiplexing, it enables us to create a large-scale quantum computer," says Endo.

Some significant challenges must be overcome to realize practical optical quantum computers. One of the biggest is achieving nonlinearity, which is critical for analysing complex, real-life processes. Conventional computers are adept at solving linear problems that can be expressed using simple mathematical functions, but by exploiting the nonlinear nature of quantum interactions, quantum computers can tackle the many nonlinear phenomena that abound in the real world. However, the interactions of light are linear at the low intensities typically used in devices.

It's very easy to create nonlinearities in superconducting and other quantum computer systems because they are inherently nonlinear systems, but it is very challenging using light because it is basically linear at low intensities. "This is the most difficult part for us," says Endo. "We're trying to introduce nonlinearity by injecting special quantum states created using photon detectors."

A BRIGHT FUTURE

Furusawa's project is part of the Japanese government's quantum computing Moonshot Programme, which is seeking to produce a fault-tolerant, large-scale, universal quantum computer by 2050. While that goal is still a long way off, optical-based quantum computer technology has reached a point where it can begin to be commercialized. "We're currently developing an actual quantum computer for neural networks. We intend to create a start-up company and make it available on the cloud in 2024," says Furusawa. "So it's not just a dream — optical quantum computers can have practical applications even in the short term."

And Furusawa predicts that the long-term direction of quantum computing will be towards optical technologies. "I think the age of conventional qubits based on standing waves is over," he says. "We're going to see optical qubits based on travelling waves taking over. My dream is to see all computers become optical quantum computers." ■

REFERENCE

1. Asavanant, W. *et al. Phys. Rev. App.* **16**, 034005 (2021).

MOONSHOT
RESEARCH & DEVELOPMENT PROGRAM

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