Researchers develop single-photon converter—a key component of quantum internet

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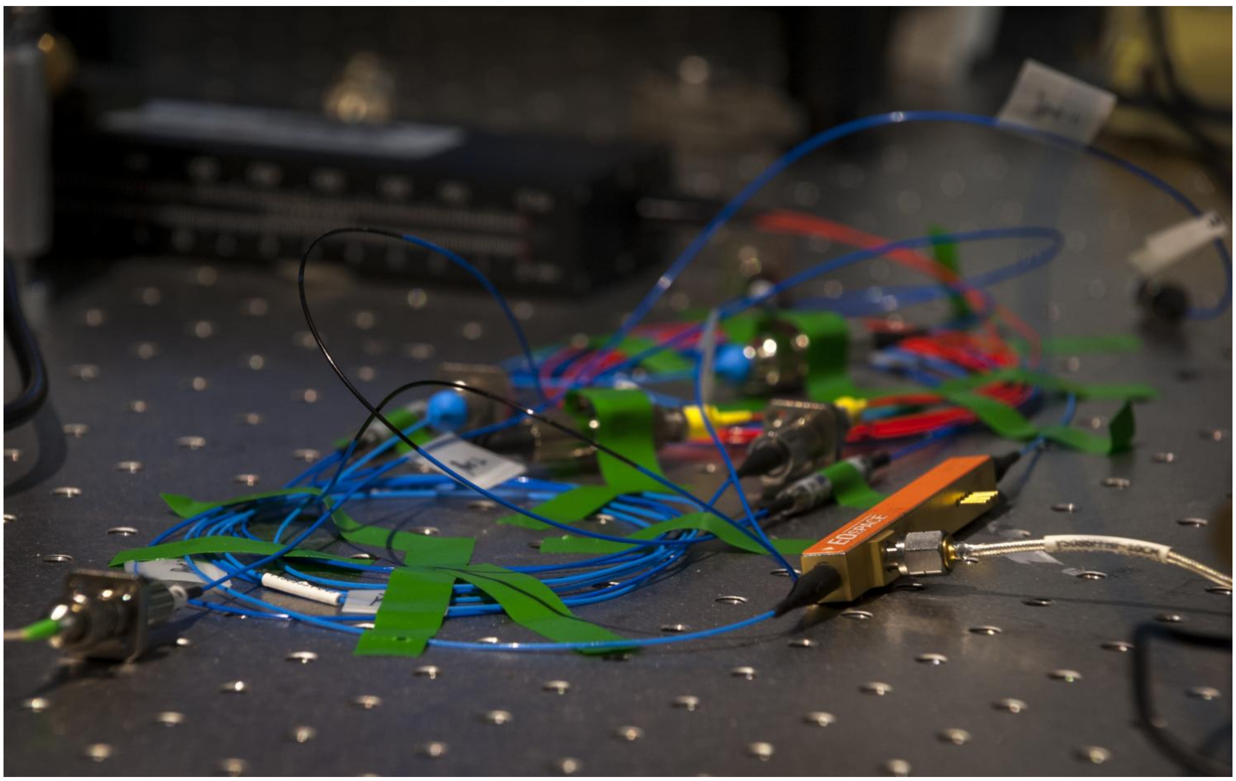


A single photon converter (a yellow-orange box) installed on an optical fiber of the laboratory setup. Credit: UW, Grzegorz Krzysewski

A Polish-British team of physicists has constructed and tested a compact, efficient converter capable of modifying the quantum properties of individual photons. The new device should facilitate the construction of complex quantum computers, and in the future may become an important element in global quantum networks, the successors of today's Internet.

Quantum internet and hybrid quantum computers, built out of subsystems that operate by means of physical phenomena, are now more than just the stuff of imagination. In an article published in *Nature Photonics*, physicists from the University of Warsaw's Faculty of Physics (FUW) and the University of Oxford report the development of a key element of such systems: an electro-optical device that enables the properties of individual photons to be modified. Unlike existing laboratory constructions, this new device works with previously unattainable efficiency and is at the same time stable, reliable and compact.

Building an efficient device for modifying the quantum state of individual photons was an exceptionally challenging task, given the fundamental differences between classical and quantum computing.

Contemporary computing systems are based on the processing of groups of bits, each of which is in a specific state: either 0 or 1. Groups of such bits are continually transferred between different subcomponents within a single computer, and between different computers on the network. We can illustrate this figuratively by imagining a situation in which trays of coins are being moved from place to place, with each coin showing either heads or tails.

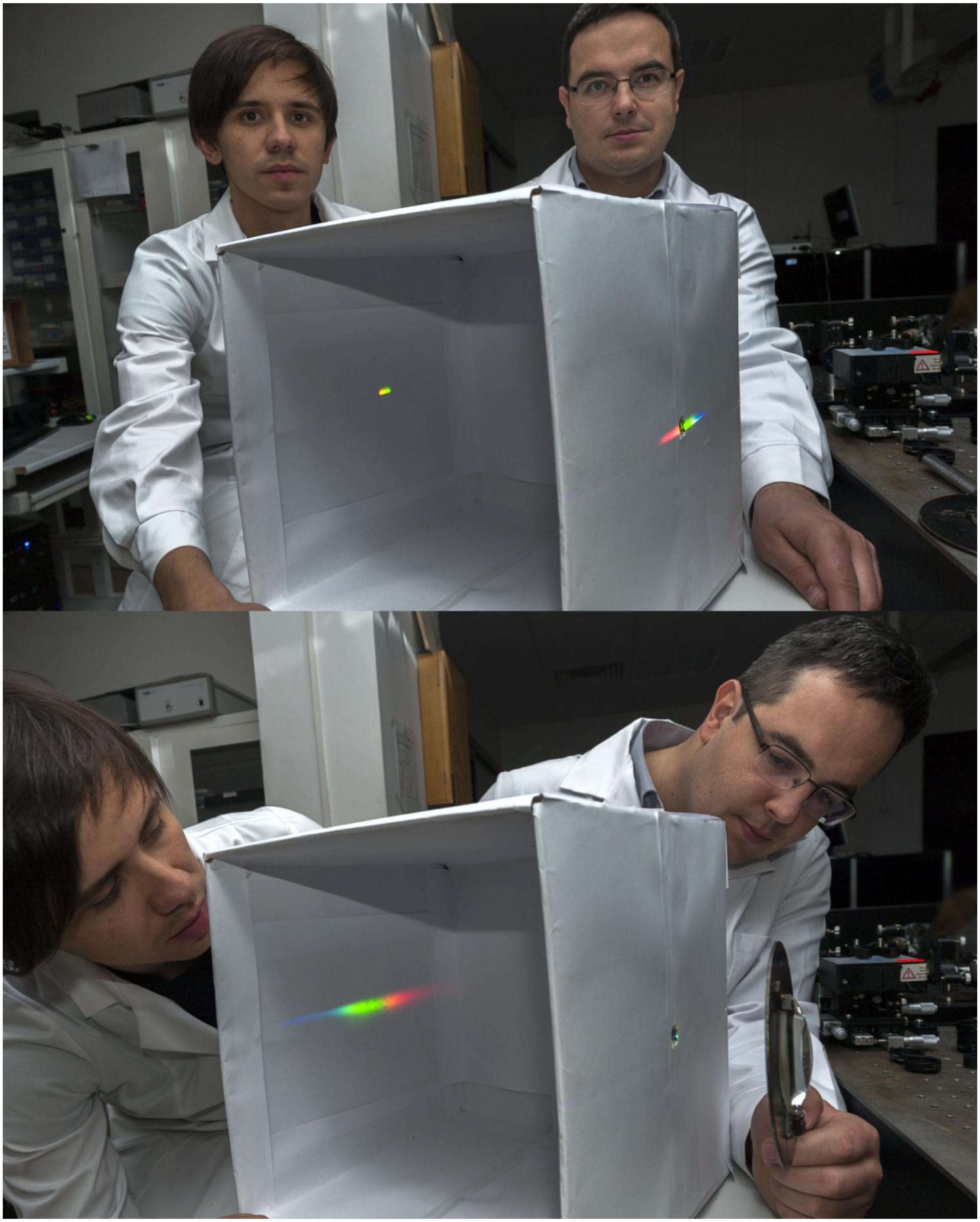
A single photon -- a carrier of quantum information -- travels like a spinning coin, in a superposition of states. Modyfing its properties is extremely hard and should be done carefully, without destroying the superposition. Credit: FUW, Grzegorz Krzyzewski

Things are more complicated in quantum computing, which relies on the phenomenon of superposition of states. A quantum bit, known as a qubit, can be both in the 1 state and the 0 state at the same time. To extend the metaphor of the coins, this is analogous to a situation in which each coin is spinning on its edge. Information processing can be described as "quantum" processing as long as this superposition of states is retained during all operations—in other words, as long as none of the coins gets tipped out of the spinning state while the tray is being moved.

"In recent years, physicists have figured out how to generate light pulses with a specific wavelength or polarization, consisting of a single quantum—or excitation—of the electromagnetic field. And so today, we know how to generate precisely whatever kind of quantum 'spinning coins' we want," says Dr. Michal Karpinski from the Institute of Experimental Physics (FUW), one of the authors of the publication. "But achieving one thing always leaves you wanting more. If we now have individual light quanta with specific properties, it would be useful to modify those properties. The task is therefore to take a spinning silver coin and move it from one place to another, while quickly and precisely turning it into a gold coin, naturally without tipping it over. You can easily see that the problem is nontrivial."

Existing methods of modifying individual photons have utilized nonlinear optical techniques—in practice, attempting to force an individual photon to interact with a very strong optical pump beam. Whether the photon actually gets modified is a matter of pure chance. Moreover, the scattering of the pump beam may contaminate the stream of individual photons. In constructing the new device, the group from the University of Warsaw and the University of Oxford decided to use a different physical phenomenon: the electro-optic effect occurring in certain crystals. It provides a way to alter the index of refraction for light in the crystal by varying the intensity of an external magnetic force that is applied to it (in other words, without introducing any additional photons).

"It is quite astounding that in order to modify the quantum properties of individual photons, we can successfully apply techniques very similar to those used in standard fiber-optic telecommunications," Dr. Karpinski says.



Usually, due to the properties mismatch, the majority of single photons cannot be effectively stored e.g. in the quantum memory (represented as a white box).

The new converter enables to modify the properties of photons so that virtually all of them can be stored inside the memory. Credit: FUW, Grzegorz Krzyzewski

Using the new device, the researchers achieved a six-fold lengthening of the duration of a single-photon pulse without disrupting the quantum superposition, which automatically means a narrowing of its spectrum. What is particularly important is that the whole operation was carried out while preserving very high conversion efficiency. Existing converters have operated only under laboratory conditions and were only able to modify one in several tens of photons. The new device works with efficiency in excess of 30 percent, up to 200 times better than certain existing solutions, while retaining a low level of noise.

"In essence, we process every photon entering the crystal. The efficiency is less than 100 percent not because of the physics of the phenomenon, but on account of hard-to-avoid losses of a purely technical nature, appearing, for instance, when light enters or exits optical fibers," explains Ph.D. student Michal Jachura (FUW).

The new converter is not only efficient and low-noise, but also stable and compact. The device can be contained in a box around 10 cm (4 in.), easy to install in an optical fiber system channeling individual photons. Such a device could enable building such things as hybrid quantum computers, the individual subcomponents of which would process information using different physical platforms and quantum phenomena. At present, attempts are being made to build quantum computers using things like trapped ions, electron spins in diamond, quantum dots, superconducting electric circuits, and atomic clouds. Each system interacts with light of different properties, which in practice rules out optical transmission of quantum information between different systems. The new converter, on the other hand, can efficiently transform single-photon pulses of light compatible with one system into pulses compatible with another. Scientists are therefore working toward quantum networks, both small ones within a single quantum computer (or subcomponent thereof), and global ones providing a way to send data completely securely between quantum computers situated in different parts of the world.

More information: Michał Karpiński et al, Bandwidth manipulation of quantum light by an electro-optic time lens, *Nature Photonics* (2016). DOI: 10.1038/nphoton.2016.228

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