Photonic Quantum Information Interface

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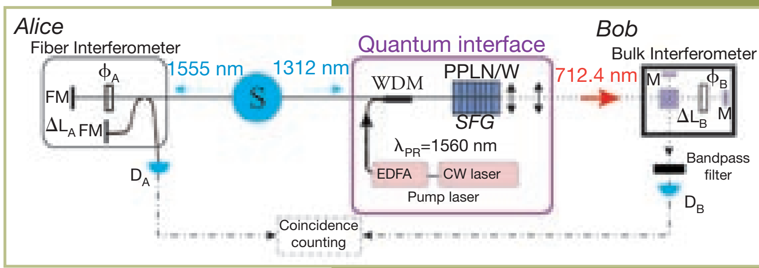

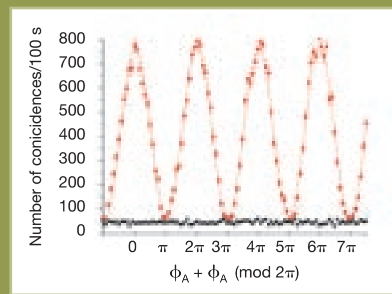

Experimental setup. First, the source (*S*) produces, by parametric downconversion, pairs of energy–time entangled photons whose wavelengths are centered at 1555 and 1312 nm, respectively. By means of telecommunications optical fibers, these photons are sent to Alice and Bob, respectively. Next, the qubit transfer is performed at Bob's location from a photon at 1312 nm to a photon at 712 nm using sum-frequency generation (SFG) in a PPLN waveguide (PPLN/W). This crystal is pumped by a cw, 700 mW, and high-coherence laser working at 1560 nm. The success of the transfer is tested by measuring the quality of the final entanglement between the newly created 712 nm photon and Alice's 1555 nm photon using two unbalanced Michelson interferometers and a coincidence-counting technique between detectors D_A and D_B. The graph shows the interference pattern obtained for the coincidence rate as a function of the sum of phases acquired in the interferometers (ϕ_A and ϕ_B). The corresponding visibility is greater than 97 percent. Compared with the 98 percent obtained with the initial entanglement, the quantum fidelity of this transfer is higher than 99 percent.[3]

Quantum entanglement is at the heart of quantum physics, with all its counterintuitive features. Furthermore, the new science of quantum information treats entanglement as a resource that is essential for the coming age of quantum technology. Yet, to be of any practical value, entanglement must be proven to be robust enough, at least under some circumstances, for one to really manipulate it.

Accordingly, a growing community of experimental physicists works with entanglement, in view of finding optimal conditions to master it. For example, it is accepted today that photons are the only candidates for carrying quantum information over long distances.[1] But for local processing of quantum bits (qubits), encoding onto atoms, ions or solid-state devices seems more promising.[2] It is thus timely to develop quantum information interfaces that allow one to transfer the qubits from one type of carrier to another.

In a recent experiment, we demonstrated the transfer of a qubit from a photon at the telecom wavelength of 1312 nm to another photon around 712 nm, a wavelength close to that of alkaline atomic transitions.[3] We performed this operation in the most general way, since the initial carrying photon was actually entangled with a third one at 1555 nm.

We could then verify that the transfer does indeed preserve the quantum coherence by testing the entanglement between the receiving photon at 712 nm and the third photon. The entanglement is found to be large enough to violate Bell's inequality,[4] despite the fact that these two photons have no common past.

The transfer of quantum information is achieved using sum-frequency generation—in other words, by mixing the initial 1312 nm single photon with a highly coherent pump laser at 1560 nm in a nonlinear periodically poled lithium niobate (PPLN) waveguide (see the figure). The probability of a successful upconversion here is of about 5 percent. The receiving single photon at 712 nm, filtered out of the huge flow of pump photons, and the remaining 1555 nm photon are then analyzed using two unbalanced Michelson interferometers in the Franson conformation.[5]

From the high quality of the resulting two-photon interference, we conclude that the fidelity of this quantum information transfer is found to be excellent—higher than 99 percent. Let us emphasize that these two photons that could violate the Bell inequalities share no common past.

Our experimental result is very encouraging for quantum information science. The mastering of entanglement is getting closer to reality.

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Spatial-Polarization State Scrambling for Image Encryption Obtained with Subwavelength Gratings

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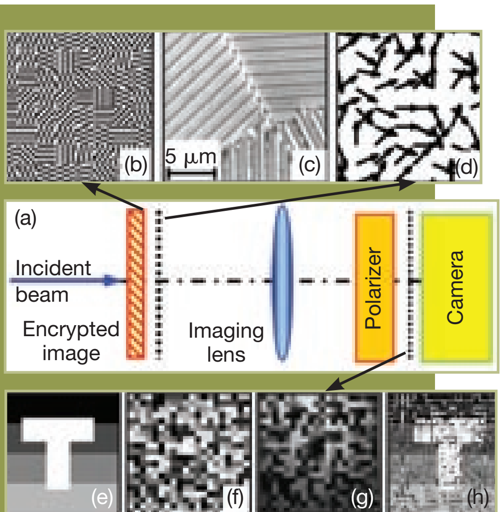
Researchers, policymakers and the public have become increasingly interested in data security over the past few years, and there has been a growing need for improved methods for data encryption. The demand for better and faster security devices is a result of the problems created by unauthorized users and commercial spies gaining access to communications networks. One of the processes that has been extensively investigated is the optical encryption technique.

Recently, polarization encryption has garnered a great deal of attention. Polarization encryption provides additional flexibility in key encryption designs by adding a polarization-state manipulation to conventional phase and amplitude manipulations. We propose an approach for polarization encryption using geometrical phase modification.[1,2]



(a) Schematic representation of the concept of geometrical phase encryption. (b) Subwavelength grating mask of the central region of the SWG. (c) Scanning electron microscope (SEM) image of the encrypted element taken from a small region in the element. (d) The measured polarization state of the beam emerging from the encrypted element taken from the central region. (e) Primary image intensity to be encrypted. (f) The wave plate's orientation function of the key element shown in grayscale. (g) A picture of the measured intensity obtained by the decryption process with the polarizer oriented at 0°. (h) Decrypted image achieved by the decryption process.

We recently demonstrated the formation of complex polarization-state manipulation by using computer-generated space-variant subwavelength gratings (SWGs).[2,3] We have also shown that such polarization-state manipulations inevitably lead to a phase modification of geometrical origin.[2,4,5]

Geometrical phase encryption, which is realized by using an SWG, results in a robust and stable encryption scheme. The method is suitable for chip integration and can be applied to personal security cards such as credit or identification cards.

To encrypt a primary image, we needed to form an SWG that encodes the image intensity while incorporating a random key function. The SWG, which is a space-variant rotating wave plate, imprints the image intensity along with the random key function in the local orientation of the wave plate's fast axes. Decryption is then performed by illuminating the encrypted element with circularly polarized light and retrieving the primary image by analyzing the emerging Stokes parameters using the correct key [part (a) of the figure]. Alternatively, instead of using the function of the correct key in the analysis, we can insert an SWG in the optical setup to serve as a decryption key.[1]

Part (b) is a magnified illustration of the subwavelength grating mask of the encrypted image. The primary image is shown in part (e). The encrypted element was comprised of 20 × 20 pixels, with each pixel having dimensions of 500 µm × 500 µm. The SWG was fabricated on a 500-µm-thick GaAs wafer to a nominal grating depth of 2.5 µm, with a 2 µm subwavelength period [part (c)].

Following the fabrication, we illuminated the encrypted element with a right-handed circularly polarized light at 10.6 µm wavelength. The beam emerging from the encrypted element was then transmitted through a polarizer at three different orientations (0°, 45° and 90°) [part (g)]. The decrypted image shown in part (h) was attained by calculating the Stokes parameters while applying the intensities and the correct geometrical phase key [part (f)].

Part (d) shows the measured space-variant polarization directions emerging from the encrypted SWG. As can be seen, the orientation of the arrows is completely random. The emerging field, which is a result of the vectorial self-interference, is a space-varying polarized field.

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