The Control of Optical States for Practical Quantum Cryptography

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Quantum cryptography has attracted considerable attention because it has the potential to provide us with unconditionally secure network communication by virtue of the principles of physics. However, the present state of the art limits its practical application to short-distance exclusive lines. To enable much wider use, such as in network communication, we need relay technology to increase the transmission distance and other breakthrough technologies for routing, error correction, and so on. To realize these technologies, utilizing quantum entanglement is indispensable.

The target of this project is to develop ways to create and to control quantum entanglement by using solid-state devices. These devices are crucial to allow miniaturization of quantum cryptography systems, and thus to enable commercial application in a broad range of markets. The theories of quantum entanglement will also be studied in this project in an effort to formulate guiding principles for developing such systems and devices.

The project team consists of the following groups.

[1] Experimental groups

(1) NEC Fundamental Research Laboratories (headed by K. Nakamura)

(2) NEC Research Institute (headed by L.J. Wang)

(3) University of Tokyo (headed by T. Kobayashi)

[2] Theoretical groups

(1) Tamagawa University (headed by O. Hirota)

(2) Communications Research Laboratory (headed by M. Izutsu)

The experimental groups will search for ways to effectively create and detect entangled photons, especially for quantum teleportation, which is one of the most important elements for quantum relay and routing technologies.

When a sender (Alice) wants to teleport a certain quantum state (usually one photon) to a receiver (Bob), they first share a pair of entangled photons. Alice then performs a joint Bell-state measurement on the photon she wants to teleport and one of the entangled photons, and randomly obtains one of the four possible Bell-states. This measurement non-locally transforms the other of the entangled pair into a corresponding quantum state. Alice then sends the measurement result to Bob by conventional means. Depending on the information, Bob applies one of the four unitary transformations to his photon of the pair to obtain a photon exactly the same as the original. This is the procedure of quantum teleportation. However, at the present stage, we cannot distinguishably obtain each of the four Bell-states. Only one of the four can be detected, thus the transmission efficiency of relay and other technologies using teleportation would be low.

In the NEC Fundamental Research Laboratories (FRL), a novel device for measuring the complete Bell-states has been proposed (Fig. 1) and will soon be fabricated. Through two-photon absorption (TPA) in a quantum dot or other appropriate material, one of the Bell-states can be detected. The other Bell-states can then be transformed into this state by using quarter wave plates (QWPs) or a rotator, and detected in order as shown. The know-how gained through the development of this device can also be used to develop our next target device - a nonlinear optical quantum gate that can create entangled quantum states at will.

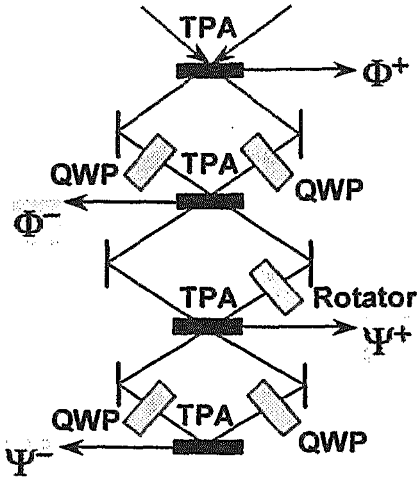

Fig.1 Complete Bell-state measurement device

The NEC Research Institute (NECI) plans to develop a highly efficient source of entangled photon pairs that will use a photonic crystal fiber (Fig. 2). Although this type of fiber is now being used to compensate wavelength dispersion in optical communication, the NECI group is the first to attempt using the fiber to create entangled pairs. The four-wave mixing in the fiber is the origin of photon pairs. These photons will be used for quantum cryptography systems and for quantum teleportation. The NECI group will also attempt to teleport the squeezed spin states of atoms.

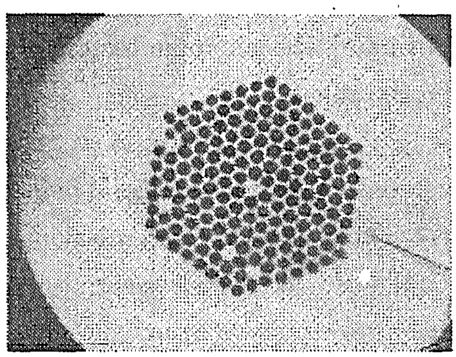
Fig.2 Photonic crystal fiber with 1.65μm -diameter air holes (black circles).

The University of Tokyo group will study the teleportation of non-classical photon states with entangled squeezed light, which can be realized only when the system fidelity is over 0.66. This high fidelity will be achieved by increasing the degree of squeezing by using two independent optical parametric oscillation sources. Teleportation with squeezed light is a promising alternative to that with single photon pairs.

The Tamagawa University and Communications Research Laboratory groups will jointly study the optimum design of quantum cryptography systems. This work will be based on a theory of how unitary control can be realized and on quantum circuit theory, and should leads to the formation of guiding principles for developing the devices described above.

The collaboration between these groups should thus accelerate the development of the devices for commercially viable quantum cryptography systems.