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NIPPON TELEGRAPH AND TELEPHONE CORPORATION

NEWS RELEASE

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Success in trapping and delaying light for over one nanosecond using photonic crystals

- Slowing down the speed of light to one 50 thousandth -

Nippon Telegraph and Telephone Corp. (NTT; Head Office: Chiyoda-ku, Tokyo; President: Norio Wada) has succeeded in trapping light over one nanosecond within a wavelength-sized micro-cavity using an artificial periodic structure called "photonic crystal", and also succeeded in reducing the speed of light down to one 50 thousandth of that in air which enabled the delay of light over one nanosecond using the same device.
It has been long believed that it is fundamentally difficult to trap and delay the light effectively. NTT has resolved this problem by finding out novel design of ultra-small optical resonators using photonic crystals and realized devices based on this design by the state-of-the-art nano-fabrication technology. This result opens up various possibilities for photonics such as, a large-scale photonic information processing chip[*1] with extremely small consumption power and an optical quantum information processor[*2] operating with single photons[*3]. This result will be reported in "Nature Photonics" magazine on December 22.

Background
Today's photonics technologies, such as B-FLET'S service of NTT, enable ultrafast information transmission and are playing a key role in recent rapid progress of our highly-networked information society. However, light cannot be stopped, and is fundamentally difficult to be trapped or delayed, which results from the requirement of Prof. Einstein's famous relativistic theory. This feature of photonics is very different from that of electronics and has limited the possibility of photonics applications such as functional photonic information processing and photonic large-scale integrated circuits. Therefore, technology enabling confining, trapping, and delaying light at will has been strongly demanded. Recently, various micro-cavities, such as micro-ring cavities, are extensively studied for achieving a long trapping time. As regards longer delay time, various materials and structures are investigated world-wide, which are generally called as "slow-light[*4] media".
Photonic crystal is an artificial dielectric structure with peridically-arranged air holes of a few nanometer radius fabricated by nano-fabrication technologies, and shows many unusual properties that do not exist in materials in nature. One of them is the formation of "photonic bandgaps". In some particular wavelength region called a photonic bandgap, it behaves as a photonic insulator and inhibits the transmission of light. Using this property, it becomes possible to strongly confine the light, which will lead to an effective way for trapping and delaying light for a long time in a small space.
NTT has found out a novel design of photonic crystals for realizing ultrasmall optical

resonators which can strongly confine the light in a wavelength-sized region, and have fabricated this design in a silicon chip by the state-of-the art high-resolution nano-fabrication technology. Consequently, NTT has succeeded in demonstrating that this tiny device can trap and delay the light signal with much longer time scale than that of conventional devices.

Experiments and Results

The present device is based on a photonic crystals with hexagonally arranged air holes with 100 nanometer radius fabricated by highly-fine electron-beam lithography and high-resolution dry etching technique on a silicon chip. (Fig. 1(a)). Our design for ultrasmall optical cavities consists of a single-missing-line of air-holes in a photonic insulator (namely, the periodic part of the lattice). This line-defect part can transmit the light, and its loss is theoretically zero. The key point for our design is that several holes surrounding this line defect are intentionally shifted toward outside by only three to nine nanometers (Fig. 1(b)). This slight shift effectively modulates the width of this line defect part and produces the strong confinement. The numerical calculation showed that an optical confined mode with extremely small leakage loss is formed in the width-modulated part.

This type of cavities have been fabricated and integrated with input and output waveguides on a silicon chip (Fig. 1(c)). The transmission spectra (Fig. 2(a)) shows an ultra-sharp resonance peak of which width is 1.3 picometers. This width corresponds to the cavity quality factor (Q-value)[*5] of 1.2 million which is the largest value ever reported for any wavelength-sized optical cavities. Next, the time-resolved output signal was measured after abruptly switching off the input (Fig. 2(b)). The results show that light is trapped in the cavity for over a one nanosecond. Subsequent pulse input measurements showed that the transmission of an optical pulse was delayed for 1.45 nanosecond by the cavity (Fig. 2(c)). This delay corresponds to the traveling speed of light reduced down to one 50 thousandth of that in air. (Note that the device length is only 8 microns, but light travels approximately half a meter in the same time period in air.) The resultant trapping and delaying times are the longest among any wavelength-sized dielectric media, and the speed reduction of light by 50 thousands is over two orders of magnitude larger than that reported for any artificial dielectric slow-light media.

Future developments

If light can be confined, trapped, and delayed freely in a wavelength-sized area, various functional components and circuits that have been thought as difficult to be achieved in photonics will be realized, such as large-scale photonic integrated circuits, highly-functional logic circuits, and optical information processing with extremely small consumption power. This means that one can replace many electronic components and circuits with photonic counterparts. NTT laboratories will try to apply the present ultra-small optical cavities to ultra-small optical processing devices, such as all-optical switches, with extremely small consumption power. In addition, NTT will investigate the possibilities for applications in optical buffering function with much longer delay time and also photonic memories in which one can directly store photon quanta. Ultimately, the combination of these technologies will lead to photonic information processing chip with extremely small consumption power, and also to quantum information processors that can be operated by single photons.

Glossary

*1 **Photonic information processing chip**

A chip can process all the information optically. Conventional information processing is done by an electronic processing chip after converting photonic high-bit rate signals transmitted by optical fibers to electronic signals. It has been expected that ultrafast and low-consumption power information processing will be possible by processing the high-bit rate information optically.

*2 **Optical quantum information processor**
A processing device that performs quantum processing, such as quantum calculations or quantum cryptography using quantum properties of light. It should be operated with a unit of single photons, and should not destroy the quantum information of photons.

*3 **Photon**
Quantum of light. Any light with lower energy than that of photon (10^{-19} Joule in 1.5 micron wavelength commonly used in optical fiber communication) cannot exist

*4 **Slow-light**
Recently, various types of materials and structures are extensively investigated so as to slow down the light velocity as much as possible with the purpose of realization of optical buffering memories and low-power optical processing. The target materials and structures are generally called as "slow-light" media. The typical examples are specific atomic states of ultra-cold atom gas and artificial dielectric structures such as photonic crystals.

*5 **Cavity quality factor (Q-value)**
Characteristic value that represents the strength of the confinement for a resonator. Q is deduced by the resonance frequency divided by the resonance width, and it represents how long the light can be confined in a resonator.

- Fig. 1(a) Fabrication process of photonic crystals, and electron micrograph images of fabricated Si photonic crystals.
- Fig. 1(b) Design and mode profile of a width-modulated line-defect photonic-crystal cavity.
- Fig. 1(c) Scanning electron micrograph and schematic of the fabricated sample with a width-modulated photonic-crystal cavity.
- Fig. 2(a) Spectral measurement.
- Fig. 2(b) Trapping experiment.
- Fig. 2(c) Delaying experiment by a pulse input.

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