Success in Trapping and Delaying Light for over 1 ns in Photonic Crystals—Slowing Down the Speed of Light to 1/50,000

NTT has succeeded in trapping light for longer than 1 ns within a wavelength-sized microcavity using an artificial periodic structure called a photonic crystal. Using the same device, it has also reduced the speed of light in the structure to 1/50,000 of that in air, which delayed the light for over 1 ns.

It has long been believed that it is fundamentally difficult to trap and delay light in any easy and convenient manner. Previous achievements required bulky apparatus and/or ultralow-temperature cooling. NTT has resolved this problem with a novel design for ultrasmall optical resonators using photonic crystals and has constructed actual devices based on this design using state-of-the-art nanofabrication technology. This opens up various possibilities for photonics such as a large-scale photonic information processing chip with extremely small power consumption and an optical quantum information processor operating with single photons.

Experiments and results

The device is based on a photonic crystal with hexagonally arranged air holes 200 nm in diameter fabricated by very fine electron-beam lithography and high-resolution dry etching on a silicon chip. 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 of our design is that several holes surrounding this line defect are intentionally shifted outwards by only 3–9 nm. This tiny shift effectively modulates the width of this line defect part and produces strong confinement. Numerical calculations have shown that an optical confined mode with extremely small leakage loss is formed in the width-modulated part.

Cavities of this type have been fabricated and integrated with input and output waveguides on a silicon chip. The transmission spectrum showed an ultrasharp resonance peak with a width of 1.3 pm. This width corresponds to a cavity quality factor (Q-value) of 1.2 million, which is the highest value ever reported for any wavelength-sized optical cavity. Next, the time-resolved output signal was measured after the input was abruptly switched off. The results show that light was trapped in the cavity for over 1 ns. Subsequent pulse input measurements showed that the cavity delayed the transmission of an optical pulse by 1.45 ns. This delay corresponds to a reduction in the propagation speed of the light to 1/50,000 of that in air. The device is only 8 μm long, but light travels approximately half a meter in air in the same time. The resultant trapping and delaying times are the longest reported for any wavelength-sized dielectric medium, and the reduction of the speed of light by 50,000 is over two orders of magnitude larger than that reported for any artificial dielectric slow-light medium.

Future developments

NTT laboratories will try to apply these ultrasmall optical cavities to ultrasmall optical processing devices, such as all-optical switches, having extremely low power consumption. In addition, NTT will investigate the possibilities for application to optical buffers with much longer delay times and to photonic memories that can store photon quanta directly. Ultimately, the combination of these technologies could lead to a photonic information processing chip with extremely small power consumption and to quantum information processors that can be operated by single photons.

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