Optoelectronics, All-optical switch, Super resolution imaging

Giant nonlinear optical scattering by Si nanoresonator

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Abstract

It is found that extremely large nonlinear optical scattering of 100,000 times compared to natural bulk values occurs in an individual nano-optical resonator of single crystalline silicon (c-Si), and this effect is caused by photothermal effect by Mie resonance. As a result, it is possible to use nonlinearity of Si with continuous wave light without using ultrashort light pulse. This is expected to be applied to all-optical switching devices, super-resolution imaging, etc. in silicon photonics elements.

Background & Results

In order to control light with light, it is necessary to increase optical nonlinearity of materials. In order to enhance the nonlinearity of Si, research has been conducted to strongly confine light into various nanostructures of such as micro-ring resonators or photonic crystals etc. Since above structures are complicated, more simple methods were required.

In this study, we focused continuous laser beam to a cubic Si nanoresonator (Fig. 1a) to investigate its scattered spectrum experimentally. We have found that nonlinear optical scattering that saturates the scattered light intensity when a light beam power of 10^5 W / cm^2 is applied to the resonator (Fig. 1b). This power density is 10^5 times smaller than that of bulk Si. In addition, observed saturation phenomenon was reversed to supersaturation depending on the size of the resonator (Fig. 1c).

If the size of a nanostructure is the same order of the wavelength of the incident light, Mie resonance occurs at specific wavelengths. At the resonance, light is strongly scattered and confined into a resonator to cause a rapid temperature rise over several hundred Kelvin. As a result, refractive index changes rapidly due to photothermal effect, and the scattering intensity is deviated largely from the linearity. On the other hand, since the volume of the resonator is smaller than 0.001 μm^3, heat is immediately escaped to the substrate when the laser is turned off. As a result, the scattering intensity of signal light of 543 nm can be modulated in ON / OFF switching by controlled light with 592 nm (Fig. 2).

Significance of the research and Future perspective

The fact that natural nonlinear optical constant of Si is significantly amplified has an impact to silicon photonics. Conventionally, the thermal optical effect has been considered to be slow, but since the relaxation time of this effect is confirmed to be the order of nano (10^{-9}) seconds, it can operate at high speed at 10 GHz in the future. Hence, this product is expected to be applied to light control devices, super-resolution imaging (Fig. 3), etc., including all-optical switches in silicon photonics.

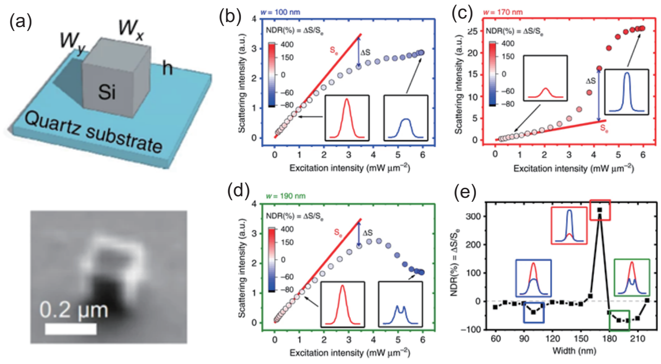

Fig.1

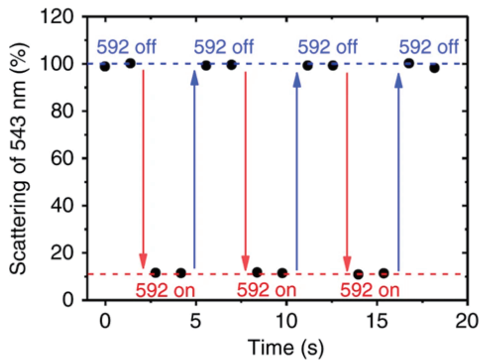

Fig.2

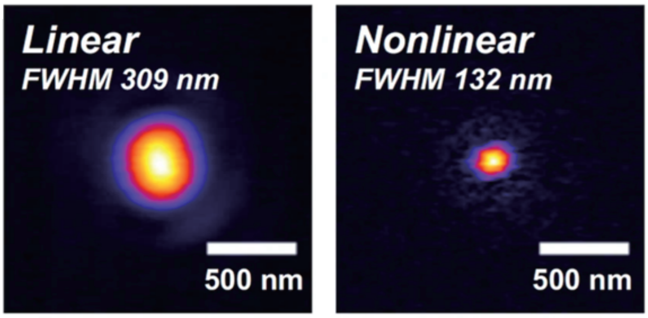

Fig.3

Patent

Treatise
Tang, Yu-Lung: Yen, Te-Hsin; Nishida, Kentaro et al. Mie-enhanced photothermal/thermo-optical nonlinearity and applications on all-optical switch and super-resolution imaging [Invited]. Opt Mater Express. 2021; 11(11): 3608-3626. doi: 10.1364/OME.431533
Duh, Yi-Shiou; Nagasaki, Yusuke et al. Giant photothermal nonlinearity in a single silicon nanostructure. Nature Commun. 2020; 11: 4101. doi: 10.1038/s41467-020-17846-6

URL

Keyword Mie resonator, Kerr effect, silicon photonics, all-optical switch