Photocatalytic materials, Solar cells

Visualizing atomic-scale structures with the optical force

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Abstract

Nanoparticles are attracting attention as photofunctional materials for use in photocatalysts, solar cells, and other applications. Near-field scanning optical microscopes can produce images that reflect the optical properties of such samples, but observation with atomic-scale resolution has not been realized.

The research team has succeeded in imaging the near-field light of composite nanoparticles, which are designed as high-performance photocatalytic materials, with a resolution of less than one nanometer using a photo-induced force microscope that measures the optical force (Figs. 1-2). The key to the high-resolution observation was the realization of observation in an ultra-high vacuum and elimination of the effects of heat caused by light irradiation. By observing the composite nanoparticles using multiple wavelengths of light, we were able to confirm that the composite nanoparticles had the chemical properties as designed by using light pressure images approaching atomic resolution, and we also succeeded in obtaining three-dimensional vector images of optical force (Fig. 3). This achievement is expected to become a new fundamental technology for the design and evaluation of functional nanomaterials.

Background & Results

Recently, a variety of nanoparticles with trapped electrons have been synthesized, and they are attracting attention as new photofunctional materials for photocatalysts and solar cells. In order to evaluate the optical functions of individual nanomaterials from a microscopic viewpoint, it is necessary to excite the sample and observe the near-field light in the vicinity of the sample on an atomic scale. Until now, scanning near-field microscopes have been used to observe the near-field light, but it has been impossible to obtain atomic-scale resolution.

The research team succeeded in achieving an order-of-magnitude higher resolution by dramatically increasing the force detection sensitivity of the photo-induced force microscope by operating it in an ultra-high vacuum, and by reducing the effect of heat generation to the utmost limit by devising a unique timing for repeated light irradiation.

The quantum dots synthesized as high-performance photocatalytic materials were observed with photo-induced force microscope using light of different wavelengths, and the data were analyzed theoretically. The results showed that the near-field optical images were obtained with a spatial resolution of less than 1 nm, reflecting the chemical properties devised to enhance the photocatalytic function. In addition, we succeeded in obtaining a three-dimensional vector image of the optical force.

Significance of the research and Future perspective

Using this technique, we can observe the near-field light of nanostructures with atomic resolution, which will greatly improve the design and evaluation for the synthesis of new nanomaterials. Therefore, this technology is expected to become a new fundamental technology for the realization of innovative photocatalytic and solar cell materials in the future.

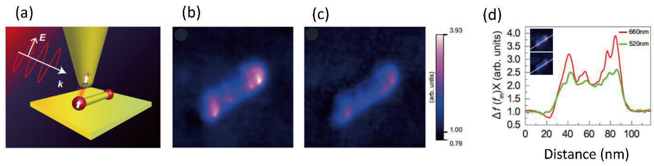

Fig.1 (a) Schematic image of photoinduced force microscopy. (b)(c) Photo-induced force microscopy images of a quantum dot measured using different wavelengths (600 nm,520 nm). (d) Photoinduced force profiles for the images. This reflects the electronic energy structure designed for photocatalysis.

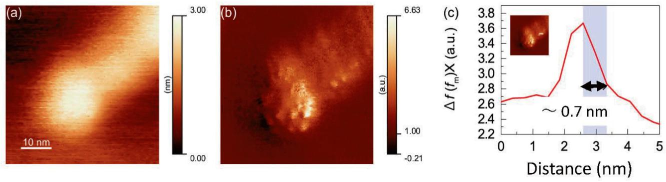

Fig.2 (a) Atomic force microscopy image of a quantum dot. (b) Photoinduced force microscopy image at 660 nm. (c) Photoinduced force profiles for the image. A spatial resolution of less than 1 nm has been obtained.

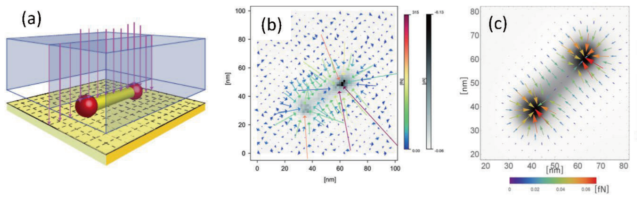

Fig. 3 (a) 3D force field mapping of the photoinduced force. (b) Experimentally obtained 3D photoinduced force field map using the laser with 660 nm wavelength. Colored arrows indicate the magnitude and direction of the force in the plane. The black and white shading indicates the magnitude of the force in the height direction. (c) Theoretically calculated 3D photoinduced force field map. The tendency to explain the results of experiments well is evident.

Patent

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