【Grant-in-Aid for Specially Promoted Research】

Development of Optical Force-Based Technologies for Discriminating, Separating, and Analyzing Quantum Signatures at the Nanoscale

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Project Information	Project Number:26H00005 Keywords:Optical forces, Fluorescent nanodiamonds, Multinary quantum dots, Stimulated recoil force	Project Period (FY):2026-2030

Purpose and Background of the Research

●Outline of the Research

Technologies for identifying and sorting matter by differences in properties are essential to materials development, medicine, and chemical analysis. Conventional methods exploit differences in size, mass, charge, or interactions with surrounding media. However, no practical method has been established for identifying, sorting, concentrating, and recovering individual nanoparticles such as quantum dots and fluorescent nanodiamonds on the basis of particle-to-particle differences in emission wavelength, emission efficiency, and quantum properties. This project addresses this challenge by using optical-force-induced motion to identify particle properties and apply them to sorting, concentration, and recovery. In particular, we will use the stimulated recoil force pioneered by the PI to extend property-based sorting toward practical recovery and use. By linking this principle with advanced nanoparticle technologies originating in Japan, we aim to create a new platform for materials based on the properties of individual particles.

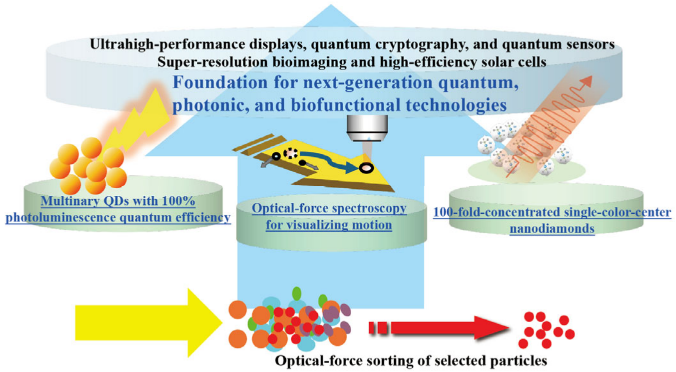

Figure 1. Schematic of nanoparticle sorting by optical forces, the present research developed on this basis, and the future technologies it aims to enable.

● Significance of This Research

A major problem in current nanomaterial development is that even particles made of the same material often show different emission efficiencies and emission wavelengths. This is particularly important for quantum dots and fluorescent nanodiamonds, which are promising for next-generation light sources, quantum technologies, and biomedical sensing, yet methods for selectively isolating only particles with well-defined performance remain undeveloped. This project will open a new route to sorting particles not by size or mass, but by the individuality of their optical functions. It will provide a basis for producing and using high-performance nanomaterials according to the properties required for specific applications.

● Academic Originality and Creativity

The originality of this project lies in moving beyond simply measuring light emission from nanoparticles to identifying their individuality through light-driven motion. Building on our finding that optical forces can convert quantum-level differences into mechanical motion, we will use the stimulated recoil force (Fig. 2) to transport and sort nanoparticles as small as ~10 nm. This globally unprecedented approach integrates spectroscopy, sorting, and recovery into a single strategy for creating advanced nanomaterials.

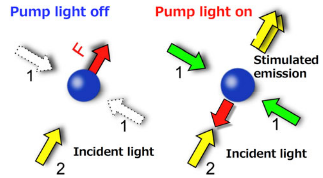

Figure 2. Concept of the stimulated recoil force. Left: Conventional optical force pushes a nanoparticle along the light direction, but saturation limits the force on very small particles. Right: Light 1 excites an electron, and incident light 2 induces emission. One photon is absorbed and two photons of the same momentum are emitted, pulling the nanoparticle toward the light source. Because this process does not saturate, a much stronger force is possible.

Expected Research Achievements

● Research Methods

In this project, nanoparticles will be manipulated in a laser-integrated microfluidic channel and identified and sorted from motion differences induced by optical forces. During sorting, particle motion will be monitored by fluorescence imaging and interferometric scattering microscopy (iSCAT) as shown in Fig. 3, while trapped and recovered particles will be examined by scanning electron microscopy (Fig. 4), enabling single-particle correlation of emission, structure, and motion. By alternately applying optical forces and observing particle properties (Fig. 5), and by incorporating the stimulated recoil force developed by the PI, this approach will advance toward a practical technology for sorting, concentration, and recovery.

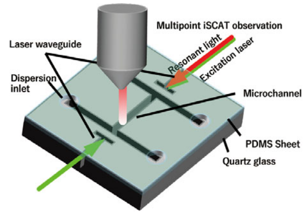

Figure 3. Laser-integrated microfluidic channel for nanoparticle sorting and motion imaging by fluorescence and iSCAT.

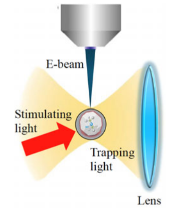

Figure 4. Schematic of a scanning electron microscope for observing the motion of optically trapped nanoparticles.

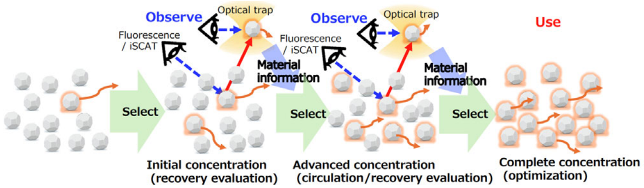

Figure 5. Concept of stepwise nanoparticle concentration through repeated selection and observation.

● Expected Research Achievements

As concrete targets, we aim to achieve 100-fold concentration and recovery of fluorescent nanodiamonds containing SiV centers, and nearly 100% photoluminescence quantum efficiency in multinary quantum dots by removing non-emissive particles. These results are expected to enable applications in single-photon sources, quantum sensing, and bio-imaging. In addition, direct observation of particle motion will establish optical-force spectroscopy as a new method for probing the optical functions and quantum individuality of single nanoparticles.

Website(s)	https://research-db.ritsumei.ac.jp/rithp/k03/resid/S002876?lang=en