【Grant-in-Aid for Scientific Research (S)】

Broad Section D

Title of Project : Development of novel optical manipulation systems based on the design of environment and luminescence

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Research Project Number : 21H05019 Researcher Number : 60273611
Term of Project : FY2021-2025 Budget Allocation : 144,800 Thousand Yen
Keyword : Optical force, Optical Manipulation, Luminescence, Nano particles, Opto-mechanics

【Purpose and Background of the Research】

Light has momentum and exerts a force on the matter by being scattered and/or absorbed. We have theoretically proposed and experimentally demonstrated the selective optical manipulation using optical force according to the quantum mechanical individuality of nanoparticles depending on their size, shape, and internal structure. In this project, we will develop a new method of optical manipulation using the force generated by "luminescence" which is one of the most fundamental phenomena in the optical response of materials, based on the strategy of designing the environment (dielectric environment and radiation environment). Using this new method, we will experimentally demonstrate the possibility of selecting nanoparticles with a specific luminescence line by using the recoil force due to stimulated emission from photo-excited particles, which is not possible with conventional optical manipulation, and also the possibility of optomechanics in which mechanical vibration is induced by luminescence. In addition, we will develop a method to select quantum dots with extremely narrow line widths below μeV under cryogenic conditions.

【Research Methods】

In this project, we will pioneer the optical manipulation by "luminescence" using the theoretical method by the research representative, the world's first technology of excitonic optical transport by the Ashida group, and the state-of-the-art technology of nanomechanical engineering by the Akita group. Specifically, we will address three research topics to clearly demonstrate the realization of optical manipulation by luminescence, as follows.

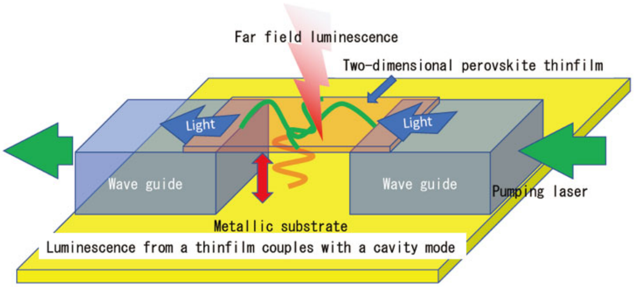
[1] Demonstration of optical force generation by stimulated emission and narrowing of emission lines through the selection of luminescent nanoparticles.

[2] Demonstration of optomechanics systems by the luminescence of perovskite films on metal substrates.

[3] Observation of optical force induced by superfluorescence of the perovskite nanoparticle assembly.

In [1], we demonstrate optical force generation using stimulated emission for nanodiamonds with NV-centers, a typical example of a four-level system, and challenge the selective transport of large volume of nanodiamonds according to the presence or absence of NV-centers.

In [2], we will use two-dimensional materials to measure mechanical resonances with high precision. The mechanical motion is induced by the luminescence of nanofilms excited via the waveguide mode. We will



Optomechanical system with 2D drum resonator structure. The coupling between the luminescence and the mechanical resonance of the thin film is analyzed.

observe the coupling between luminescence and a cavity composed of the thin film and the substrate to realize luminescence-induced optomechanics. (See above figure.)

In [3], perovskite nanoparticles in superfluid helium are strongly excited to form an inverted population, and superfluorescence is induced by a stimulating laser. Then, by observing particle motion, we will clarify the correlation between the superfluorescence and the particle dynamics caused by the recoil optical force.

【Expected Research Achievements and Scientific Significance】

Fundamental aspect: By converting luminescence into mechanical motion of nanostructures, the formation of quantum coupling can be realized even without the photodetection, which will lead to a novel platform for studying quantum systems through "mechanical motion".

Applications: The selective manipulation of single-photon emitters with an ultra-narrow line will realize ultra-sensitive sensors and quantum entanglement generation systems, which will contribute to the realization of information and biosensing devices. Further, the platform for studying novel methods of nanoscale manufacturing will be realized.

【Publications Relevant to the Project】

・ H. Ishihara, "Optical manipulation of nanoscale materials by linear and nonlinear resonant optical responses" Advances in Physics: X, 6, 1885991 (2021)
・ H. Ishihara, "Nanoscale Optical Response" Comprehensive Nanoscience and Nanotechnology Vol. 4, p323-346 (2019) (Elsevier Science and Technology)

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