学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Study on plasmonic-photonic hybrid systems for efficient excitation of nonlinear phenomena
（非線形現象の高効率励起に向けたプラズモニック-フォトニックハイブリッドシステムの研究）

Localized surface plasmons (LSPs) induced in metal nanostructures have been the subject of intensive research in recent years, because they have the ability to confine light into the nanoscale areas beyond the diffraction limit and to enhance the light-matter interaction. They have been used in various applications, such as optical sensing, surface enhanced Raman spectroscopy, two-photon excited fluorescence (TPF), and second harmonic generation (SHG). Specially, during the last decade, enhanced nonlinear phenomena induced by surface plasmon have been extensively studied as new light sources at the nanoscale. However, because of the huge scale mismatch between photons and metal nanostructures, it is difficult to couple light into single metal nanostructure efficiently, resulting in the use of a high intense pulsed laser excitation for nonlinear phenomena.

Therefore, to harness the merits of plasmonic nanostructures for nonlinear application, it is necessary to improve the coupling of light to single metal nanostructure. In this study, I propose two types of plasmonic-photonic hybrid systems to efficiently excite LSPs at the single metal nanostructure, and demonstrate the nonlinear phenomena (SHG and TPF) within these plasmonic-photonic hybrid systems under a weak continuous wave (CW) excitation.

Firstly, one plasmonic-photonic hybrid system composed of an Au-coated tip and a tapered-fiber-coupled microsphere resonator is proposed. From the results, it is found that a tapered-fiber-coupled microsphere resonator could focus the light into a nanoscale domain of the Au-coated tip with high coupling efficiency (~93%). This hybrid system is demonstrated to possess not only high Q factor (~10^6), but also small mode area (less than ~10^3nm^2). In order to experimentally verify the efficient excitation of LSPs at the Au-coated tip, SHG from the top of Au-coated tip under a weak CW excitation is investigated. Furthermore, I also observe TPF from pseudoisocyanine (PIC) dye molecules attached on the Au-coated tip using the same plasmonic-photonic hybrid system. The results suggest that the synergetic effect of strong optical confinement effect of a microsphere resonator and optical antenna effect of an Au-coated tip using this proposed system tremendously results in the strong light-matter interaction at the nanoscale.

Whereas the photonic microsphere resonator with the ultra-high Q factor facilitates the efficient coupling of light from the tapered fiber to the single plasmonic nanostructure, this hybrid system is complicated which result in difficult alignment in the experiment. Thus, I also demonstrate a simple tapered fiber based photonic-plasmonic hybrid nanostructure composed of a thin tapered fiber and an Au-coated tip. Using this simple hybrid nanostructure without photonic microresonator, a thin tapered fiber, which has small transverse dimensions, can also efficiently couple light into single metal nanostructure with small dimensions. I also succeed in observing TPF from the PIC dye molecules under a weak CW excitation condition, although it has weak field enhancement and low Q factor.

In brief, taking advantages of both plasmonic and photonic elements, the two types of plasmonic-photonic hybrid systems have been proposed to improve the efficient coupling of light into the nanoscale domain of single metal nanostructure, which tremendously result in the strong light-matter interaction at the nanoscale. Furthermore, nonlinear phenomena within these hybrid systems under a weak CW excitation condition (~kW/cm^2) are investigated. They are the promising tools for single photon sources, highly efficient plasmonic sensors, and integrated nonlinear plasmonic devices.