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論　文 題目	Hybrid photonic systems consisting of dielectric photonic crystals and plasmonic meta-atoms for nanoscale light manipulation (誘電体フォトニック結晶とプラズモニックメタ原子結合系におけるナノスケール光制御)		

（論文内容の要旨）

This doctoral dissertation contains 7 chapters to study how light can be manipulated in a tiny space via cavity mea-atom interaction.

As an essential technical progress towards the nanometric functionality, obtaining nanoscale controllability for radiative photons where sub-diffraction-limited region will pave the way for extended photon controllability, and have various applications in a broad range of research fields. Although several methods have been devised to control polarizations and angular momentum of light using dense arrays of plasmonic nano-antennae, so far, they have not been effective in the nano-region due to the weak polarizability along single nano-elements. However, nanocavity-assisted architecture that can boost the interaction strength to a nano-element could play an important role in overcoming this problem and realizing nano-scale functionality. One promising approach that can increase interaction strength to nano-elements is modifying the local optical density of state of their surrounding environment. Dielectric-based photonic crystals can provide such a successful photonic platform to modify and concentrate photonic density of state into a point - defect. Accordingly, combining photonic crystals and plasmonic meta-atoms which can provide sub wavelength electric/ magnetic resonance is an inevitable step to introduce microscopic-functional devices. Thus, we investigate hybrid photonic architectures that consist of photonic crystal nanocavity (PCNC) and plasmonic meta-atoms to attain nanosclae controllability.

In chapter 1, we briefly introduce our research aims to extend manipulation degree of freedom into a nanoscale region, and suggest the possible approach with fundamental concept of nanosclae light manipulation.

In chapter 2, as the starting point for our discussion, theoretical background and numerical method are discussed here. In an optical point of view, we provide a brief historical overview of metallic study, and we derive general properties of plasmonic modes and scattering resonance for dispersive gold material by assuming simple geometric case with Drude-Lorentz form.

In chapter 3, we suggest the elements of the composite system, and investigate optical characteristics of the each element. Electric and magnetic resonant element using plasmonic meta-atoms and a PCNC are chosen for the components of hybrid photonic system. Single BAR/ SRR (Split ring resonator) structure has shown an induced electric/magnetic polarizability owing to their collective charge oscillation in response to geometric linear/circular shape, respectively. Resonant features at optical frequency regime associated with geometric parameters are discussed through the numerical calculation.

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In chapter 4, we design a hybrid photonic system, and fabricate it. Structural design is suggested based on numerical calculations. Particularly, the perturbation effect of meta-atoms are severe enough when it directly attached on high refractive index material (Si n=3.4). We introduce low-refractive-index space layer such as Silica (n=1. 45) to attain a resonant matching condition between meta-atoms and PCNC. In the case of fabrication part, SOG (Spin on glass) thickness was discussed to precisely control the thickness of the intermediate layer.

In chapter 5, we investigate cavity meta-atom responses. We have demonstrated local magnetic response as well as electric response using composite systems consisting of PCNC+BAR and PCNC+SRR. We measured quality factor of composite systems to validated cavity meta-atom response: PCNC+BAR showed ΔQ~9. 1 dB changes and PCNC+SRR showed ΔQ ~7.4 dB as a function of meta-atom position. The location dependence of the interaction shows sub wavelength scale locality based on electric and magnetic field coupling by enhancing meta-atom radiation.

In chapter 6, we suggest methods that can design arbitrary polarizations by controlling the intensity and the radiation phase from the meta-atom-loaded PCNC. In the case of circular polarization, we use two meta-atoms within sub-diffraction-limited range where the each radiation element can be simultaneously excited. Because of BAR and SRR has orthogonal radiation pattern, circular polarization from a PCNC can be achieved by phase controlled excitation. Furthermore, wavelength selective LHC (Left hand circular polarization) and RHC (Right hand circular polarization) has been experimentally demonstrated at an on-chip level by taking advantage of integration with photonic-crystal-based circuit.

In chapter 7, we investigate further design concept, and suggest an overall conclusion. Practically, we combine photonic band edge mode and meta-atoms to extend our concept. We discuss the possible methods for selective excitation of guided resonance mode by showing numerical results, and summarize our work and present future outlook of this research.

Finally, it is notable that our manipulation concept using a cavity meta-atom interaction of the local electric/magnetic fields is applicable to any types of photonic-crystal cavity structure, and not only provides the control of simple polarization states, but also has expandability such as control of more complex polarization state (vector beams), and arbitral molding of near-field distribution. In addition, this technique can be used in a reverse way to collect light with specific polarization states into photonic circuits. Therefore, a photonic crystal cavity that combines meta-atoms may invite new functionality in nanosystems and stimulate wide optical applications from photonics, chemistry, and biology.