Interaction and Mutual quantum control of light and matter

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1．Purpose

Various phenomena and function that cannot be realized by ordinary optical devices are expected in photonic crystals and metamaterials whose permittivity (and/or permeability) is modulated on a scale comparable to or smaller than the wavelength of the electromagnetic waves. In our laboratory, we study cavity quantum electrodynamic effects and nonlinear optical effects of photonic crystals, microcavities, metal nanostructures, and metamaterials, that can mutually control light and matter. The goal is to create devices that operate based on new principles that will play a role in 21st century science and technology such as optical information communication and quantum computing.

2．Research Summary

In this study, we investigate various light and matter interaction in Fabry-Pérot microcavities represented by one-dimensional photonic crystals and metamaterials, and attempt mutural quantum control. Our recent results are as follows.

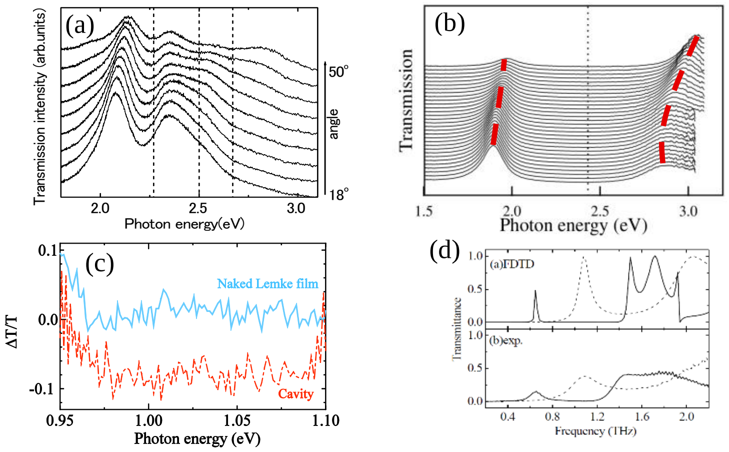

Fig.1 Experimental results

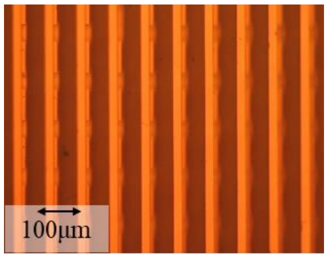

Fig. 2 Microscope Image of THz Fabry-Pérot microcavity made of wire grid structures containing metamaterials

In the visible region, we have energetically conducted research on cavity polaritons in microcavities containing organic materials. As shown in Fig. 1 (a), we have succeeded in observing a cavity polariton with multiple branches using a Fabry-Pérot cavity with metal mirrors in a perylene-based liquid crystalline organic semiconductor [1]. In addition, as shown in Fig. 1 (b), we have succeeded in observing giant Rabi splitting exceeding 1 eV by using Lemke dye [2]. This corresponds to the ultra-strong coupling regime and is a phenomenon that has been receiving attention in recent years. Furthermore, as shown in Fig. 1 (c), we succeeded in observing transient absorption, which seems to be a transition between polariton branches in this system [3].

In the THz region, we have succeeded to fabricate microcavity samples in which metamaterials were introduced into a Fabry-Pérot cavity with wire grids as a mirror as shown in Fig. 2, and the large transmission peak splitting similar to that of the cavity polaritons was successfully observed as shown in Fig. 1(d). This is currently under paper submission [4].

3．Utilization of results

So far, we have investigated various optical properties of one-dimensional photonic crystals and metamaterials that are expected to be applied to new optical devices. In the future, Bose-Einstein condensation and generation of entangled photon pairs can be expected in microcavities that exhibit ultra-strong coupling. And ultrafast transmission modulation switching is possible in THz-region microcavities that include metamaterials, which is expected to be applied to information, imaging and sensing devices.

4．References

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[2] "Observation of cavity polaritons in a metal-mirror Fabry-Pérot microcavity containing liquid-crystalline semiconductor based on perylene bisimide units", N. Kani, *et al*., Phys. Rev. E, Vol 100, 032701 (2019).
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