論文 / 著書情報
Article / Book Information

題目(和文)	フォトニック結晶と光学薄膜を融合したナノフォトニックシステム
Title(English)	The hybrid nanophotonic systems with photonic crystals and thin optical films
著者(和文)	千葉永
Author(English)	Hisashi Chiba
出典(和文)	学位:博士(理学), 学位授与機関:東京工業大学, 報告番号:甲第11367号, 授与年月日:2020年3月26日, 学位の種別:課程博士, 審査員:納富 雅也,藤澤 利正,宗片 比呂夫,相川 清隆,平原 徹
Citation(English)	Degree:Doctor (Science), Conferring organization: Tokyo Institute of Technology, Report number:甲第11367号, Conferred date:2020/3/26, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	要約
Type(English)	Outline

Abstract

In this research, we aim to apply a nano film material having unique optical functionalities to a photonic crystal which strongly confines light, and to apply it to a novel light control element.

The previous research studies of photonic-crystal-based light-control elements employed intrinsic properties, such as optical nonlinearity, of materials constituting the photonic crystal. Hence, the material choices and available functionalities were limited. Here, we focus on a functional nano film exhibiting phase transition or a dramatic change of the refractive index. It is expected that photonic crystals with functional nano thin films can realize a novel light-control element. In addition, the problem that the nano film has a small interaction with light because of its deep sub-wavelength thickness can be solved by enhancing the light-matter interactions by strong light confinement of photonic crystals.

We theoretically demonstrate that tiny resonant cavities can be formed using the refractive index modulation by nano films loaded on photonic crystals. Photonic crystal cavities loaded with graphene were studied by several research groups, but they did not propose a method to form a cavity by graphene on a photonic crystal without a cavity prefabricated. Furthermore, not only graphene but also the cavity formation by a sub-wavelength nano thin film itself has not yet been demonstrated.

In order to demonstrate the graphene-induced cavity formation proposed, it is necessary to control the Fermi energy of graphene loaded on a Si photonic crystal. In this research, we first investigate methods to fabricate graphene-loaded photonic crystal devices whose Fermi level can be controlled by ion gel gates. An ion gel gate has a larger capacitance than a thin film oxide insulator gate, and thus the Fermi energy can be greatly modulated at a lower gate voltage. We have developed a manufacturing method to implement an ion gel gate by transferring and patterning graphene on Si wafer, loading a metal electrode by electron-beam vapor deposition, and applying ion gel. We demonstrate that the graphene resistance can be successfully varied by the voltage of the ion gel gate, which confirmed that the Fermi energy of graphene-loaded devices can be controlled. Next, we investigate the resonance tunability of the graphene-loaded devices with electrostatic gating. Finally, we demonstrate the nanocavity formation we proposed using the fabricated devices. We have successfully observed a resonant peak appears in the transmission spectrum of the device as the Fermi level increases, and the result agrees well with our theoretical simulation.

In addition to graphene-loaded photonic crystals, we investigate similar structures loaded with nano films based on phase-change materials, including $Ge_2Sb_2Te_5$ and VO_2. Phase change materials lead to a large change in the real and imaginary parts of the refractive index by the phase transition. Thus, we can use the same cavity formation mechanism, but this process can be now achieved in a non-volatile way. We theoretically demonstrate that the cavity Q and resonant wavelength can be greatly changed by the phase transition in Si photonic crystals loaded by $Ge_2Sb_2Te_5$ or VO_2. It is expected that nonvolatile optical memory operation can be realized by employing the large change in the transmittance induced by the change in the cavity Q and resonant wavelength at the phase transition.

Finally, we investigate optical nonlinearities of ion-gel-gated graphene-loaded Si PhC waveguide. Here we focus on Fermi level dependences on the optical nonlinearities of graphene, such as saturable absorption and two-photon absorption. Recently, optical nonlinearities of graphene attract great attention because of its superior performance, but its Fermi level dependence was unexplored. Considering the fact that the linear optical response of graphene is greatly changed by the Fermi level, a nonlinear response should also be changed by the Fermi level. It would be very promising and important to investigate the optical *nonlinear* response of graphene with the electric gate tuning. We have performed detailed nonlinear experiments for fabricated ion-gel-gated graphene-loaded Si PhC waveguides, and have found two important results. First, the saturable absorption has clear Fermi level dependence, and the saturation intensity can be reduced while maintaining the nonlinear transmittance variation. This shows that one can reduce the operation energy of graphene-based all-optical switching devices by adequately controlling the Fermi energy by an electrostatic gate. Second, we found Fermi level dependence of two-photon absorption of graphene, which was not reported before.