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Unique Characteristics of Synthetic Opals and Replicas Infiltrated with Materials with Large Dispersion in Refractive Index

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Recently photonic crystals with three-dimensional periodic structure of the order of optical wave length has attracted much attention from both fundamental and practical view points. We have prepared a synthetic opal by the sedimentation of SiO_2 spheres of several hundreds nm in diameter and studied it as one example of photonic crystals. Replicas of opals which are prepared by infiltrating various materials in the percolated periodic array of voids in the synthetic opal and then removing SiO_2 spheres by HF, also exhibit unique characteristics as photonic crystals. We have also demonstrated that synthetic opals and replica opals infiltrating with various functional material, exhibit novel properties.

Here in this paper, we discuss the property of synthetic opals and replicas infiltrated with materials with large dispersion in refractive index, that is, the material whose refractive index changes remarkably (even anomaly) with wave length of light.

When this material with large dispersion in refractive index also exhibits non-linear effect, that is, the refractive index change with increasing light intensity, new aspects and exciting phenomena appear.

The optical property of photonic crystal such as width and central wavelength of photonic band gap depends on various factors such as periodicity, filling factor of constituents, refractive index of constituents, crystal structure etc. To realize large photonic band gap, generally speaking, one of the constituent is desirable to have large refractive index. For example, the refractive index of SiO_2 forming the synthetic opal is about 1.46 and is not big enough. There are not so many materials which have large refractive index in the visible range. However, if some material has a large dispersion in the refractive index as shown in Fig.1(a) schematically, the situation is much different. It should be noted that, generally, the refractive index increases upon approaching the wavelength of light near to the absorption edge. That is, for the photon energy close to the band gap (not photonic band gap but electronic band gap), the refractive index becomes larger. It should be mentioned that many effects related with photonic crystal is concerned with the light of the photon energy near the electronic band gap. Therefore, for example the synthetic opals infiltrated with materials with the band gap (electronic band gap) in the visible range, the relevant refractive index must be much larger. In such a case we must use the refractive index of the large dispersion range. Then the photonic band gap is the function of the optical wavelength and for the light with the photon energy near the electronic band gap of the infiltrated material, relatively large photonic band gap can be obtained. By changing temperature the refractive index changes. Especially the refractive index at the wave length near the electronic band gap changes drastically, because the band gap also changes with temperature.

It should be also pointed out that the material which shows anomalous dispersion can exhibit an unique photonic band gap structure. For example, in the material in which the refractive index exhibits sharp peak at some wavelength as schematically illustrated in Fig.1(b), anomalous photonic band structure can be realized. Such anomalous dispersion of the refractive index may be realized in some material and in some cases with sharp absorption peak corresponding to exciton and localized states or specific electronic levels etc.

In such cases, photonic band gap can appear at the two wavelength regions with different central frequency. Especially the material exhibiting such anomalous dispersion also has non-linear effect, can demonstrate dramatic change of the optical properties.

Same scenario is applicable for the replicas made by material with large dispersion in refractive index.

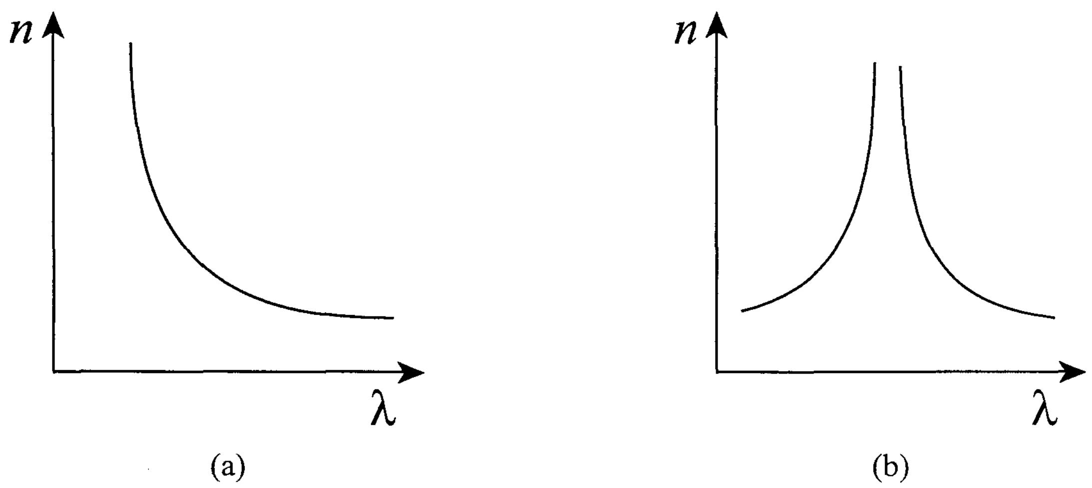

Fig.1 Schematic explanation of large dispersion (a) and anomalous dispersion (b) of refractive index.