High-Q Resonant Cavities in a Photonic Amorphous Diamond

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In 1987, Yablonovitch[1] and John[2] proposed the idea that a photonic band-gap (PBG), in which no photonic states exist, can be realized in artificial three-dimensional (3D) dielectric strucutures, namely, photonic crystals. Such photonic crystals with a PBG can be regarded as the photonic version of semiconductors in electronic systems. By introducing defects into a photonic crystal with a PBG, localized photonic states can be formed, by which we can confine light in the vicinity of the defects. Such light confinement by the introduction of defects leads to their use as optical resonant cavities in the case of point defects, and as optical waveguides in the case of line defects. In principle, by combining these elementary devices, various types of light-controlling devices can be realized.

Because Bragg scattering of light due to lattice periodicity has been considered to be the main origin of gap formation, it was commonly believed that lattice periodicity is indispensable for the realization of PBGs. However, in contrast, it was recently demonstrated by a numerical simulation[3] and by microwave transmission experiments[4] that a 3D amorphous structure with no trace of lattice periodicity can form a sizable PBG. This amorphous structure consists of a random network of dielectric rods with a diamond-like local tetrahedral configuration and is therefore named "photonic amorphous diamond (PAD)" (fig.1).

As described above, defects disrupting lattice periodicity in conventional photonic crystals with a PBG create localized photonic states. Though the PAD lacks lattice periodicity, its structure has a well-defined local order of tetrahedral configuration. We have previously shown that a point-defect, which disrupts such an order in PAD, can form a localized state within the PBG[3]. However, one might doubt whether such point-defects in PAD can confine light as strongly as those in conventional photonic crystals. The purpose of the present study is to clarify this point. Here, we have calculated the *Q*-factors for the point-defects introduced in PAD and have compared them with those of a point-defect in a conventional photonic crystal with a crystalline diamond structure (a photonic crystalline diamond (PCD)).

The PAD and PCD structures were designed according to a previous paper[3], where the rod radius was $r_0 = 0.26d$, (d: the rod length) and the refractive index of rods was $n = 3.6$. Point-defects were introduced by removing selected rods from the PAD and PCD structures. The frequency and the field distribution of the created defect modes were calculated by a finite-difference time domain (FDTD) method. The *Q*-factors of the modes were calculated as follows. First, the spherical region with radius R containing a point defect at the center was cut out from the structure. The sphere was placed in a cubic cell with the edge length $2R$. Then, FDTD calculations were performed with perfectly-matched-layer absorbing boundary conditions applied to the walls of the cubic cell. Here, the defect modes were exited by a Gaussian pulse with frequency range covering the mode frequencies of interest. The Q-factor of the mode was deduced from the decay rate of the electric field intensity at the defect position.

Figure 2 shows the structure-size dependences of the Q-factors calculated for PAD and PCD. For PAD, the results for three defects whose mode-frequencies are close to the midgap are shown. On the other hand, for PCD, the results should be independent of the selection of the rod because all the rods in PCD are symmetrically equivalent. All the data show exponential increase of Q with the structure size, i.e., $Q = A \cdot \exp(B \cdot R)$ without any sign of saturation. Here, the values of A and B are approximately the same for PAD and PCD, and $Q \geq 10^6$ at $R = 10d$. These facts lead to the conclusion that PAD can confine light as strongly as PCD.

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References

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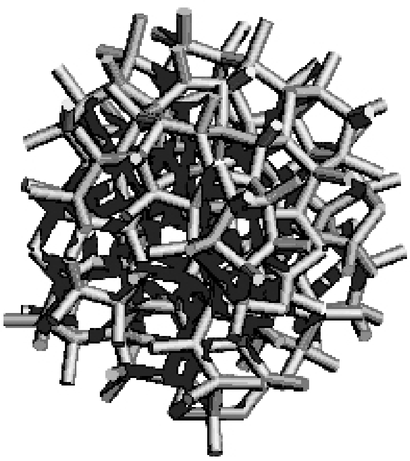

FIG. 1. A computer graphics image of PAD.

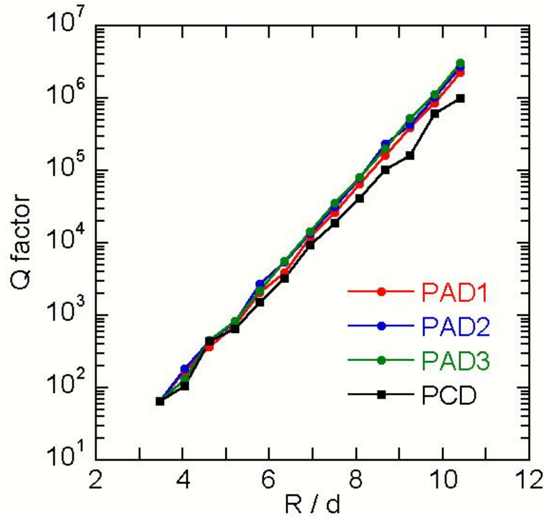

FIG. 2. Structure-size dependences of Q-factors for PAD and PCD.