Supplemental Document

Optics EXPRESS

Optical perfectly matched layers based on the integration of photonic crystals and material loss: supplement

SHENG ZHANG,[1,2] ZUOHENG YANG,[3] BINGBING LIU,[1,2] JIE LUO,[4,6] AND ZHI HONG HANG[1,2,5,7,]

[1] *School of Physical Science and Technology and Collaborative Innovation Center of Suzhou Nano Science and Technology, Soochow University, Suzhou 215006, China*
[2] *Institute for Advanced Study, Soochow University, Suzhou 215006, China*
[3] *Ulink College of Suzhou Industrial Park, Suzhou 215125, China*
[4] *Institute of Theoretical and Applied Physics, School of Physical Science and Technology, Soochow University, Suzhou 215006, China*
[5] *Provincial Key Lab of Thin Films, Soochow University, Suzhou 215006, China*
[6] *luojie@suda.edu.cn*
[7] *zhhang@suda.edu.cn*

Supplement DOI: https://doi.org/10.6084/m9.figshare.22207963

Parent Article DOI: https://doi.org/10.1364/OE.486253

Optical perfectly matched layers based on integration of photonic crystals and material loss: Supplemental Material

1. Optimization of PhC exhibiting near-omnidirectional impedance matching

To achieve near-omnidirectional impedance matching, we have optimized the topology of the PhC. Here, we take the theoretical model, i.e., the PhC in Figs. 2 and 3 in the main text, as an example. Fig. S1 shows the simulated transmittance through the PhC slab consisting of 10 layers of unit cells along the x direction as a function of incident angle for different values of ratio b/a. The working frequency is $fa/c = 0.20648$. We see from Fig. S1 that near-omnidirectional perfect transmission happens when $b/a = 1.37$. Therefore, we set $b/a = 1.37$ for PhCs in the main text.

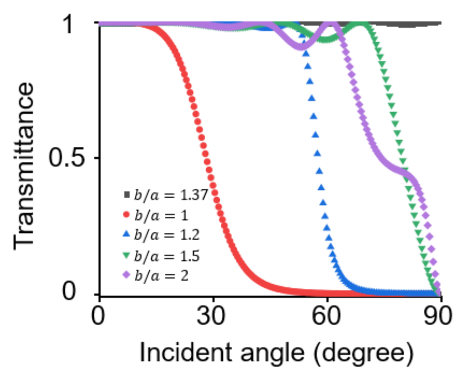

Fig. S1. Transmittance through a 10-layered PhC slab as a function of incident angle for different values of ratio b/a at $fa/c = 0.20648$.

2. Characteristics of the experimental PhC

In the microwave experiments, we have fabricated a 2D PhC consisting of a rectangular array ($a = 10$ mm, $b = 13.7$ mm) of alumina cylinders (relative permittivity 7.5) in free space. The unit cell is illustrated in the inset of Fig. S2(a). Here the wrapping absorptive foam around each alumina cylinder is not considered. The band diagram of the PhC for TM polarization (electric field along the z direction) is presented in Fig. S2(a). The red dashed line denotes the normalized frequency $fa/c = 0.3389$, which corresponds to the working frequency of 10.16 GHz. As shown in Fig. S2(b), the EFC of PhC at this frequency is nearly a part of ellipse centered at the X point (red solid line), which has the same height (i.e., the maximum k_y) as the EFC of air (black dashed line). These properties are crucial for the realization of near-omnidirectional impedance matching.

To explore the impedance characteristic of the PhC, we plot the difference of effective wave impedance of PhC and wave impedance of free space in Fig. S2(c), showing very small impedance difference at $fa/c = 0.3389$ for a wide range of k_y. This indicates the near-omnidirectional impedance matching effect of the PhC. For verification, we calculate the transmittance through the PhC slab consisting of N ($N = 4, 5, 10, 15$) layers of unit cells as the function of incident angle. The configuration of numerical setup is illustrated in the inset of Fig. S2(d). We see that the transmittance is higher than 0.95 for incident angles ranging from $0°$ to $83°$ irrespective of the layer number N, demonstrating the near-omnidirectional impedance matching effect of the PhC.

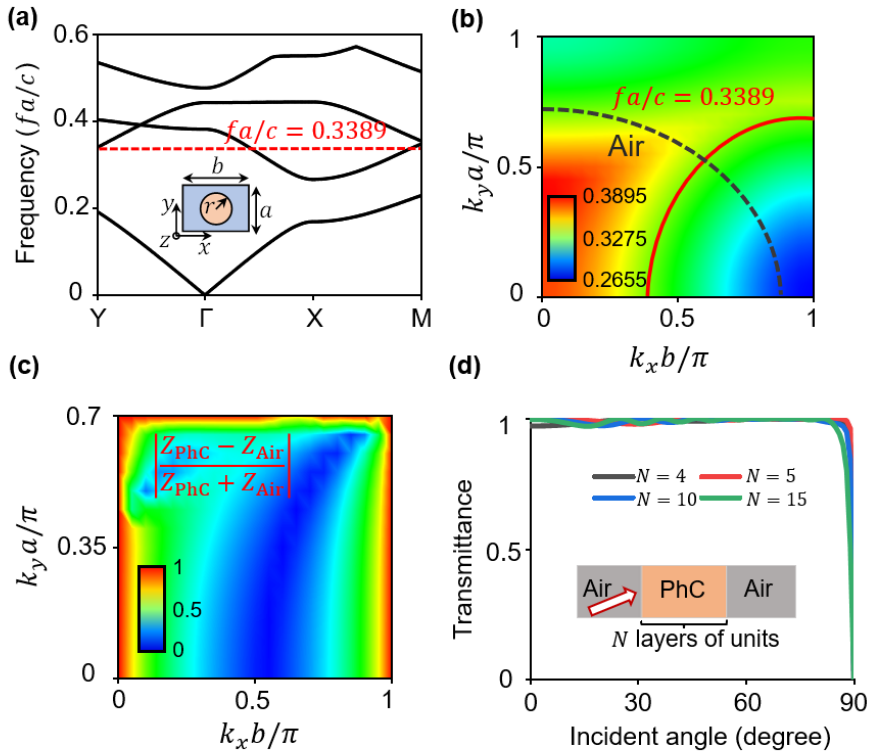

Fig. S2. (a) Band diagram for TM polarization of the experimental PhC, whose unit cell is illustrated in the inset. Here the wrapping absorptive foam around each alumina cylinder is not considered. (b) The EFCs of the second band. The red solid and black dashed lines denote the EFC of the PhC and the EFC of air at $fa/c = 0.3389$. (c) The impedance difference between the PhC and air. (e) Simulated transmittance through the PhC slab consisting of N layers of unit cells along the x direction. The inset illustrates the configuration of numerical setup.

3. Influence of material loss on the experiment PhC

In experiments, the material loss is introduced through wrapping each alumina cylinder with a ring of absorptive foam (relative permittivity of $1.5 + 1i$). The overall material loss of the PhC can be easily tuned by changing the foam ring thickness d. In the following, we numerically investigate the influence of the thickness d on impedance matching and absorption performance. Fig. S3(a)-S3(d) show the absorptance of the PhC slab as a function of incident angle and layer number N for different values of d ($d =$ 0.25 mm, 0.5 mm, 1 mm, 1.25 mm). The black dashed lines denote the equi-absorptance contours of $A = 0.9$. We find the near-omnidirectional impedance matching effect maintains in the case of small d, which however requires a larger layer number N to obtain high absorption. On the other hand, in the case of large d, the impedance matching at large incident angles would be destroyed. Therefore, considering the balance of absorption performance and layer number, we set $d = 1$ mm in experiments.

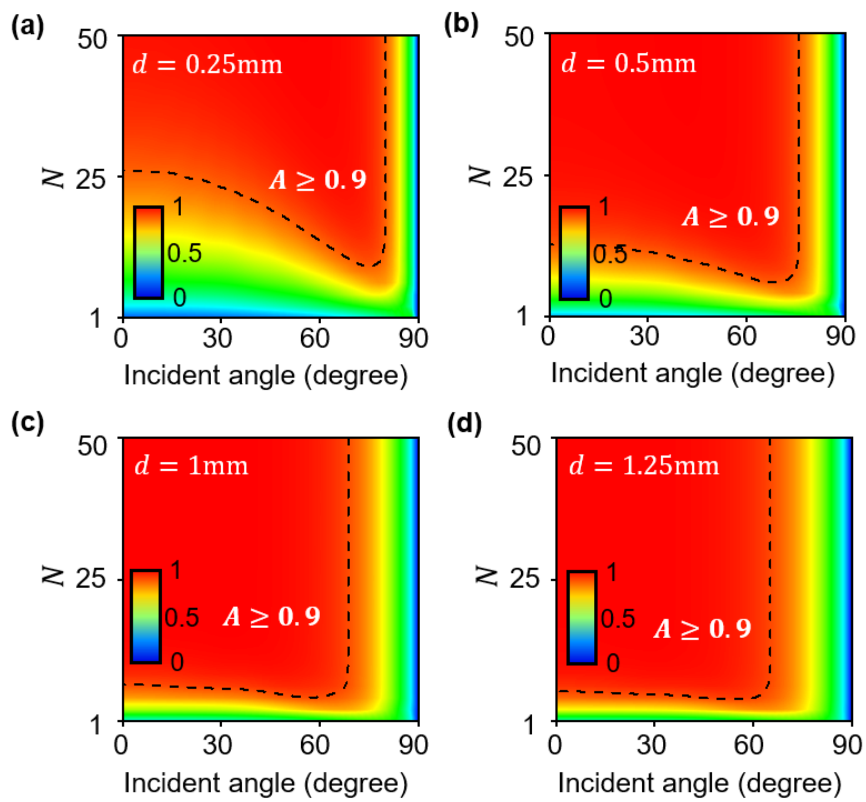

Fig. S3. (a)-(d) Simulated absorptance of the experimental sample as the function of incident angle and layer number N and for different values of foam ring thickness d. The black dashed lines denote the equi-absorptance contours of A=0.9.