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COMMENT

Comment on 'Absorption in one-dimensional metallic–dielectric photonic crystals'

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Abstract

Using the transfer matrix method for calculating the transmittance, absorptance and photon density of states of one-dimensional metallic–dielectric photonic crystals, we investigate the origin of the absorption enhancement in these photonic systems. The effect of the metallic layer thickness on the electric field distribution is discussed.

A recent publication [1] has reported theoretical results for the absorptive properties of a one-dimensional (1D) metallic–dielectric photonic crystal (MDPC). It is found that the absorption is enhanced considerably over the constituent metal. Based on the numerical results that the frequency ranges of enhanced absorption correspond to the photonic passbands, the enhancement is attributed to the conservation and redistribution of photon states. Since the number of total states is conserved and the states are forbidden in the photonic bandgap (PBG) range, more states are believed to concentrate on the photonic passband range.

The author's explanation is unconvincing and debatable. If the number of photon states plays a decisive role in the absorptive behaviour and the movement of photon states from PBGs to passbands has really happened as the authors regard, the absorption in PBG regions should be suppressed while it is enhanced in photonic passbands. In addition, it is well known that the photonic densities of states (DOSs) resonate in passbands, decrease in PBG regions and dramatically increase at band-edges [6]. Thus, the minimum and maximum absorption magnitudes should appear at the middle frequency and the band-edges of PBG, respectively. However, this is not the truth as we will show below.

The MDPC investigated here consists of alternate layers of Ag and MgF_2 with five periods. The thickness of the silver layer in each period is 12 nm, and the dielectric layer is 250 nm instead of 120 nm in [1]. The structure is so chosen to avoid the passband of the MDPC overlapping the naturally transparent range near the plasma frequency of Ag, about 320 nm. The optical constants for Ag and MgF_2 were taken from [5] and directly used in calculation. The numerical approach is a standard transfer matrix method [1–3].

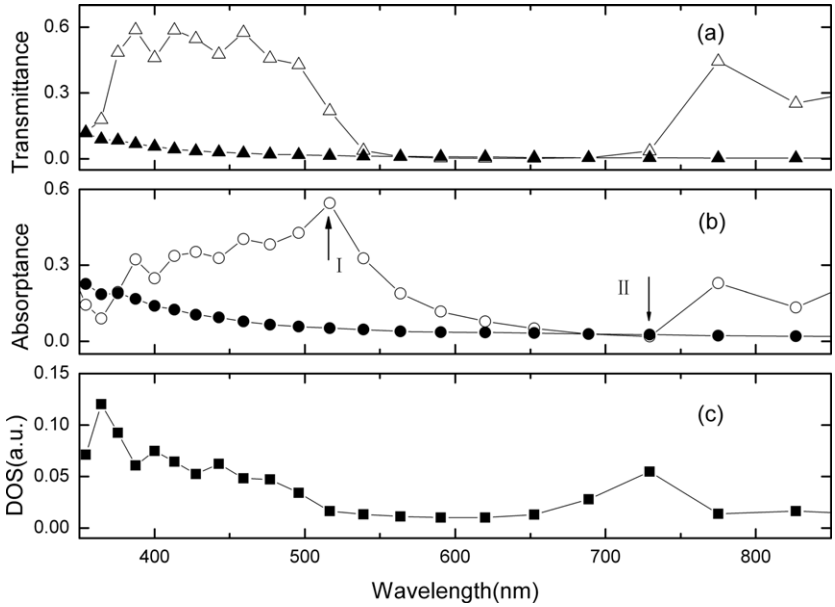

Figure 1. (a) Calculated transmission spectrum for 1D Ag/MgF_2 MDPC of five periods (−△−) and for 60 nm Ag silver film (−▲−). (b) Calculated absorption spectrum for 1D Ag/MgF_2 MDPC of five periods (−○−) and for 60 nm Ag silver film (−●−). (b) Calculated photonic density of states in the 1D Ag/MgF_2 MDPC of five periods (−■−).

Figure 1(a) shows the calculated transmission spectrum of the 1D MDPC together with that of a 60 nm silver film. The total thickness of Ag layers in the MDPC is equal to the silver sample. In the frequency range discussed, there exists no obvious transmission for the silver film. For the MDPC sample, one highly transmissive passband appears, from 360 to 540 nm. This enhanced transmissive behaviour is in agreement with references [1–3]. The frequency range without notable transmission, from 540 to 730 nm, is the PBG region. The absorption spectra of the 1D MDPC and the silver film are displayed in figure 1(b). It can be seen clearly that the minimum absorption magnitude appears at the bottom band-edge (region II), instead of at the middle frequency of the PBG, and the maximum absorption magnitude appears at the top band-edge (region I). On the other hand, the absorption in most of the PBG range is enhanced, not suppressed, over the bulk metal as in the photonic passband. It is worth noting the corresponding photonic DOS shown in figure 1(c), which is calculated using the method described in [6]. In contrast to the absorption spectra, more DOS exists in region II than in region I.

The result shown above is consistent with the reflective characteristics studied in [4] and can be easily explained by the redistribution of the electric field [8]. At the top of the gap, electric field in photonic crystals tends to be concentrated on low refractive index regions (metallic layers here). The good overlap of electric field and metal causes the large absorption at region I. At the bottom of the gap, electric field tends to be concentrated on high refractive index regions (dielectric layers). The overlap of electric field and lossless dielectric causes the lower absorption in region II.

To provide some physical insight into the metallic absorption enhancement in PBGs of an MDPC, we study the influence of metallic film thickness on electric field distribution. As shown in figure 2, though the magnitudes of the fields in silver films with different thicknesses

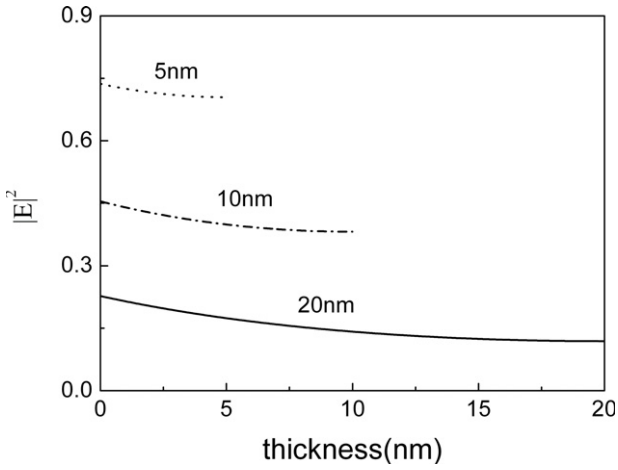

Figure 2. Numerically calculated electric field distribution within the 5 nm (dotted line), 10 nm (dash–dotted line) and 20 nm (solid line) silver samples in air for 826.6 nm incident light, respectively. The magnitude is normalized to the incident field.

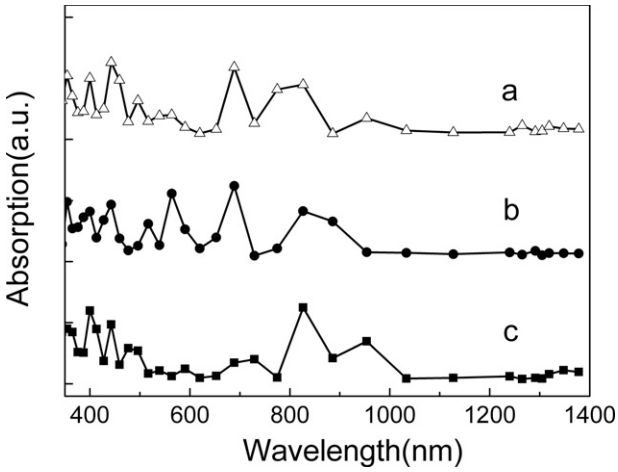

Figure 3. Calculated absorption spectra for a perturbed 1D Ag/MgF_2 MDPC of five periods. The thicknesses of Ag layers remain 12 nm, and those of MgF_2 layers are chosen from a uniform distribution on the interval (0, 250) nm in all three structures.

all exhibit an exponential decrease, the value at the incident point reduces quickly with the increase of thickness. As a result, the electric field intensity per amount of metal thickness increases after a bulk metal is sliced into many thinner layers, which is the reason why the absorption in nearly all the frequency range exhibits an increase in an MDPC. This can be confirmed by the absorptive behaviours of perturbed MDPCs shown in figure 3. In these structures, the thicknesses of Ag layers remain unchanged (12 nm) and the dielectric layers are chosen from a uniform distribution on the interval (0, 250) nm. The maximum absorptances of these structures all reach more than 0.6.

In conclusion, the result of Yu *et al* [1] that metallic absorption can be enhanced considerably in an MDPC over the bulk metal reference is correct. However, the explanation

that the enhancement arises from the movement of photonic states from PBG regions to photonic passbands is problematic. In our opinion, more photon states are not equivalent to more electric field in metal layers, and the distribution of electric field plays a more important role than the distribution of photonic states in the metallic absorption of an MDPC. In some cases, the absorption in the PBG region even can exhibit bigger enhancement than in the photonic passbands, which we will discuss in detail elsewhere [7].

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