Optical transmission spectra in Fibonacci photonic multilayers with mirror symmetry

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Abstract
It is the aim of this work to study the transmission properties of a light beam normally incident from a transparent medium into a symmetric Fibonacci photonic multilayers, made up of both positive (SiO2) and negative refractive index materials with a mirror symmetry (see Fig. 1 for details). These spectra are calculated by using a theoretical model based on the transfer matrix approach, in which many perfect transmission peaks (the transmission coefficients are equal to the unity) are numerically obtained. Besides, the transmission coefficients exhibit a six-cycle self-similar behavior with respect to the generation number of the Fibonacci sequence.

The numerical simulations were done for the light transmission considering medium A as silicon dioxide (SiO_2), whose refractive index is $n_A = 1.45$, while medium B is a metamaterial with $n_B = -1$. Also, we assume the individual layers to be quarter-wave layers, for which the quasiperiodicity is expected to be more effective [1], with the central wavelength $\lambda_0 = 32$ mm. These conditions yield the physical thickness $d_J = (8/n_J)$ mm, J = A or B, such that $n_A d_A = n_B d_B$, yielding a reversed phase shift in the two materials. Considering medium C as vacuum, the phase shifts are given by $\delta_A = (\pi/2)\Omega \cos(\theta_A)$ and $\delta_B = (\pi/2)\Omega \cos(\theta_B)$, where Ω is the reduced frequency $\Omega = \omega/\omega_0 = \lambda_0/\lambda$. For normal incidence, $\theta_A = \theta_B = 0$, and $\delta_A = -\delta_B$. Here, the negative phase shift for medium B means that the light waves propagate in a direction opposite to the energy flux (+z-direction), i.e., one plane light wave, whose electromagnetic field is proportional to $\exp(-i\delta_B)$, propagates in the −z-direction, while the Poynting vector propagates in the +z-direction. Therefore, inside medium B the effect of the negative refraction index is to change the forward waves $\exp(i\delta_B)$ into backward waves $\exp(-i\delta_B)$ and vice-versa. This effect keeps the same configuration for the incident and reflected electromagnetic wave at the interface AB, but the electromagnetic wave at layer B has now a sign change in the exponentials when compared to the electromagnetic wave at layer A.

The optical transmission spectrum for the 16th-generation of the quasiperiodic Fibonacci sequence with mirror symmetry, as a function of the reduced frequency Ω, is depicted in Fig. 2(a). The transmission spectrum presents a unique mirror symmetrical profile around the central peak frequency Ω =1, which is of course the mid-gap frequency of a periodic quarter-wavelength multilayer, since in this case the phase-shift $\delta_A = \delta_B = \pi/2$. Besides, the structure is transparent (the transmission coefficient is closely equal to 1.0) in the central range of frequency 0.942< Ω <1.058, and at the reduced frequencies distributed symmetrically at Ω = 0, 0.330, 0.487, 0710, 1,290, 1.513, 1.670 and 2.0, respectively. The condition of transparentness implies that the layers A and B$ are equivalent from a wave point of view. The photonic band gaps can be better characterized if one consider the narrow frequency range $0.977 \leq \Omega \leq 1.023$ for the optical transmission spectrum, as it is depicted in Fig. 2(b). It is important to mention that the symmetric internal structure of the one-dimensional quasiperiodic systems can greatly enhance the transmission intensity, with a striking self-similar behavior occurring every time the difference between two generation numbers of the Fibonacci sequence is equal to six [2]. The transmission spectrum has scaling property with respect to the generation number of the Fibonacci sequence, within a symmetrical interval around. Our results present some differences from those found for the case of symmetric Fibonacci multilayers with both positive refractive index materials [2–4], namely, the transmission peaks are different in the form and in the intensity, mainly for low values of the number of generation of the Fibonacci's sequence.

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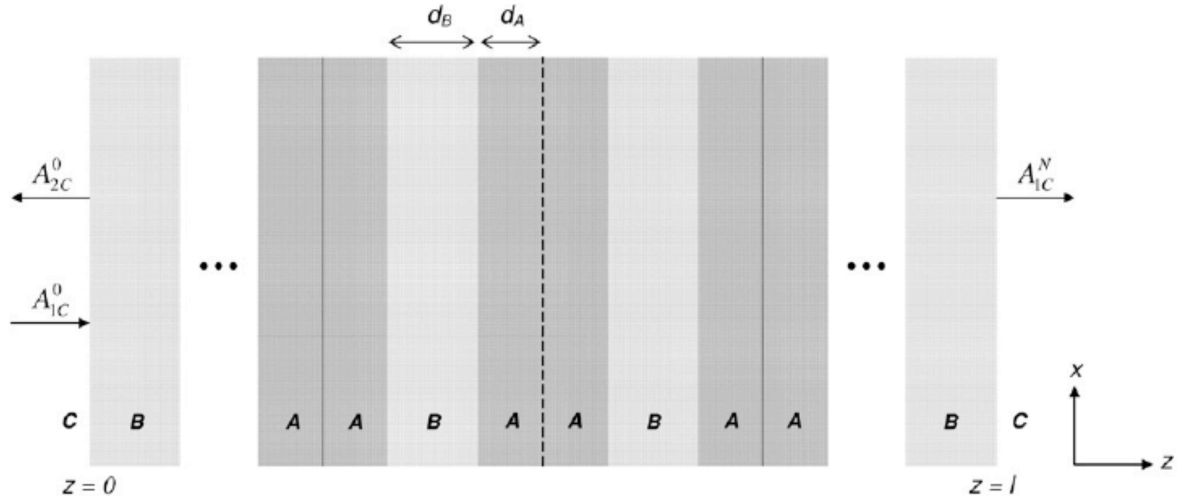

Figure 1: Geometrical arrangement of the symmetrical Fibonacci quasiperiodic multilayer system considered in this work.

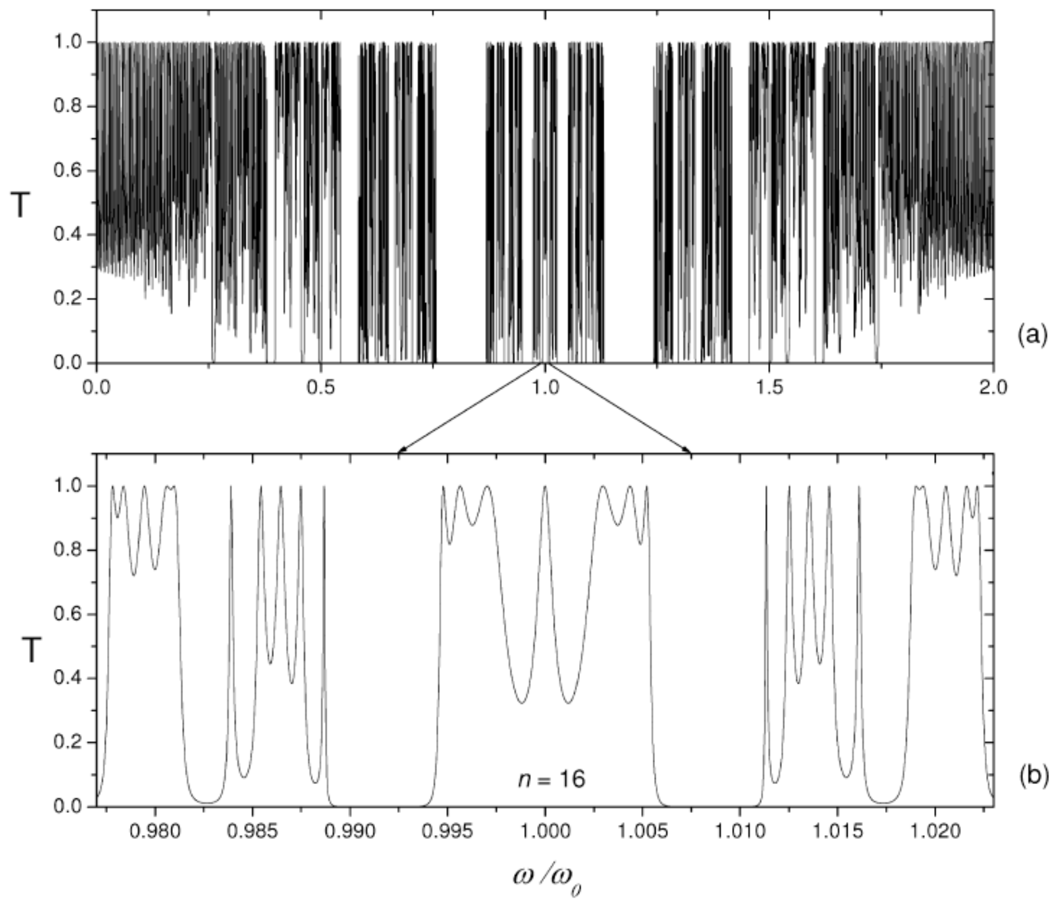

Figure 2: Normal-incidence transmission spectra of a light beam into a Fibonacci multilayered photonic structure with mirror symmetry as a function of the reduced frequency $\Omega = \omega/\omega_0 = \lambda_0/\lambda$ for the 16th generation of the Fibonacci sequence: (a) the transmittance T for the range of frequency $0 < \Omega < 2$. (b) same as in (a), but for the range of frequency $0.977 < \Omega < 1.023$.