Available online at www.sciencedirect.com
SciVerse ScienceDirect
PHOTONICS AND NANOSTRUCTURES Fundamentals and Applications
Photonics and Nanostructures – Fundamentals and Applications 10 (2012) 459–462
www.elsevier.com/locate/photonics

Photonic stop bands in quasi-random nanoporous anodic alumina structures

Ivan Maksymov [a], Josep Ferré-Borrull [b], Josep Pallarès [b,*], Lluis F. Marsal [b]

[a] *Nonlinear Physics Center, Research School of Physics and Engineering, Australian National University, Canberra, ACT 0200, Australia*
[b] *Universitat Rovira i Virgili, Nano-electronic and Photonic Systems, Av. Paisos Catalans 26, 43007 Tarragona, Spain*

Received 15 November 2010; accepted 14 February 2012
Available online 22 February 2012

Abstract

The existence of photonic stop bands in the self-assembled arrangement of pores in porous anodic alumina structures is investigated by means of rigorous 2D finite-difference time-domain calculations. Self-assembled porous anodic alumina shows a random distribution of domains, each of them with a very definite triangular pattern, constituting a quasi-random structure. The observed stop bands are similar to those of photonic quasicrystals or random structures. As the pores of nanoporous anodic alumina can be infiltrated with noble metals, nonlinear or active media, it makes this material very attractive and cost-effective for applications including inhibition of spontaneous emission, random lasing, LEDs and biosensors.

Keywords: Photonic crystals; Quasi-random structures; Nanoporous anodic alumina; Photonic stop bands

1. Introduction

The proposal of photonic crystals (PhCs) by Yablonovitch [1] and John [2] have extended the research into the field of nanophotonics devices benefiting from the formation of a photonic band-gap (PBG) and the inhibition of the spontaneous emission of light. These remarkable physical properties have made PhCs very promising for a wealth of applications such as lasers [3], waveguides [4], photonic circuits [5] or optical cloaking [6]. Further investigation has been motivated by the search for other materials with similar physical properties, but that would offer advantages over PhCs for many applications even when the refractive index contrast among the constituent materials is low. One of the solutions has been found in the use of one [7] and two-dimensional [8] photonic quasicrystals (PQCs). PQCs have a higher degree of rotational and point-reflection symmetry than conventional PhCs. These symmetries facilitate the formation of the PBGs even in materials with low refractive index contrasts. These PBGs are significantly more isotropic and bands of their dispersion relations are flat [9], which is advantageous for use as highly efficient isotropic thermal radiation sources [10]. PQCs structures can support a rich variety of localized modes (such as constant flux modes [11]) as well as take advantage of Anderson localization phenomena [12]. Consequently PQCs can be employed to design random lasers with tailored field patterns with possible application to biological sensing [13]. In LED applications, PQCs help to extract light and boost LED emission characteristics [14].

* Corresponding author. Fax: +34 977559605.
E-mail address: josep.ferre@urv.cat (J. Pallarès).

1569-4410/$ – see front matter
doi:10.1016/j.photonics.2012.02.003

In this work we pay attention to the self-assembled nanoporous anodic alumina [15] (NAA), a material thoroughly investigated and widely applied in nanotechnology [16]. To our best knowledge, no paper has been published to study the PBG properties of an NAA structure. NAA is obtained by the electrochemical etching of aluminum. Under proper conditions its nanoporous structure shows a self-ordered lattice with a two-dimensional triangular periodic arrangement [15]. The lattice constant can be tuned from some tens of nanometers up to some hundreds. Although this triangular arrangement can be achieved over a long range by nanoimprinting the aluminum [17], in self-assembled NAA the lattice is broken into domains with a size of some tens of lattice sites and randomly oriented. One can see this as a quasi-random pattern, similar to a polycrystal, random in nature but with some degree of order. Fig. 1 shows an example of a NAA structure obtained with the conditions described in Ref. [18].

Hereafter we investigate the formation of photonic stop-bands in quasi-random NAA structures. A superposition of the stop-bands from the triangular periodic arrangement of their domains leads to the formation of a general PBG. Given that the orientation of the domains is random, the investigated structures are isotropic in a macroscopic sense. This isotropy should favor the formation of a PBG in the same way the higher rotational symmetry of photonic quasicrystals produce PBGs for smaller index contrasts than for periodic structures. However, the higher rotational symmetry of NAA structures is counteracted by the finite size of the domains, and thus, it is necessary to investigate to what extent this is affecting the gap formation.

2. Computational approach

In our study of the stop-band formation in NAA structures we employ a 2D finite-difference time-domain (FDTD) method. The FDTD is a grid-based numerical method for simulating the propagation of electromagnetic waves in arbitrary media [19]. This makes the FDTD especially attractive for calculating transmission properties of NAA structures. A triangular pore arrangement of the NAA domains facilitates the analysis because their photonic properties are in close physical analogy to those of 2D perfect triangular-lattice photonic crystals, whose physics is well understood to a certain extent. Hereafter we will perform systematic 2D FDTD calculations assuming that the investigated structure is infinite in the direction normal to the apertures of pores in anodic alumina. We will restrict ourselves to the *H*-polarization, for which the magnetic field is oriented along the *z*-axis (Fig. 2).

Despite a certain analogy with perfect periodic structures, we cannot employ computational approaches widely used in the PhC research relying on the use of periodic and symmetric boundary conditions simplifying the calculation. In order to study the photonic properties of NAA structures, we use the structural data from experimentally obtained samples such as that of Fig. 1 and perform statistical calculations over a set of randomly chosen domains. The procedure is as follows: the pore positions are determined by processing a SEM picture of a NAA

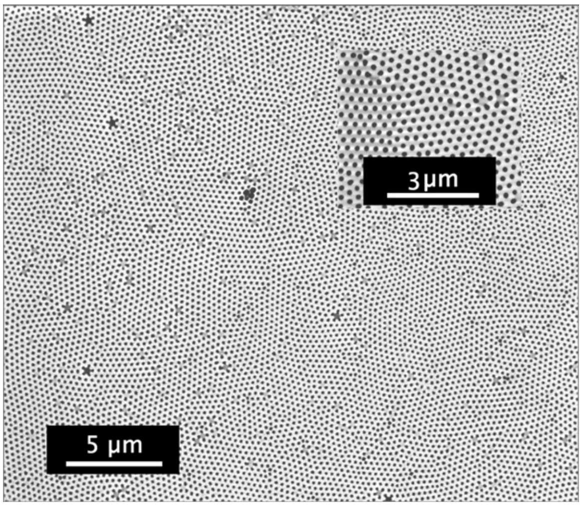

Fig. 1. SEM picture of a NAA structure used to extract the pore positions considered in the simulations.

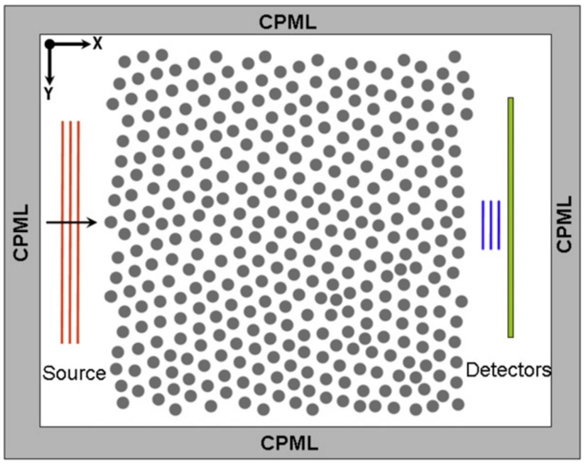

Fig. 2. Schematic of the computational domain. Gray circles denote the scatterers of the investigated NAA subdomain, white background corresponds to the alumina.