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Optical filters using Cantor quasi-periodic one dimensional photonic crystal based on Si/SiO_2

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Quasi-periodic one-dimensional Cantor photonic crystals are elaborated by depositing alternating silicon and silica Si/SiO_2 layers by radiofrequency magnetron sputtering technique with cold plasma. Transmittance and reflectance spectra of these quasi crystals exhibit a large photonic band gap in the infrared range at normal incidence which is well reproduced by a theoretical model based on the transfer matrix method. The obtained wide photonic band gap reveals the existence of permitted modes depending on the nature and characteristics of the built in system which can constitute optical windows. This effect can be a good alternative for the design of flexible filters used in many areas of applications such as telecommunication and optoelectronic devices.

1. Introduction

Since the first studies previously reported by Yablonovitch [1] and John [2], the photonic crystals became the subject of great interest in fundamental as well as applied research. Photonic crystal is stacked by two materials that their dielectric constant may vary periodically in one, two or three dimensions (1D, 2D, 3D) [3].

One dimensional photonic crystal has been the subject of much interest of researchers for the simplicity of their fabrication and their fundamental properties due to the apparition of photonic band gap in which the photon propagation is prohibited for arbitrary polarization in some or even all directions [1–4].

Recently quasi-periodic structures of photonic crystals have become significant systems [5] which can be generated by substitution rules based on two building blocks H and L, with High n_H and Low n_L refractive indexes respectively. These rules obey to a periodic mathematical sequences as Fibonacci [6], Thue-Morse [7], Cantor [8] and period doubling [9]. Compared to periodic photonic crystals [10], quasi-periodic structures do not have translation symmetry [11].

One dimensional photonic multilayer structures have many interesting applications such as reflectors, optical sensors, couplers, detectors and optical filters due to their ability to control and manipulate the flow of light in terms of bending, switching, reflecting and filtering [6]. Photonic systems seem to be a useful alternative for optical wavelength division

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filtering and multiplexing/demulteplexing applications, for example, the telecommunication sector takes benefit of a lot of technological developments by the use of photonic channel filters based on these structures [12,13]. Among these structures, Cantor one dimensional quasi crystal characterised by its fractal [14] structure having two distinctive properties, scalability and sequential splitting closely related to the geometrical peculiarities of the multilayer [15], which is one of the most useful structures to design optical filters, due to their applications in optical communications and ultra-fast optical processing [16].

In the present paper, we focus on Cantor sets of dielectric multilayers using Si/SiO_2 as high/low index materials respectively. This type of structures is investigated theoretically and experimentally to demonstrate multiple omnidirectional photonic band gap (PBG) in the near infrared range of wavelength. This structure has been elaborated by using radiofrequency magnetron sputtering deposition technique (RFMS).

2. Theoretical model

2.1. Cantor sequence

The Cantor sequence is a deterministic fractal geometry obtained by repeating a simple rule.

Starting with a given initiator material H which exhibits a high refractive index and corresponding to the generation number N = 0. Then, for the next generation N = 1, the material H is replaced by a stacking of three materials HLH, where L corresponds to a material with a low refractive index. For the generation N = 2, taking the stacking sequence of generation N = 1, in which each material H is replaced by a stacking of three materials HLH, and each material L is replaced by stacking of three materials LLL. Then, for each additional generation N, the same process is repeated for a certain number [17,18]. The resulting assembly is Cantor triadic system which is defined by simple substitution rule as presented bellow for the first generations N (varying from 0 to 3):

N = 0: H
N = 1: H → HLH
N = 2: HLH → HLHLLLHLH
N = 3: HLHLLLHLH → HLHLLLHLHLLLLLLLLLHLHLLLHLH.

A schematic representation of a cantor multilayers structure with the stacking of H and L materials, for a generation number N varying from 0 to 3, is given in Fig. 1, where H and L correspond, respectively to the high and low refractive index materials. We also present in the inset of this figure the calculated possible number of stacked layers as a function of generation number N. It is to be noticed that the number of layers increases rapidly with N, following a 3^N law, and it is higher than 2000 layers for the seventh generation. Such a great number of layers does not have any physical interest as it will be justified below in section 2.3.

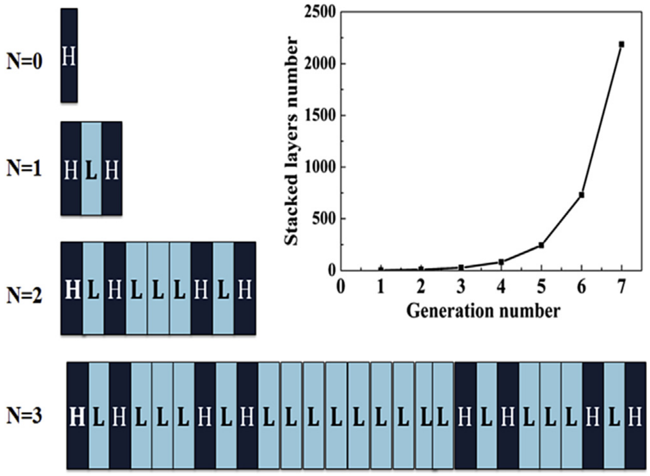

Fig. 1. Schematic representation of the Cantor sequence built structure as a stacking of H and L material layers, as a function of the generations number N, for N varying from 0 to 3. The inset of this figure presents the calculated possible stacked materials layers number as a function of the generation number. H and L denote, respectively, the high and low refractive indexes material.