

Study of light propagation in TiO_2 multilayer DBRs

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Abstract

This work take for objective to develop an efficient simulation code to determine the optical properties of some photonic materials based on TiO_2 , namely DBRs. Basing on the Transfer matrix method (TMM), we have implemented an algorithm which calculates the reflectance and the transmittance of multilayered photonic materials and plots the corresponding spectra.

1. Introduction

During the 21st century, manipulation of photons has become the core study of area of the photonics. Photons are fast and unlimited natural sources that could replace the role of electronics. A novel class of materials referred to as “photonic crystals” is synthesized to manipulate light.

Photonic crystals [1, 2] are structures which dielectric constant is periodically changed on length scale in one, two or three dimensions (1D, 2D and 3D) with periodicity comparable to the light wavelength [3]. As analogous to electrons in an atomic crystal, the propagation of electromagnetic waves in periodic dielectric structures can be forbidden in certain directions and within a certain frequency range [4],

[5]. Because of this similarity, this frequency range, in which photonic crystals exhibit strong reflection, is called as photonic. The one-dimensional multilayered structure is the simplest photonic crystal.

Distributed Bragg reflectors (DBRs) are periodic structures with a unit cell of two dielectric layers having different refractive indices and thicknesses. They can be considered as unidimensional photonic crystals and are used in a wide variety of optoelectronic devices including semiconductor lasers, solar cells and so on.

In this work, we developed an efficient simulation code to determine the optical properties of two DBRs, such as TiO_2/air and $\text{TiO}_2/\text{SiO}_2$ (1D).

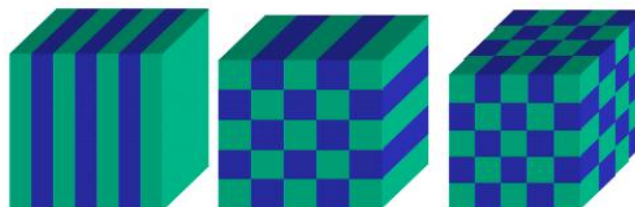


Figure 1: Samples of photonic structures 1D, 2D and 3D

2. Theoretical background

Photons that are propagating into a photonic crystal are analogous to electrons moving into a conventional crystal “semiconductor”. That photon-electron analogy is due to the analogy between the equation of Helmholtz, derived from Maxwell equations [6], and the equation of Schrödinger.

$$\nabla^2 \Psi(\vec{r}) = -\frac{2m}{\hbar^2} (U - V(\vec{r})) \Psi(\vec{r}) \quad (1)$$

$$\vec{\nabla} \times [\vec{\nabla} \times \vec{H}(\vec{r})] = \left(\frac{\omega}{c}\right)^2 \epsilon(\vec{r}) \vec{H}(\vec{r}) \quad (2)$$

As there is similarity between electronic semiconductors and photonic crystals, the concepts of solid state crystals, viz, reciprocal space, brillouin zones, dispersion relations, Bloch wave functions [7], etc; can also be applied to photonic crystals. That is why it is logical to call the periodic dielectric structures photonic crystal.

3. Algorithm and validation

Basing on the Transfer matrix method (TMM) [8], we have implemented an algorithm which calculates the reflectance and the transmittance of multilayered photonic materials and plots the corresponding spectra.

We have used a technique that is basing on the finite differences in frequency domain, and chosen the real space instead the space of Fourier to build the transfer matrix of each layer of the photonic structure. The calculation of transfer matrix is done by a recursive algorithm. The code developed using MATLAB 2009 can calculate the reflectance and the transmittance of any one-dimensional photonic crystal as well as their Bloch modes via the determination of eigenvalues of the transfer matrices.

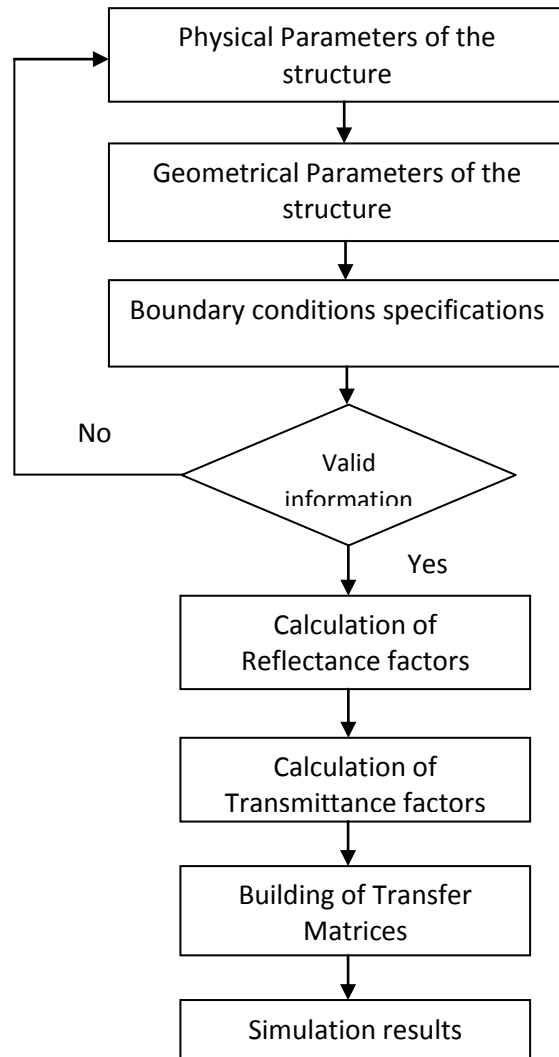


Figure 2: the algorithm flowchart

The reflectance and the transmittance of a TiO₂-SiO₂-based DBR were calculated in order to validate the efficiency of our code. The results are in

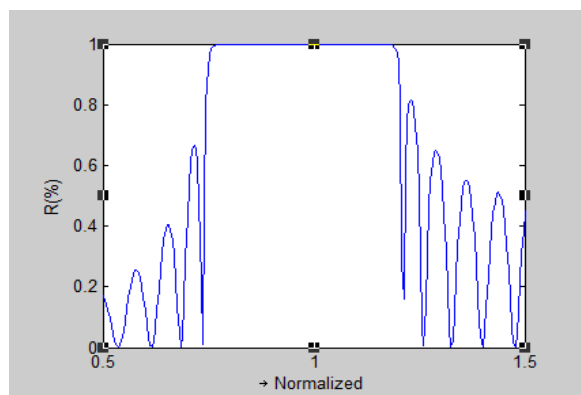


Figure 3: Reflectance spectrum of TiO₂-SiO₂ DBR

good agreement with those found in literature as well as those obtained by other methods.

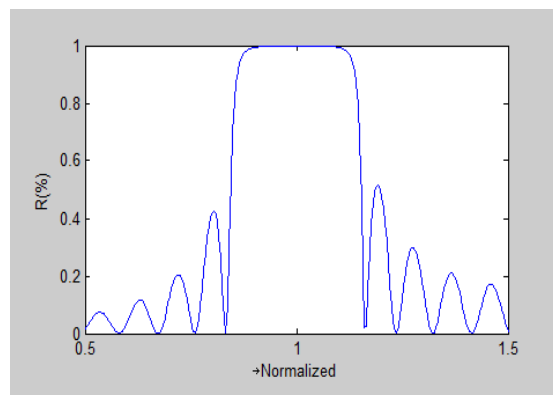


Figure 4: Reflectance spectrum of TiO₂-air DBR

4. Conclusion

In this work, the development of an algorithm and a computer code to calculate the optical properties (reflectance and the transmittance) of multilayered 1D photonic crystals is presented. The algorithm developed is based on the transfer matrix method TMM in the frequency domain. We have described briefly the algorithm and presented the flowchart related to.

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