

Design and fabrication of optical filters with very large stopband (≈ 500 nm) and small passband (1 nm) in silicon-on-insulator

Wei Jia^{a,b,c,*}, Jun Deng^c, Benjamin P.L. Reid^b, Xu Wang^b, Christopher C.S. Chan^b,
Hong Wu^a, Xiangyin Li^a, Robert A. Taylor^b, Aaron J. Danner^c

^a Department of Physics, Nanjing University of Science and Technology, Nanjing 210094, China

^b Department of Physics, Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU, United Kingdom

^c Department of Electrical and Computer Engineering, National University of Singapore, 4 Engineering Drive 3, Singapore 117576, Singapore

Received 31 October 2011; received in revised form 5 January 2012; accepted 3 February 2012

Available online 14 February 2012

Abstract

In this paper, we report on the design, fabrication and characterization of a broadband photonic crystal filter. Modeling with a genetic algorithm (GA) was used to investigate the effect of changing the number of periods and thickness ratios of a photonic crystal filter structure with two alternating materials. Theoretical optimized parameters were obtained as a function of wavelength for a photonic crystal filter with a very broad filter bandwidth as well as a very narrow transmission window. We used the determined optimum parameters at a wavelength of 1550 nm to fabricate the structure using e-beam lithography and inductively coupled plasma (ICP) etching. Experimental results show that the structure indeed has a very narrow transmission window and a low loss of just 4 dB. Hence, this structure can be regarded as a high precision filter for optical communication and photonic integrated chip technologies.

© 2012 Elsevier B.V. All rights reserved.

Keywords: Photonic crystal filter; Heterostructures; Bandwidth

1. Introduction

Since the pioneering work of Yablonovitch [1] and John [2], photonic crystals (PCs) have been the subject of extensive research work in the areas of optoelectronics and optical communications. One of the most important optical components in the PC area, the photonic crystal filter, can be classified into three categories: 1D, 2D, and 3D photonic crystal filter [3–8]. As is well known, the structure of 1D photonic crystal

filter is simpler than 2D and 3D photonic crystal filter, and the optimization process for 1D photonic crystal filter also can be realized easily. In the design of one-dimensional filter, the common design methods are the following: Multiperiodic gratings [9], Aperiodic lattices [10], Superposition of photonic heterostructures [11–15].

With the development of research, one-dimensional photonic heterostructures have attracted a great deal of interest as fabrication is easier than for 2D photonic crystal filter and 3D photonic crystal filter, and 1D photonic crystal filter are predicted to have narrow frequency transmission windows and a sharp angular defect mode [14,17]. Based on such a heterostructure,

* Corresponding author at: Department of Physics, Nanjing University of Science and Technology, Nanjing 210094, China.

E-mail address: njustjw@yahoo.com.cn (W. Jia).

many filters with both narrow-frequency-window transmission filtering and sharp angular spatial filtering have been successfully designed [3]. Murphy designed and fabricated Bragg-Reflection Filters (filter bandwidth ≈ 40 nm) in Silicon-on-Insulator Ridge Waveguides [23]. In 2009, Krauss designed Optical filter (filter bandwidth ≈ 300 nm) based on a photonic-crystal vertical-directional coupler [24]. However, the filter bandwidth in previous studies is not very broad. In order to achieve high precision filters with broad bandwidth, we apply a genetic algorithm (GA) to design the photonic heterostructure [18]. As a popular seeking algorithm, GA has the following features: robustness, capacity to search without gradient information, independence of the initial guess, and ability to operate on discrete and continuous parameters simultaneously. So it is very suitable to deal with optimization problems for such multilayer systems in our study. Using the optimized design parameters obtained through use of the GA, the structure has been fabricated using electron beam lithography and ICP etching [19–21].

2. Model and methods

A typical photonic heterostructure is exhibited in Fig. 1. In our study, two alternating materials A and B with refractive indices $n_A = 3.47$ (Si) and $n_B = 1$ (air) are chosen to construct the photonic heterostructure. This heterostructure can be divided into four substructures, S' , S'' , S''' , and S'''' as shown in Fig. 1. Substructure S' consists of N alternating layers of materials A and B, with a physical thickness of material A given by $d'_A = f \cdot \lambda_0 / (4n_A)$ and physical thickness of material B by $d'_B = f \cdot \lambda_0 / (4n_B)$, where λ_0 is the central wavelength of the incident waves, and f represents the thickness ratios. We denote this structure as $S' = f[(BA)^N]$. Similarly, we denote the other substructures as $S'' = r[(BA)^N]$, $S''' = t[(AB)^N]$, and $S'''' = g[(AB)^N]$, so that the entire

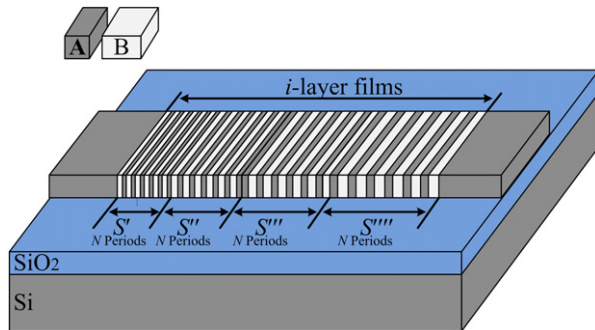


Fig. 1. Schematic sketch of the photonic heterostructure.

structure is denoted by $S = S' \cup S'' \cup S''' \cup S'''' = f[(BA)^N]r[(BA)^N]t[(AB)^N]g[(AB)^N]$. Here, N represents the number of PC periods in each sub-heterostructure, while f , t , r , and g each represent the thickness ratios d_A : $\lambda_0/(4n_A)$ and d_B : $\lambda_0/(4n_B)$, of each sub-heterostructure. It should be pointed out that all the materials here are assumed to be linear, homogeneous and non-absorbing. In this paper, optical transmission matrix formulae [16,22] have been used to calculate the transmittance through the photonic heterostructure with a total of i film layers. This procedure is used within the genetic algorithm to evaluate structure performance as part of the optimization routine.

Following techniques found in literature [3], in our system, we define the total substructures as $S = S' \cup S'' \cup S''' \cup S'''' = f[(BA)^N]r[(BA)^N]t[(AB)^N]g[(AB)^N]$. When f , t , r , and g satisfy the following conditions: $1 - f = g - 1$ and $1 - r = t - 1$ (the thickness ratio of each layer of 1D PC is symmetric in a quarter-wavelength λ_0), the total structure can just be allowed to propagate central wavelength λ_0 in the case of normal incidence. In other words, it means that, for the range of frequency of interest, only light with an integral multiple of the central frequency ω_0 ($\omega_0 = 2\pi c/\lambda_0$) at normal incidence can propagate through the composite structure, so we only need to optimize the filter bandwidth of the heterostructure,

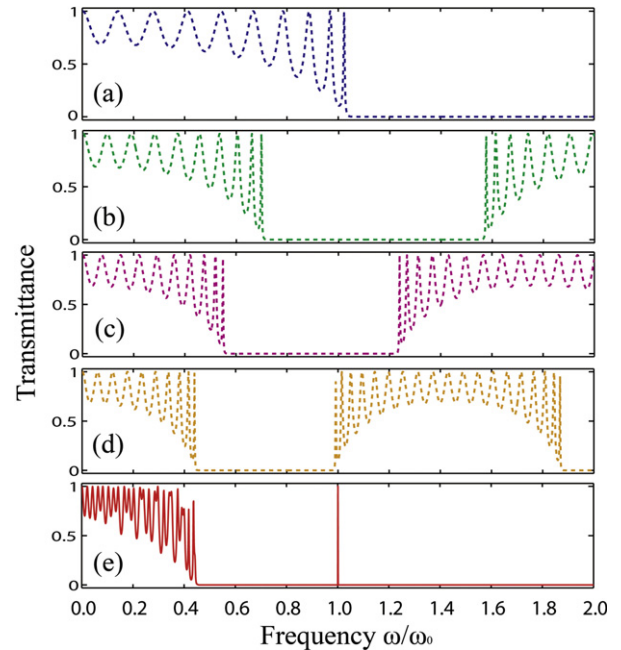


Fig. 2. Computed transmittance for the structures (a) $S' = 0.60[(BA)^N]$, (b) $S'' = 0.88[(BA)^N]$, (c) $S''' = 1.12[(AB)^N]$, (d) $S'''' = 1.40[(AB)^N]$, and (e) $S = S' \cup S'' \cup S''' \cup S''''$ at normal incident angle.

Download English Version:

<https://daneshyari.com/en/article/1543342>

Download Persian Version:

<https://daneshyari.com/article/1543342>

[Daneshyari.com](https://daneshyari.com)