COUPLING PROPERTIES OF DIRECTIONAL COUPLERS BASED ON SPECIAL WAVEGUIDES

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Received 10 August 2012

ABSTRACT: *The coupling characteristics of a novel kind of directional couplers composed by two parallel non-conventional waveguides are theoretically analyzed in details. The coupling length as a function of the operating wavelength and their optical and geometrical parameters are determined by an efficient frequency domain finite element method.* © 2013 Wiley Periodicals, Inc. Microwave Opt Technol Lett 55:949–951, 2013; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.27489

Key words: *directional couplers; periodical segmented waveguides; nanowires waveguides; photonics; numerical simulation*

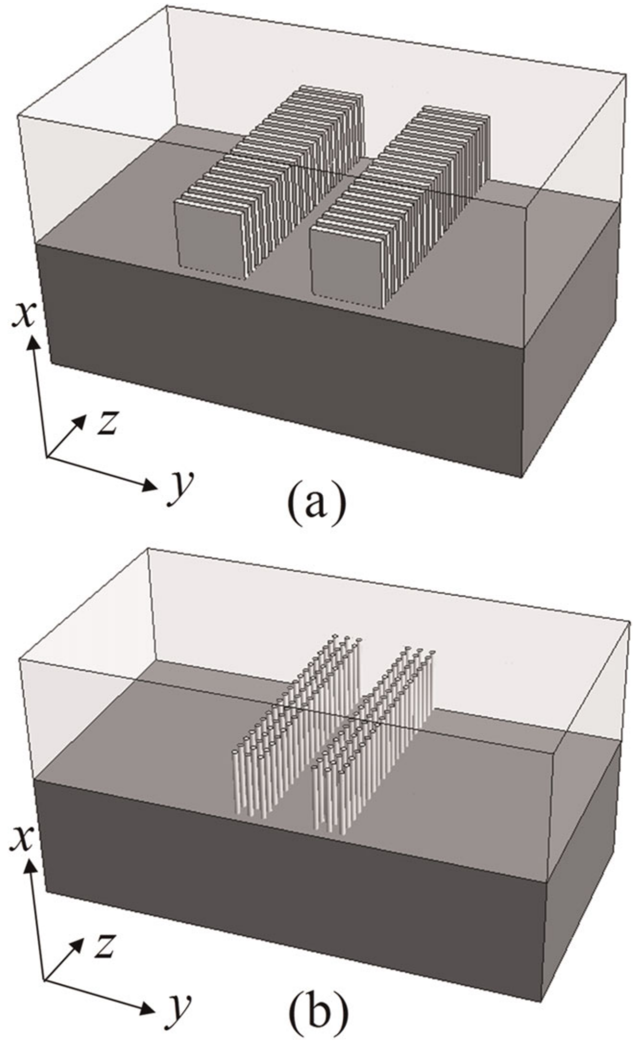

Figure 1 Schematic of the directional couplers based on two parallel waveguides: (a) SNWs and (b) PSWs

1. INTRODUCTION

Directional couplers are of great application in photonic circuits [1–3], and they are composed by two parallel waveguides where the electromagnetic energy transfers from one to another waveguide in a periodical way after propagating a distance called the coupling length. The geometry of the waveguides can be arbitrary, i.e., rib waveguides, channel waveguides, optical fibers [1, 2], photonic crystal waveguides [3], plasmonic waveguides [4], and ultralow refractive index metallic nanostructures [5, 6]. In this letter, novel kind of waveguides called the periodic segmented waveguide (PSW) [7] and the silicon nanowires waveguides (SNW) [8] have been considered to be in close proximity in order to create a directional coupler and their coupling properties have been analyzed by an efficient frequency domain finite element method (FEM) [9]. The geometries of the couplers analyzed are shown in Figures 1(a) and 1(b). The wave propagation is along the *z* axes. The main advantages of using PSWs [7] and SNWs [8] for the proposed couplers are their low propagation losses due to the delocalization of the electromagnetic fields inside the substrate and their ability to tailor their effective refractive index by changing the filling ratio in the waveguide region [7, 8] as well as it promissory usage in waveguides crossings [10].

The guiding mechanism in both types of waveguides is the total internal reflection and because of the subwavelength size along the propagating direction, there is no Bragg's diffraction.

The proposed couplers are promising candidates for sensor applications such as fluid or gas sensors due to the facility of interaction with fluids and gases which can easily change their coupling properties. The analysis of the coupling characteristics has been carried out by an efficient 2D FEM in the frequency domain with periodical boundary conditions of Bloch type in the propagation direction [9]. The 2D approach is in general adopted in order to reduce the computational effort and

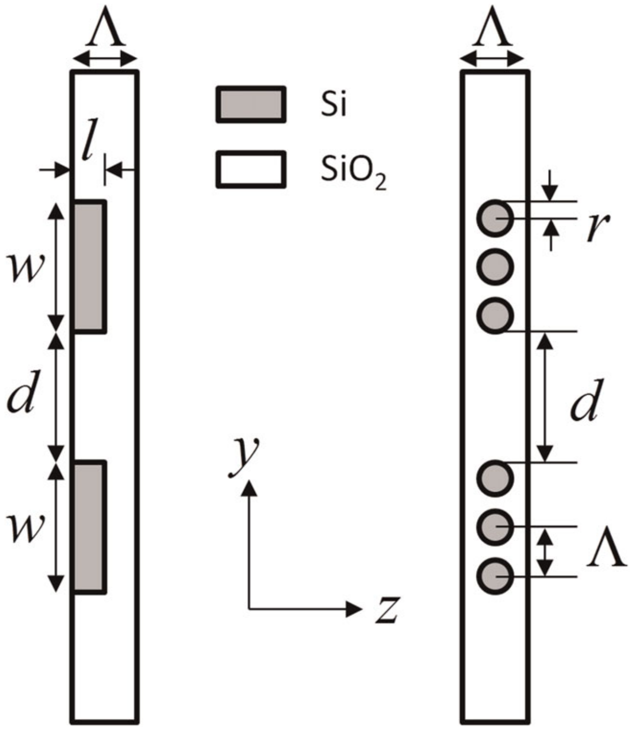

Figure 2 2D unitary cells corresponding to the directional couplers based on PSWs (left) and SNWs (right)

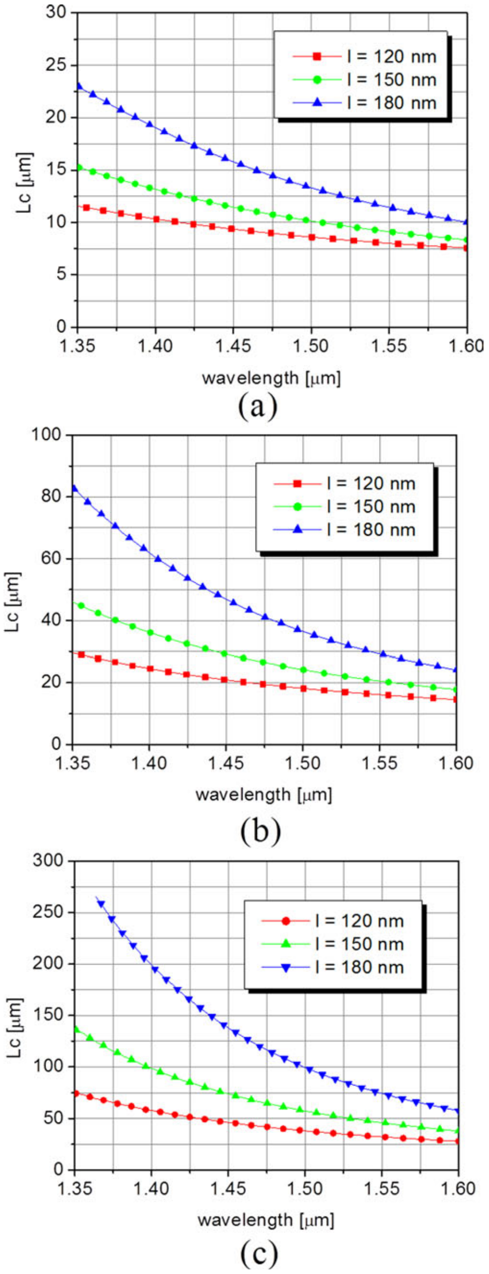

Figure 3 Coupling length of PSWDCs for waveguide separation of (a) 500 nm, (b) 700 nm, and (c) 900 nm. In all cases, $w = \Lambda = 300$ nm. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

resources and it can provide a good feeling of the actual device behavior. Under these considerations, the unitary cells considered as computational domains are shown in Figure 2.

2. METHOD OF ANALYSIS

To obtain the coupling characteristics of the proposed directional couplers (DCs), the supermode approach [11, 12] has been adopted here. It consists on the calculation of the effective refractive indexes, n_{even} and n_{odd}, corresponding to the even and odd supermodes of the structure composed by the two parallel waveguides, respectively. The effective refractive indexes were obtained by using the frequency domain FEM with isoparametric second-order triangular elements [9]. The accuracy of the FEM applied to the modal analysis of periodic structures has been already demonstrated and has been largely reported in the literature [3, 5, 13, 14]. Periodical boundary conditions of Bloch type have been imposed in the propagation direction by equating the fields over the left and right edges of the unitary cell, i.e., $\phi(z) = \phi(z + \Lambda)$, where ϕ is either the electric or magnetic field in the x direction for the TE or TM mode, respectively. Consequently, only the unitary cell shown in Figure 2 must be discretized. Finally, the coupling length can be obtained by using [11, 12],

$$\begin{aligned} L_{\text{c}} &= \frac{L_{\text{beat}}}{2} = \frac{\pi}{(\beta_{\text{even}} - \beta_{\text{odd}})} = \frac{\pi}{k_0(n_{\text{eff even}} - n_{\text{eff odd}})} \\ &= \frac{\lambda}{2(n_{\text{eff even}} - n_{\text{eff odd}})} \end{aligned} \tag{1}$$

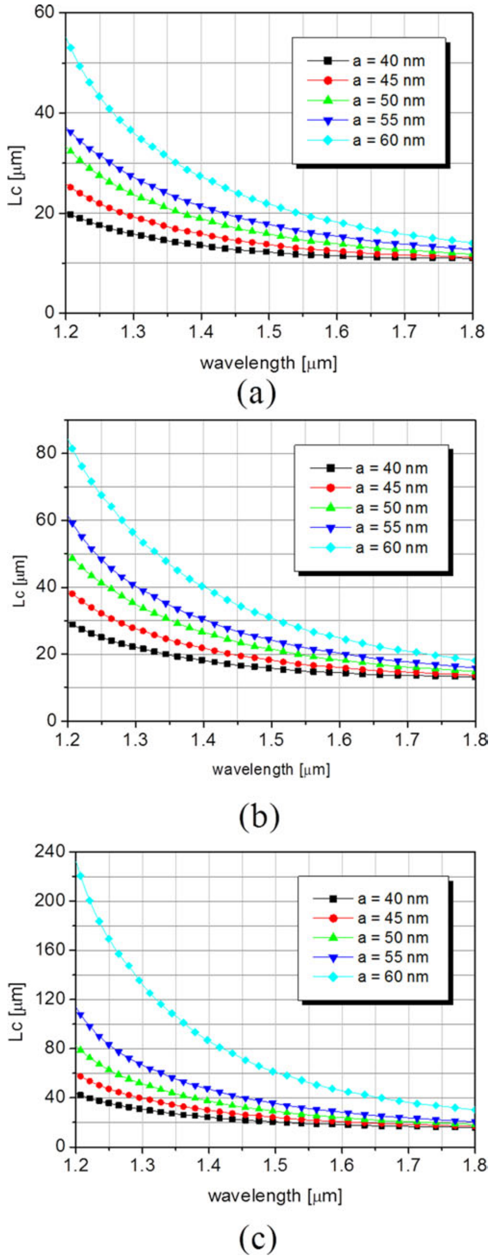

Figure 4 Coupling length of SNWDCs for waveguide separation of (a) $d = 500$ nm, (b) $d = 700$ nm, and (c) $d = 900$ nm. In all cases, $\Lambda = 3a$. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

3. NUMERICAL RESULTS

3.1. Periodical Segmented Waveguide Directional Coupler

The coupling characteristics of periodical segmented waveguide directional couplers (PSW-DCs) have been obtained by sweeping the parameters: segment length l, waveguide separation d, and the operating wavelength λ. In all the cases, the waveguide width and the period remain constant, $w = \Lambda = 300$ nm. E_x polarized field has been considered in our calculations. The results are shown in Figure 3.

The coupling length behaves as in a conventional waveguide where the total internal reflection is the propagation mechanism. When the operating wavelength increases, the coupling length decreases because the field becomes less confined in the core waveguide. The same occurs when the segment length decreases, resulting in a waveguide with equivalent homogeneous refractive index with a low value, resulting in a low confinement of power in the core waveguide and high penetration of the evanescent wave. It can also be realized an increasing on the coupling length when the waveguide separation increases.

3.2. Silicon Nanowires Waveguide Directional Coupler

As a second case, the coupling characteristics of silicon nanowires directional couplers (SNW-DCs) for E_x polarization have been obtained by sweeping the parameters: radius a, pitch Λ, waveguide separation d, and the operating wavelength λ. In all the cases, the waveguides are composed by three nanowires in the y direction and the pitch is three times the radius, $\Lambda = 3\ a$. The results are shown in Figure 4. The same behavior as the PSW-DCs can be also observed.

In conclusion, the coupling properties of new directional couplers based on their dependence on their geometrical and optical parameters have been theoretically obtained, and a more realistic analysis using a 3D formulation that permits the analysis of radiation losses is under consideration.

ACKNOWLEDGMENTS

This work was supported by INCT/Fotonicom, CNPq under grant 302390/2009-0, FAPESB, PET-SESu/MEC, and UFBA.

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LOW PROFILE SLOT ANTENNA WITH DUAL BAND-NOTCHED FUNCTION FOR UWB SYSTEMS

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Received 10 August 2012

ABSTRACT: *In this article, a new multi-resonance slot antenna, with dual band-notched performance for UWB applications is presented. In the proposed structure, by cutting a rotated C-shaped slot on top of the ground plane, additional resonances are excited and hence much wider impedance bandwidth can be produced, especially at the middle band. To generate single band notch characteristics, we use a rotated C-shaped parasitic structure in the ground plane. Also to achieve dual band notch function, we insert a rotated C-shaped slot at square radiating stub. The measured results reveal that the presented dual band-notched slot antenna offers a very wide bandwidth with two notched bands covering all the 5.2/5.8 GHz WLAN, 3.5/5.5 GHz WiMAX, and 4 GHz C bands.* © 2013 Wiley Periodicals, Inc. Microwave Opt Technol Lett 55:951–954, 2013; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.27488

Key words: *slot antenna; rotated C-shaped structure; dual band-notched performance; UWB communications*

1. INTRODUCTION

In UWB communication systems, one of key issues is the design of a compact antenna while providing wideband characteristic over the whole operating band. Consequently, a number of microstrip antennas with different geometries have been experimentally characterized. Moreover, other strategies to improve the impedance bandwidth which do not involve a modification of the geometry of the planar antenna have been investigated [1–4]. The frequency range for UWB systems between 3.1 and 10.6 GHz will cause interference to the existing wireless communication systems, such as the wireless local area network (WLAN) for IEEE 802.11a operating in 5.15–5.35 GHz and 5.725–5.825 GHz bands, WiMAX (3.3–3.6 GHz), and C-band (3.7–4.2 GHz); therefore, UWB antenna with a single and dual band-stop performance is required [5, 6].