High-Q two-groove resonator for all-dielectric Bloch surface wave platform

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Abstract. We propose a simple integrated resonant structure for the Bloch surface wave platform, which consists of two subwavelength grooves patterned on the surface of a one-dimensional dielectric photonic crystal. We demonstrate that the investigated structure can operate in a parasitic-scattering-free regime and, in this case, provide unity transmittance and zero reflectance at resonance conditions associated with the excitation of a leaky mode of the structure localized at the central ridge formed by the grooves. The proposed structure may find application in integrated photonic devices for optical filtering and analog optical computing.

1. Introduction
In recent years, all-dielectric nanophotonics has attracted considerable research attention due to both theoretical interest and potential practical applications driven by the possibility of obtaining high-Q low-loss resonant structures [1]. One of the promising platforms of all-dielectric integrated nanophotonics is the Bloch surface wave (BSW) platform. Bloch surface waves are electromagnetic waves supported by the interfaces of photonic crystals. In the simplest case, they propagate along an interface between a one-dimensional photonic crystal and a homogeneous dielectric medium [2]. For Bloch surface waves, various integrated optical elements have been proposed, for example, refractive lenses [3] and phase-shifted Bragg gratings [4].

In the present work, we propose and numerically investigate a simple resonant structure for Bloch surface waves, which comprises two parallel grooves on the surface of a one-dimensional dielectric photonic crystal. We show that if the bandgap configuration of the photonic crystal is chosen properly, the structure can operate without any “parasitic” scattering in the case of oblique incidence of a TE-(transverse electric) polarized BSW, exhibiting high-Q resonances. The quality factor of the resonances can be tuned by changing the width of the grooves and, neglecting the absorption losses, surface imperfections and finiteness of the structure, can be made arbitrarily large. The obtained results may be useful for filtering as well as pulse- and beam-shaping applications in integrated nanophotonics.
2. Results and discussion

The geometry of the investigated resonant integrated structure is shown in Fig. 1(a). The structure consists of two grooves on the surface of a one-dimensional dielectric photonic crystal (PC). Here, we consider an example with the following parameters: free-space wavelength of the incident wave \( \lambda = 630 \text{ nm} \), refractive indices of the PC layers \( n_1 = 2.3227 \) (Nb_2O_5) and \( n_2 = 1.4762 \) (SiO_2), and thicknesses of the PC layers \( h_1 = 63 \text{ nm} \) and \( h_2 = 189 \text{ nm} \). Thickness of the upper layer of the photonic crystal having the refractive index \( n_1 \) amounts to \( h'_1 = 136 \text{ nm} \), and the thickness of this layer in the groove regions equals \( h''_1 = 69 \text{ nm} \). At the given parameters, the interface of the PC supports a TE-polarized BSW with effective refractive index (propagation constant normalized by the wavenumber) \( n_{\text{BSW}} = 1.95 \) and a TM-polarized BSW with effective refractive index \( n_{\text{BSW,TM}} = 1.6 \). At the same time, in the groove regions, no BSWs are supported. We will study the oblique incidence of the TE-polarized BSW on the two-groove structure (the angles of incidence \( \theta \) are measured in the \( \text{yz} \)-plane from the negative direction of the \( z \) axis). The bandgap and interface of the PC are designed in such a way that at angles of incidence exceeding the “critical” angle \( \theta = 66.5^\circ \), no reflected and transmitted cross-polarized (TM-polarized) BSWs are excited, and no energy is scattered from the PC interface to the superstrate and to the “bulk” part of the PC. Thus, all the energy of the incident TE-polarized BSW is divided between the reflected and transmitted BSWs having the same polarization. In this case, the considered two-groove structure can be considered as an integrated counterpart of a resonant three-layer structure in a high-index environment, which was considered in [5] for achieving large optical field enhancement over a large volume.

![Figure 1](image_url)

**Figure 1.** (a) Geometry of the two-groove resonant structure on the Bloch surface wave platform. (b) Angular transmittance spectra of three two-groove structures with groove width \( s \) ranging from 200 to 400 nm. (c) Distribution of the \( y \)-component of the electric field at resonance conditions \( (s = 300 \text{ nm}, \theta = 70.42^\circ ) \).

Let us consider the optical properties of three two-groove structures with a fixed ridge width \( w = 350 \text{ nm} \) and different groove widths \( s \) of 200, 300, and 400 nm. Figure 1(b) shows the dependencies of the transmittance on the angle of incidence \( \theta \) for the three considered groove widths. These plots were calculated using an efficient in-house implementation of the Fourier modal method [6] adapted for the solution of integrated optics problems [7]. It is evident that the structures exhibit resonant peaks, the width of which can be changed by changing the groove width. For ease of
comparison, the transmittance spectra are shown vs. the deviation from the resonance angle $\theta_0$, which is slightly different for the three considered structures and ranges from $\theta_0 = 70.40^\circ$ to $\theta_0 = 70.47^\circ$. Away from the resonance, the incident wave is almost completely reflected by the structure due to an effect similar to total internal reflection. However, if the leaky mode of the central ridge is excited, which in this case acts as a ridge BSW waveguide [8], the energy is “tunnelled” through the grooves and is completely transmitted. The resonant nature of the transmittance peaks is confirmed by Fig. 1(c) showing the field distribution in the structure at resonance conditions. Note that from the theoretical point of view, the width of the transmittance peaks can be made arbitrarily small by increasing the groove width. Let us also note that similar resonant transmittance peaks are observed in the frequency spectra of the investigated structures, which are not presented here for the sake of brevity.

3. Conclusion
In this work, we presented a simple resonator for Bloch surface waves, which can be effectively used as a spatial (angular) or spectral BSW filter operating in transmission. The proposed resonator consists of two parallel grooves on the surface of a one-dimensional photonic crystal. The grooves form a central ridge, the leaky modes of which are excited in the geometry of oblique incidence of a TE-polarized BSW. The quality factor of the resulting resonance can be controlled by changing the width of the grooves. We believe that the obtained results may find application in novel integrated nanophotonic devices.

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