Fabrication of Photonic Crystal Line Defect Waveguides by Use of Optical Lithography and Focused Ion Beam

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Abstract: A fabrication strategy for realizing photonic crystal structures with long interfacing waveguide has been reported. The technique utilizes a combination of optical lithography and focused ion beam milling to fabricate the device.

OCIS codes: (130.0130) Integrated optics; (130.5296) Photonic crystal waveguides

1. Introduction

Photonic crystals (PhCs) are structures with periodic dielectric functions that prohibit the propagation of electromagnetic waves for a particular band of frequencies indicated by the photonic band gap. The property of photonic band gap has been exploited by many researchers to realize various compact photonic devices like filters [1], lasers [2], sensors [3] and resonators [4]. PhCs can be realized in two-dimensions by etching holes periodically in a high index material. Breaking the periodicity of a PhC structure can be used to confine and to slow down the propagation of light. Line defects in a PhC structure has been used for slowing down light and exaggerating various optical phenomena.

Realizing submicron-scale PhC structures with long interfacing waveguides is challenging due to the issue of resolution. Focused Ion Beam (FIB) is a very promising tool for fulfilling such requirements. The advantage of using FIB is the removal of proximity effects because the substrate is etched directly without using any mask. FIB milling also allows real-time imaging of the substrate during the entire process of etching. This promotes accurate positioning of the ion beam and thus permit precise integration with a previously defined pattern in the substrate. However, realizing photonic components using FIB is still challenging. Fabricating perfect vertical walls is difficult because of the re-deposition of etched material. Furthermore, bombardment of ions lead to implantation and thus modifies the crystalline nature of the substrate. Implantation causes absorption of light and hence deteriorates the desired device performance. However, device performance can be improved by post-etch annealing [5].

This paper concentrates on fabrication of line-defect PhC waveguide (PhCW) based devices along with interfacing waveguides having a full device length of approximately 1 cm on a silicon-on-insulator (SOI) substrate by combining optical lithography with FIB processing. The outer layout comprising of interfacing waveguides is realized by lithography technique followed by reactive ion etching and the sub-micron PhC structure in a pre-defined area is patterned by using FIB milling. The technique is faster and cost-effective as compared to e-beam lithography process in defining large device area with PhC structures.

2. Structure Design

The device considered here comprises of a ring-type line defect in a PhC structure. The PhC structure is considered by placing holes with radius (R) of 240 nm hexagonally with a lattice constant (a) of 600 nm in 250 nm silicon device layer of a SOI substrate. The device has been designed for refractive index sensing applications where the filling factor of the line defect is vital. The sensitivity parameter of a PhCW highly depends on the amount of change in the effective refractive index in the waveguide region. It has been shown previously that ring-type line defect PhCW shows a higher sensing potential as compared to hole-type line defect PhCW for the same defect filling factor [6]. The ring-type PhCW has a relatively higher transmission strength as compared to hole-type line defect waveguide with comparable sensitivity for the same defect filling factor due to its narrower forbidden band gap range. Therefore, the PhCW in this paper has been realized by replacing a single row of holes with ring-type structures in the Γ-K direction of the PhC lattice. The rings have an outer radius (R_{out}) of 240 nm and an inner radius (R_{in}) of 140 nm, which create a trench width of 100 nm. The ring parameters create a defect filling factor of ~40%, which corresponds to a sensitivity adequate for monitoring minute changes in the refractive index of analytes [7].