Vertically Coupled Wedge Disks for a Coupled-Resonator Optical Waveguide

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***Abstract*—We present a proof of concept of a coupled-resonator optical waveguide composed of 11 wedge disks coupled vertically. The device is modeled, fabricated and exhibits 3.91 dB loss per resonator.**

Keywords—delay lines, optical resonator, optical device fabrication, slow light, coupled resonators, microdisks

I. INTRODUCTION

With an increase of photonic circuit complexity, compactness and waveguide crossing challenges occur. Vertical integration of planar photonic devices is an attractive response to these issues. 3D photonics responds to the problem by using multiple layers of photonic components coupled with each other. With this approach, different materials can be used and electronics can also be integrated. It has been shown that whispering gallery mode resonators can be coupled with a waveguide on a lower layer [1], thus enabling the integration of wedge disk resonators on chip. Since wedge disks exhibit low losses with quality factors up to 8.8×10^8 [2], they are the most suitable type of integrated resonator.

Resonators are used for multiple applications like sensing [3] or filtering [4] and are also building blocks for coupled resonator optical waveguide (CROW). Types of resonators include racetracks, rings and disks. In this latter case, disks can be in the same plane and coupled horizontally [5]. However, with that approach, the gap definition between the two disks is a microfabrication challenge due to lithography. Therefore, we propose vertical coupling between two layers of wedge disks in order to form a CROW. The design advantages are an improved coupling gap control, compactness and facilitated photolithography. CROW applications are delay lines and filters.

II. MODEL

The interference condition within an optical cavity allows only specific wavelengths to resonate. Whispering gallery mode cavities are a particular type of optical resonator where light is propagating by total internal reflection at the edge of a circular structure like a disk or a sphere. With a wedge disk, the optical mode is pushed towards the center. Since the mode interacts less with the disk surface, the scattering losses are reduced.

The coupling coefficient between two wedge disks is obtained by considering two straight waveguides with a constant distance d [6]. The mode field distribution of each disk is obtained by numerical modeling with the vertical gap Δz and the overlap Δx (Fig. 1 (a)). The effective coupling length L_C is determined by taking the propagation length along the light pathway y where the distance $d(y)$ between the two mode paths is flat (Fig. 1 (b)).

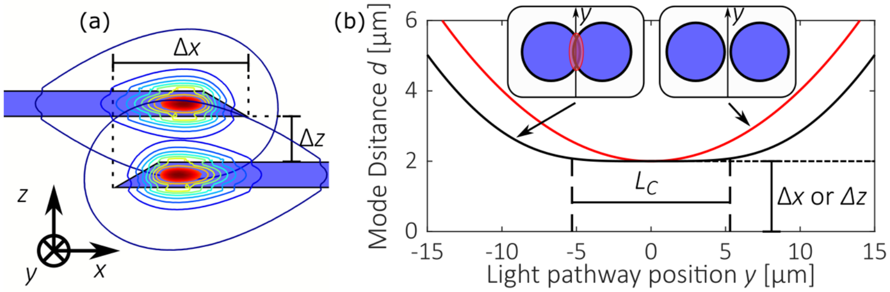

Fig. 1. (a) Side view of vertical coupling of two wedge disks with light mode field superposition. (b) Mode distance d along the light pathway y for vertical (red) and horizontal (black) coupling.

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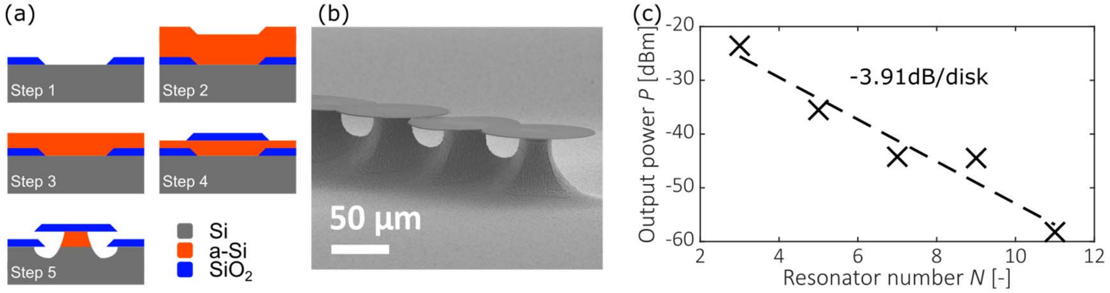

Fig. 2. (a) Microfabrication process. (b) Scanning electron micrograph of final device. (c) Optical power transmission peak versus number of cavities.

III. FABRICATION

The fabrication process (Fig. 2 (a)) begins with a Si wafer with 0.8 µm oxide (SiO_2) top layer. Photolithography and wet etching define the bottom layer of disks (step 1). The photoresist peel-off generates a wedge at the edge of the disks [7]. A 2 µm layer of amorphous silicon (a-Si) is deposited by sputtering (step 2). Chemical mechanical polishing (CMP) is used to planarize the surface (step 3). The a-Si is partially oxidized to form the second 0.8 µm SiO_2 layer. The remaining a-Si layer will serve as a gap between the two photonic layers. Photolithography and wet etching steps are repeated to structure the top layer (step 4). A final dry etching step is performed to define the pillars and release the disks (step 5).

IV. EXPERIMENTAL RESULTS

Scanning electron microscopy is used to characterize the final device (Fig. 2 (b)). The two overlapping layers of wedge disks are shown. The CROW is formed by 11 disks that have a diameter of 50 µm. Measured wedge angles are 65° and 40° for the top and bottom disks respectively. The vertical gap is 0.7 µm and the overlap length is 9.0 µm.

The CROW optical characterization was performed by taking the power output of a transmission peak after *N* disks between two tapered fibers. Using a linear regression (Fig. 2 (c)), a loss per disk of 3.91 dB is obtained.

V. CONCLUSION

In conclusion, we have demonstrated the proof of concept of a CROW made of wedge disks arranged in two layers and coupled vertically. This design is the first of its kind to our knowledge and opens the possibility to integrate high-Q CROWs on chip. This device could be used as a filter or a delay line for applications in optical routers, optical computers and phased array antennas.

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