Silica Microdisk Coupled Resonator Optical Waveguide

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Abstract—This paper presents the first reported experimental results of optical transmission through microdisk Coupled Resonator Optical Waveguide structures made of silica. Transmission through a seven cavity waveguide is presented for an optical delay of 109ps.

I. INTRODUCTION

Coupled resonator optical waveguides (CROWs) have been proposed as a new type of optical waveguide based on the energy transfer between a series of weakly coupled high-Q microcavities [1]. These structures have shown great potential in many applications such as compact optical delay devices due to their ability to strongly reduce the group velocity of an optical signal [2]. These delay devices are extremely important for the next generation telecommunication all-optical routers, to fulfill the need for optical buffers. Other avenues have been explored to slow light down, such as the use of Bose-Einstein condensate where the speed of light can be exceptionally low (17m/s) but cryogenic temperatures are needed to reach the effect [3]. Coupled resonator optical waveguide structures have been discussed and in some cases demonstrated using different types of cavities: 2D photonic crystals [4], microrings [2], microdisks [5] and microspheres [6]. Conceptual analysis of different technologies by Poon et al. [7] showed great interest in the use of silica whispering gallery mode resonators due to their extremely high quality factors (up to $10^8$) and their low optical loss [8]. Microdisks are a type of silica microresonator that can easily be fabricated, using conventional microfabrication processes, into patterns that allow optical coupling between cavities.

This paper demonstrates the first results of optical transmission through a microdisk CROW using silica as guiding medium. We will discuss how these structures are fabricated and results showing optical transmission through a near 500μm waveguide.

II. SILICA MICRODISK CROWS

Slow light propagation in a CROW structure is obtained by trapping light into a series of optical microcavities, each cavity delaying the signal by a few tens of picoseconds before sending it to the next cavity. To fabricate such a structure, we use a conventional fabrication technique presented earlier [9]. An oxidized silicon wafer is used Fig. 1a); the microcavity pattern is defined using photolithography Fig. 1b); microdisks are then transferred into $\text{SiO}_2$ by vertical reactive ion etching Fig. 1c); an isotropic etch is used to shape the silicon support pillar Fig. 1d). Figure 1e) shows a fabricated CROW structure made of eight $35\mu$m radius microdisks with $1.1\mu$m gap between cavities.

Light is injected into the CROW by evanescent coupling into one of the end cavity with a tapered optical fiber. Once inserted into the first cavity, the optical signal is trapped in the form of a whispering gallery mode resonators due to their extremely high quality factors (up to $10^8$) and their low optical loss [8]. Microdisks are a type of silica microresonator that can easily be fabricated, using conventional microfabrication processes, into patterns that allow optical coupling between cavities.

This paper demonstrates the first results of optical transmission through a microdisk CROW using silica as guiding medium. We will discuss how these structures are fabricated and results showing optical transmission through a near 500μm waveguide.

III. RESULTS OF SILICA CROW TRANSMISSION

Figure 2 presents transmission measurements for CROW devices of three ($212\mu$m), five ($354\mu$m) and seven ($496\mu$m) cavities. These measurements were obtained using a tunable

Fig. 1. a-d) Microfabrication process for the silica microdisk CROW structures. a) Initial oxidized silicon wafer, b) Lithographic patterning of the optical cavities, c) Reactive ion etching to transfer microdisks into $\text{SiO}_2$, d) isotropic etch of the support pillar. e) SEM photograph of CROW structure featuring eight $35\mu$m radius coupled microdisks. 

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This maximum delay time is defined as the time for the intrinsic quality factor of our individual microcavities, \( Q \), where
\[
\alpha = \frac{m \pi}{|\kappa|} Q \text{ int},
\]
where \( n_{eff} \) is the cavity’s effective index of refraction, \( R \) is the individual cavity’s radius, \( N \) is the number of optical microcavities in the waveguide, and \( c \) the speed of light.

The coupling coefficient \( |\kappa| \) was calculated versus gap by integrating the modal overlap of two whispering gallery modes (see Fig. 3). For a gap of 1.1\( \mu \)m we have \( |\kappa| = 0.031 \). Using Eq. 1 we obtain a delay of 109ps after seven cavities. Equation 2 describes the relation between the optical loss per cavity \( \alpha_c \) (measured experimentally at \( \alpha_c = -6.13\text{dB/cavity} \), see inset of Fig. 2) and the CROW properties [7]:

\[
\tau = \frac{\pi n_{eff} R N}{|\kappa| c},
\]
where \( n_{eff} \) is the cavity’s effective index of refraction, \( R \) is the individual cavity’s radius, \( N \) is the number of optical microcavities in the waveguide, and \( c \) the speed of light.

These results demonstrate transmission through a seven cavity microdisk CROW. The inset of Fig. 2 describes the attenuation of the optical signal along the length of the waveguide. We note a Slope of -6.13dB/cavity.

IV. DISCUSSION

The maximum delay in a CROW device is function of the intrinsic quality factor of an individual cavity (\( Q \) int) as \( \tau_{max} = Q \text{ int}/\omega \), were \( \omega \) is the cavity’s resonant frequency [7]. This maximum delay time is defined as the time for \( 1/e \) of the input power to be lost. Furthermore, it is possible to determine the delay caused by a specific configuration of CROW using

\[
\tau = \frac{\pi n_{eff} R N}{|\kappa| c},
\]

where \( n_{eff} \) is the cavity’s effective index of refraction, \( R \) is the individual cavity’s radius, \( N \) is the number of optical microcavities in the waveguide, and \( c \) the speed of light.

Using this quality factor we find a \( \tau_{max} \) of 10ps. It is thus extremely important to optimize the fabrication process to minimize geometric defects and surface roughness in order to achieve quality factors several orders of magnitude higher. The range of quality factors needed for long delay CROW structures (> 10^9) has previously been demonstrated using silica circular microresonators [8]. We have shown here the feasibility of creating CROW structures with silica microdisks, which will likely lead to the development of all-optical buffers.

V. CONCLUSION

This paper demonstrated the possibility of creating optical buffers using silica microdisks. When a series of microdisks are coupled together into a CROW structure, it is possible to slow the group velocity of light and thus temporarily store an optical signal. We presented results of transmission through a seven cavity waveguide producing a delay of 109ps. Previous demonstrations of much higher Q silica resonators [8] show the very high potential of using silica microdisk resonators to generate slow light in CROW structures.

REFERENCES