Optical Materials 85 (2018) 138–142

Contents lists available at ScienceDirect

Optical Materials

journal homepage: www.elsevier.com/locate/optmat

# High quality factor silicon oxynitride optical waveguide ring resonators

Yue Jia, Xiaoyu Dai, Yuanjiang Xiang*, Dianyuan Fan

*International Collaborative Laboratory of 2D Materials for Optoelectronic Science & Technology of Ministry of Education, Engineering Technology Research Center for 2D Material Information Function Devices and Systems of Guangdong Province, College of Optoelectronic Engineering, Shenzhen University, Shenzhen 518060, China*

ARTICLE INFO

*Keywords:*
SON
Q factor
Ring resonator
LSCVD
Bragg-grating coupler

ABSTRACT

In this manuscript, we report the design, manufacturing and characterization of silicon oxynitride (SiON) based optical waveguide ring resonators (OWRR) which achieve higher quality factors with respect to the state-of-the-art waveguide ring resonators. To improve the coupling efficiency, Bragg grating couplers are used at both ends of the designed resonators instead of the conventional directional couplers. In the proposed design, the core of OWRR structure was realized in the optimized refractive silicon oxynitride films deposited by liquid source chemical vapor deposition (LSCVD), under controllable composition ratio, time slot duration, and deposition temperature. The SiON based resonators have achieved a measured waveguide loss of 4.07 dB/cm and a quality factor of $0.93 \times 10^5$ in the transverse electric (TE) mode, and this by the way outperforms the results fulfilled with the state-of-the-art waveguide ring resonators.

## 1. Introduction

Optical waveguide ring resonators (OWRR) play an important role in the construction of many optical devices such as sensing systems [1], optical de-multiplexing systems [2], optical filters [3,4], and optical modulators [5], due to their excellent transmission characters, like wavelength selectivity, tunability [6,7], special compact size, and flexible structure. Recently, it turns out that silicon oxynitride ($SiO_xN_y$) materials, which are always written as SiON for short, represent an excellent choice for fabricating the OWRRs due to their controllable high wide range refractive index ranging from 1.45 ($SiO_2$) to 2.0 ($Si_3N_4$) [8–11]. Accordingly, it can be used to produce medium refractive index contrast optical waveguide [12–14]. Additionally, due to their low transmission losses, this kind of SiON waveguide is beneficial in reducing the coupling loss, scattering loss, and tolerance sensitivity of the OWRRs [15]. Moreover, compared to $SiO_2$ waveguide, its eminent optical transparence of SiON ranges from 210 nm to beyond 2000 nm, this makes it possible to manufacture low loss optical waveguides [16]. Furthermore, SiON optical waveguides can be lightly produced by standard photolithography and reactive ion etching (RIE) technique [17]. Some SiON optical waveguide devices, such as integrated spectrometers [18], adaptive gain equalizers [19] or micro ring resonators [20], rings [21], and elliptic couplers [22] have been also reported.

High quality factor (Q) ring resonators are considered as a cornerstone constituent in optical facilities, for instance, low power modulators, high sensitivity sensors, and narrow pass band filters [23,24]. One of the important requirements that should be satisfied in ring resonators is the higher quality factor, because high quality factor value can enhance many waveguide parameters of the resonators [25,26]. For the sake of improving the Q factor of the ring resonators, many efforts have been done, including enlarging the light maintenance within the ring as well as reducing the bending loss of the device. Among the effective methods which can be used to decrease the bending loss, reduce the scattering loss of OWRRs by smoothing the sidewall roughness, and increase the radius of the ring resonators, show excellent performance especially for cases that seek ultra-high quality micro ring resonators [27].

This paper describes a type of optical waveguide ring resonators which are deposited with SiON core layers and indicates the optical features of the resulting OWRRs. We introduce OWRRs with SiON films, produced by the Liquid source CVD (LSCVD) method, in which Bragg grating couplers are employed at both the output and input terminals to couple light to the resonators directly. LSCVD is the preferred process for the non-volatile molecular precursors with a very low vapor pressure. Serious OWRRs with different radius are introduced, depositions and fabrications are also used to optimize these high quality and low loss OWRRs. A propagation loss of 4.07 dB/cm and a quality factor of $0.93 \times 10^5$ are achieved from OWRR with 150 μm radius and 0.2 μm gap width. This study provides a method for developing high quality OWRRs and their optimization by utilizing LSCVD deposition of the SiON film and demonstrates their feasibility on the low energy, small footprint applications of photonic integration platforms.

---

* Corresponding author.
*E-mail address:* xiangyuanjiang@126.com (Y. Xiang).

https://doi.org/10.1016/j.optmat.2018.08.031
Received 23 April 2018; Received in revised form 7 August 2018; Accepted 11 August 2018

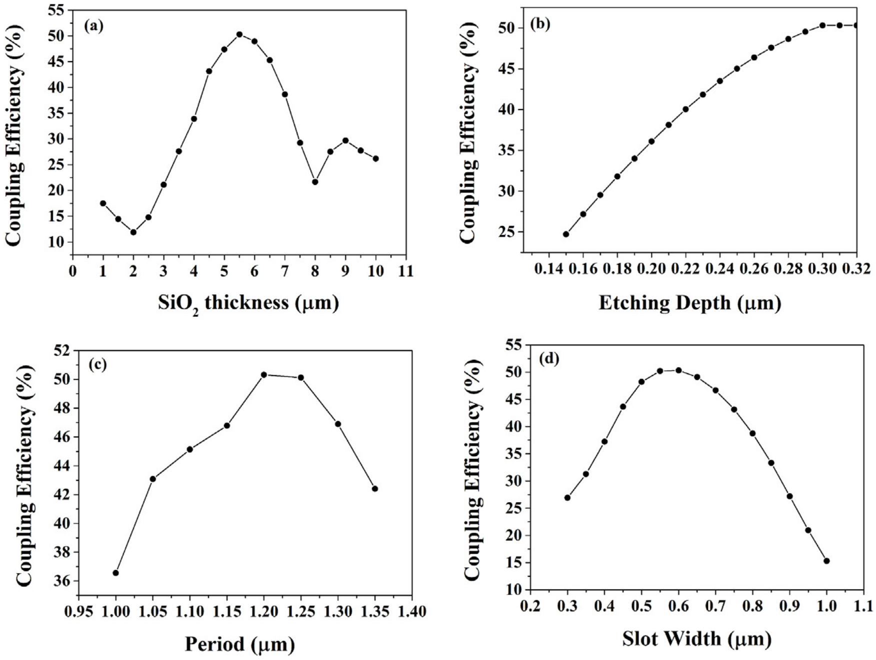

**Fig. 1.** (a) Change of coupling efficiency versus thickness; (b) Change of coupling efficiency versus etching depth; (c) Change of coupling efficiency versus grating period; (d) Change of coupling efficiency versus slot width.

## 2. Experimental

The light coupling efficiency from a grating to a single mode fiber (SMF) is calculated with the assumption that it is the same in the reverse direction, from fiber to the grating. A wavelength of 1550 nm TE polarized light is sent through the Bragg grating coupler to the waveguide ring resonator. The output power is obtained from a normative SMF which makes ten degrees angle with the vertical axis on top of the Bragg grating. The variation of the computed coupling efficiency for the Bragg grating couplers versus the $SiO_2$ thickness and the core etching depth are shown in Fig. 1 (a) and (b). It is obvious from the results that, the optimum $SiO_2$ thickness is 5.5 μm, and the optimum core SiON thickness is 0.32 μm. The change of the computed coupling efficiency for Bragg grating couplers with extensive periods and widths are showed in Fig. 1 (c) and (d). From the results, it can be noticed that the coupling efficiencies are extremely dependent on the period and width. When the grating period is about 1.2 μm and the duty cycle is set to 0.5, the coupling efficiency can approach a maximum value of 50.1%.

The schematic cross section of the designed waveguide, showing the layer structures and the devised parameters of the prospected SiON waveguide, is described in Fig. 2 (a). The cross sectional distribution of the optical field intensity in basic TE mode field simulated by the beam propagation method using Rsoft is shown in Fig. 2 (b). We set the refractive indices of the SiON, $SiO_2$ and cladding film as 1.81, 1.45, and 1.45, respectively, and the wavelength is set to 1550 nm. It is observed that most of the light in the waveguide extends deeply into the $SiO_2$ layer. Such a field distribution can be attributed to both the high refractive index contrast and the ultra-thin SiON.

The deposited core layer SiON is sandwiched between the bottom cladding of silicon dioxide ($SiO_2$) and the over cladding of a poly (methyl methacrylate) (PMMA). The lower cladding layer is deposited by LSCVD with a thickness 5.5 μm above the Si substrate. The SiON layer with a thickness of 0.32 μm and controlled refractive index upon $SiO_2$ layer is fabricated using a normative parallel-plate LSCVD system. The liquid of this LSCVD system is SiN-X source (SiN-2). By controlling the flow rates of $N_2$ and $N_2O$, the refraction index of the SiON films could be alterative from 1.45 to 2.0. SiON film is grown with the thickness of 0.32 μm, and refractive index of 1.81 [28,29] at temperature of 150 °C with the flow rate of $N_2$ and $N_2O$ which is 100 and 10 sccm, respectively. Finally, we chose SiN-2 in a flow rate of 1.0 sccm and deposition time of 6.5 min to get this refractive index by serious examining the refractive index with different SiN-2 flow rate and time.

The patterns of OWRRs, and grating couplers are all transferred onto the resist layer upon SiON by applying the electron beam lithography (EBL) technique. Direct writing and high resolution of EBL allow to get the high accuracy and small feature size of the OWRRs. The samples are developed by oxylene for one minute and exposure baked for 5 min at 145 °C to re-flow the resist surface further to decrease the

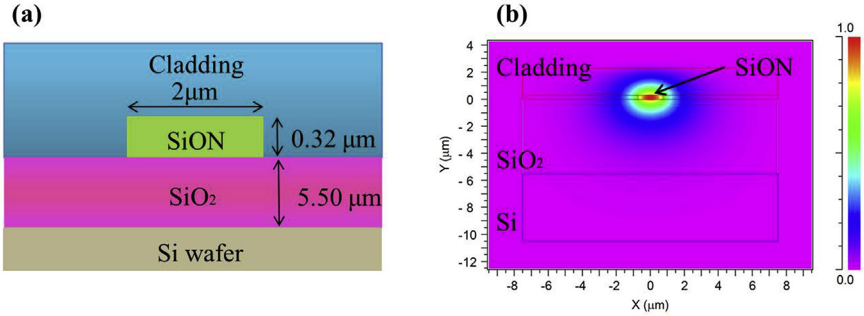

**Fig. 2.** (a) Schematic cross section and prospected design parameters of SiON/$SiO_2$ waveguide; (b) Simulated TE mode profile.