Minimized losses in a cylindrical microresonator by use of a cladding: experimental and numerical study.

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I. INTRODUCTION

Cylindrical microresonators (MRs) have been demonstrated as add/drop multiplexer (see e.g., [1]-[7]), microlaser [8] and proposed as platform for nonlinear processing [9]. Most design-approaches are based on controlling the bend loss by using a high contrast technology with air as cladding. The position of the resonance wavelengths of a MR is sensitive for technological variations and external influences like the ambient temperature. For many applications the resonance wavelength has to be controlled accurately and preferably for each MR on the chip independently. This clearly demonstrates the need for MRs with a cladding, which serves as passivation layer (also see [10]) and platform for the electrodes used for thermo/electro-optically tuning of the resonance wavelength. In this contribution, we present an experimental study of the influence of a cladding on the losses in a cylindrical MR. The experimental results are corroborated with detailed numerical simulations and examples of devices which exploit the presence of a cladding are given.

Fig. 1 Top view and cross-section (A-A) of the waveguide-coupled microring resonator.

II. EXPERIMENTS

Fig. 1 shows a top view and vertical cross-section of the MRs we realized in Si₃N₄ on SiO₂ technology

[11]. For MRs with air cladding, we demonstrated finesse up to $F \sim 182$ [5]-[7]. By spinning a PMMA cladding (index $n_{\text{cladding}} \sim 1.476$) on top of these devices and measuring the power in the through port we studied the effect of a cladding on the device performance. From the measured power in the through port (P_{through}) for 0.5 and 0.75 μm gaps (Fig. 2) it can be concluded that the MR with PMMA cladding shows a spectral response similar to the MR with air cladding. For the MRs with PMMA cladding we could also observe minima in P_{through} for a 1 μm gap. For a more quantitative discussion of the effect of a cladding on the device performance, we compared the 'experimental' parameters for the MRs with air and PMMA cladding, see TABLE I.

TABLE I Experimental parameters of the TE_{0,0} MR-mode for air and PMMA cladding ($\lambda \sim 1530$ nm)

cladding	α [dB/cm]	gap [μm]	F	$ \kappa $ [%]
Air	12	0.5	22	27
		0.75	120	7
		1.0	---	---
PMMA	27	0.5	25	30
		0.75	61	10
		1.0	61	7

From TABLE I, it can be concluded that for the MR with PMMA cladding the propagation losses of the TE_{0,0} MR-mode ($\alpha \sim 27$ dB/cm) are considerable higher than for the MR with air cladding ($\alpha \sim 12$ dB/cm). Using the measured propagation losses of the TE_{0,0} mode in a similar 1 μm wide SW ($\alpha_{\text{SW}} \sim 10$, 20 dB/cm for air and PMMA cladding respectively) we found estimates for the bend losses of the TE_{0,0} mode of the MRs: $\alpha_{\text{bend}} \sim \alpha - \alpha_{\text{SW}} \sim 2$, 7 dB/cm for air and PMMA cladding respectively. The high losses of the devices with PMMA cladding are attributed to the high absorption losses in the (non-optimized) PMMA layer. The observed increase of the fraction ($|\kappa|$) of the field coupled from the SW to the MR for the MR with PMMA cladding is attributed to the filling of the gap with PMMA.

III. DISCUSSION

From the experiments, it was concluded that the presence of a PMMA cladding somewhat increased

Fig 2 (a)-(d) Measured power in the through port for 500 and 750 nm gaps for devices with PMMA and air cladding.

the bend losses. In order to investigate the effect of a cladding on the bend losses into more detail, we calculated the bend losses for the TE_{0,0} mode as a function of the index of the cladding using a commercially available 2D modesolver, see Fig. 3. A good agreement between the measured and calculated bend losses can be observed.

Fig 3 Calculated and experimental bend losses of the TE_{0,0} modes vs index of upper cladding.

From Fig. 3 it can be concluded that upon increasing the index of the cladding (from $n_{\text{cladding}} \sim 1$) the bend losses decrease from $\alpha_{\text{bend}} \sim 2.4$ dB/cm towards a minimum of $\alpha_{\text{bend}} \sim 0.8$ dB/cm for $n_{\text{cladding}} \sim 1.3$. This observation is somewhat counterintuitive, as one would expect the bend loss to increase when introducing a cladding. Both numerical calculations and measurements however show that the SWs become bimodal when introducing a PMMA cladding, which corresponds to an increased lateral contrast indicating lower bend losses. Increasing n_{cladding} beyond the index of the SiO₂ buffer layer (which gives a symmetric layer stack) results in a strong increase of the bend losses: e.g., $\alpha_{\text{bend}} \sim 13.9$ dB/cm for $n_{\text{cladding}} \sim 1.5$. This

indicates that a MR with minimized bend losses tends to a symmetric layer stack.

IV. CONCLUSION AND OUTLOOK

By carefully choosing the index of the cladding one can minimize the bend losses. The minimum in the bend losses is mainly attributed to an increase of the lateral contrast by the cladding layer. The possibility of a cladding on top of the MRs without drastically increasing the bend losses, allows for active tuning of individual MRs on a chip; which considerably relaxes the technological tolerances. As a cladding layer reduces the index contrast at the etched interfaces of the MR, we also expect a decrease in the sidewall scattering losses. Cylindrical MRs with a cladding layer optimized for sensing, lasing applications are under study.

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