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Pulley Couplers for Broadband Microcomb Generation in Si_3N_4 Ring Resonators

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Abstract. Microresonator solitons enable high repetition-rate optical frequency combs. Their spectral span scales inversely with the strength of the resonator's anomalous group velocity dispersion. In a thick (800 nm) silicon nitride platform, wide resonator waveguides (>2 µm) with weak anomalous dispersion are especially promising for the generation of broadband spectra. As wider waveguides have a weaker evanescent field, the coupling strength to their bus waveguide is reduced. To address this challenge, alternative coupler designs, such as pulley couplers are required. Here, we investigate pulley couplers for wide waveguide specifically targeted at broadband soliton generation. We observe significant improvement of the coupling ideality compared to conventional coupler geometries and broadband four-wave mixing spectra are observed in 2.8 µm wide microresonators.

1 Introduction

Microring resonators are highly versatile devices [1]. Regardless of the specific application, it is necessary to transfer light between the resonator ring and an adjacent bus waveguide through evanescent coupling. This is often achieved by placing a *straight bus waveguide* (Fig.1a) adjacent to the resonator ring, such that light can couple across what is usually a few-hundred nanometer gap. It has been reported that this scheme suffers from a number of drawbacks, among which are parasitic coupling to undesired spatial modes [2], reducing the coupling ideality (the ratio of coupling to the desired mode to that of all coupling contributions), as well as difficulties in coupling to rings with wide waveguide or small bend radii due to the necessity for small gaps [3]. This is also a challenge in thick Si_3N_4 (800 nm layer height), where ring resonators with wide waveguide (>2 µm) are attractive for the generation of broadband comb spectra owing to their weak anomalous group velocity dispersion (Fig.1c). *Pulley couplers* [4, 5] can address this challenge. In a pulley coupler configuration, the bus waveguide is wrapped around a section of the ring resonator (Fig.1b) effectively increasing the coupling length and allowing for a larger coupling gap. Here we use this scheme to achieve critical coupling with high coupling ideality to targeted mode families in wide waveguide microresonators for broadband comb generation.

2 Results

The pulley couplers developed in this work are designed such that for a given gap between bus and microring resonator the azimuthal propagation constant of the TE_{00} mode in the bus wavegudie matches that of the targeted mode in the resonator (TE_{00} or TE_{01}). To achieve this, the bus needs to have a smaller waveguide width than the resonator [3]. Matching propagation constants enables efficient coupling to the targeted resonator mode family while also suppressing coupling to other spatial mode families due to the phase mismatch.

The ring resonators are fabricated by LIGENTEC SA using deep UV stepper lithography. To characterize the devices, we extract the resonance linewidths and on-resonance transmission from a frequency-calibrated laser scan (1520 nm to 1605 nm) of the bus waveguide transmission. In order to compare our design to the straight bus coupler baseline, we record linewidth and on-resonance transmission for resonator with a 2.2 µm wide waveguide and a radius of 75.8 µm (free spectral range of ~300 GHz) using both straight and a pulley coupler designs with varying gap size (i.e. coupling strengths). From this data we extract the coupling ideality of the couplers and the intrinsic linewidth of the resonators. As shown in Fig. 2a the coupling ideality in the case of the straight bus coupler is ~ 0.25. As a coupling ideality below 0.5 prevents access to the critical- and overcoupled regimes [2], these resonators are poorly suited for non-linear applications where achieving high intracavity power is key. As shown in Fig. 2b, pulley couplers permit a coupling ideality close to unity. Interestingly, we also observe a significant reduction of the intrinsic linewidth $\kappa_0/(2\pi)$ from ~50 MHz to 33 ~ MHz. We attribute this to the much larger gap in the pulley configuration (well beyond the UV lithography's resolution limit), which in turn improves the consistency and quality of the fabricated coupling section, reducing the as-

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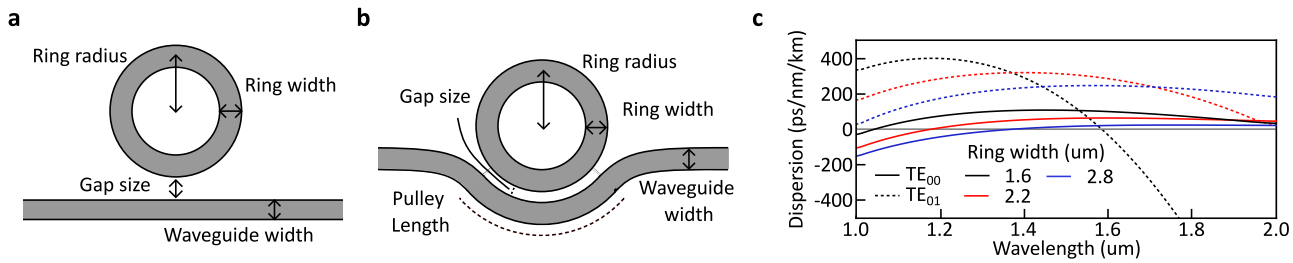

Figure 1. Schematic of a straight coupler (**a**) and pulley coupler (**b**) geometries. **c**, Simulated dispersion of the TE_{00} and TE_{01} modes for different resonator ring waveguide widths in thick (800 nm high) Si_3N_4. The resonator ring radius is 75.8 µm corresponding to an ~300 GHz free spectral range.

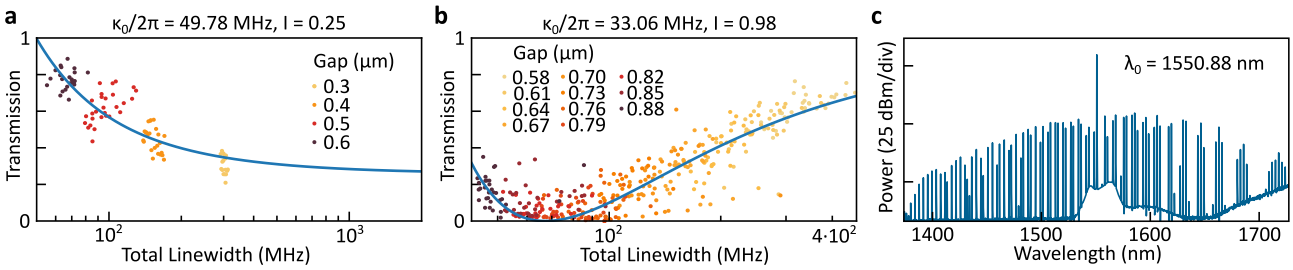

Figure 2. a, Measured on-resonance transmission vs total linewidth for various coupling gaps (ie. coupling strength) in 300 GHz free spectral range microring resonators with 2.2 µm wide ring waveguide in straight bus coupler configuration. The coupling ideality and intrinsic linewidth are extracted by fitting the data according to [2]. Due to the small gap size and coupling to higher order modes, coupling ideality is ~ 0.25 and critical coupling cannot be achieved. **b**, same as in **a** but with a pulley coupler configuration. Here the bus is 1.75 µm wide in order to phase-match the ring and bus TE_{00} modes. Notably, coupling ideality is ~ 0.98 as coupling to undesired modes is nearly absent. **c**, Broadband spectrum obtained from pumping the TE_{00} mode in a microring resonator with a 2.8 µm wide waveguide. This is sample has a coupling ideality of ~0.9 and an intrinsic linewidth of 25 MHz.

sociated scattering losses. In a pulley-coupled resonator with a waveguide width of 2.8 µm, a width which cannot be efficiently addressed using straight bus couplers, critical coupling is accessible with a high coupling ideality of ~ 0.9. The dispersion of the 2.8 µm wide microring is even weaker than for the previously shown 2.2 µm thick ring, resulting in the broadband spectrum shown in Fig. 2c, which can possibly be extended to ultrashort soliton formation [6].

3 Conclusion

In summary, we demonstrate efficient coupling with high ideality to microring resonators with wide waveguides via pulley couplers. Owing to their low intrinsic loss and small dispersion, such resonators are of high relevance for broadband nonlinear phenomena, including broadband frequency combs and ultrashort soliton pulse generation.

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