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1.4 million Q factor Si_3N_4 micro-ring resonator at 780 nm wavelength for chip-scale atomic systems

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Abstract: A silicon nitride micro-ring resonator with loaded Q factor of 1.4 million at 780 nm wavelength on silicon substrates for chip-scale atomic systems targeting the ^{87}Rb atomic transition at 780.24 nm. © 2020 The Author(s)

1. Introduction

Chip-scale atomic devices such as atomic clocks [1–3], magnetometers, quantum effects metrology references [4], quantum gravimeters, and gradiometers, use atomic transistions with wavelengths well away from the standard telecoms 1310 nm and 1550 nm. Systems that use ^{87}Rb atoms require 780.24 nm photonic components if photonics integrated circuit systems for thermal or cold atom systems are to be realized. As the wavelength is reduced, however, the scattering losses in waveguides increase significantly as a function of the inverse of the wavelength [5]. Previously we have demonstrated a low loss silicon nitride (Si_3N_4) with silicon dioxide (SiO_2) cladding photonic platform with integrated 780.24 nm distributed feedback (DFB) lasers coupled through spot sized converters to provide over 15 mW of laser power on the chip [6, 7]. Cold atom systems require laser frequency stabilization [2] which can be achieved by locking to a micro-ring resonance peak. A micro-ring resonator has also been used to achieve Doppler cooling of Cesium atoms with evanescent field interactions [8].

In this work, we demonstrate micro-ring resonators with Q factors up to $(1.38 \pm 0.04) \times 10^6$ at 780 nm developed in a 200 nm thick Si_3N_4 photonic platform on 150 mm diameter silicon substrates, see Fig. 1. This thickness of waveguide material has been chosen to support both TE and TM fundamental modes allowing for design of integrated polarization control and other essential integrated active and passive photonic components for thermal and cold atom systems resulting in a design criteria intermediate to the usual large [9] or small [10] waveguide modal overlapping approaches for high Q factor micro-rings.

2. Method

Si_3N_4 layers for waveguide cores were deposited by a low-pressure chemical vapor deposition (LPCVD) tool at 750 °C onto a 4 µm thick thermal SiO_2 layer grown by wet oxidation at 1000 °C. The waveguide pattern was written in hydrogen silsequioxane (HSQ) negative resist using electron beam lithography and etched using a CHF_3/O_2 reactive ion etch. A SiO_2 top cladding layer 900 nm thick was added using plasma-enhanced chemical vapor deposition (PECVD) at 300 °C.

Transmission spectra were recorded using a SolsTiS titanium sapphire laser manufactured by M Squared Lasers with tunable wavelength range of 675 - 1050 nm and a linewidth of <50 kHz. To minimize interaction with the etched waveguide sidewalls and reduce scattering loss, a waveguide width of 1100 nm was used. The temperature dependent wavelength shift was found by simulation to be 13.1 pm/K [11]. To stabilize the temperature of the micro-ring such that the the wavelength is within the actuation range of the resonance peak, a temperature stability of less than ± 15 mK would be required.

3. Conclusion

Micro-ring resonators have been fabricated in a 200 nm thick Si_3N_4 photonics platform with Q factors up to $(1.38 \pm 0.04) \times 10^6$ at 780 nm wavelength. These results have been achieved without chemical mechanical polishing or anneals above 1100 °C which have been essential for high Q factors at 1550 nm [9, 10, 12]. Further optimization should therefore allow higher Q factors to be realized at a wavelength of 780 nm. The temperature stability required for laser frequency stabilization is readily achievable with a commercial thermo-electric cooler or by using a top cladding layer that would reduce the waveguide thermo-optic coefficient.

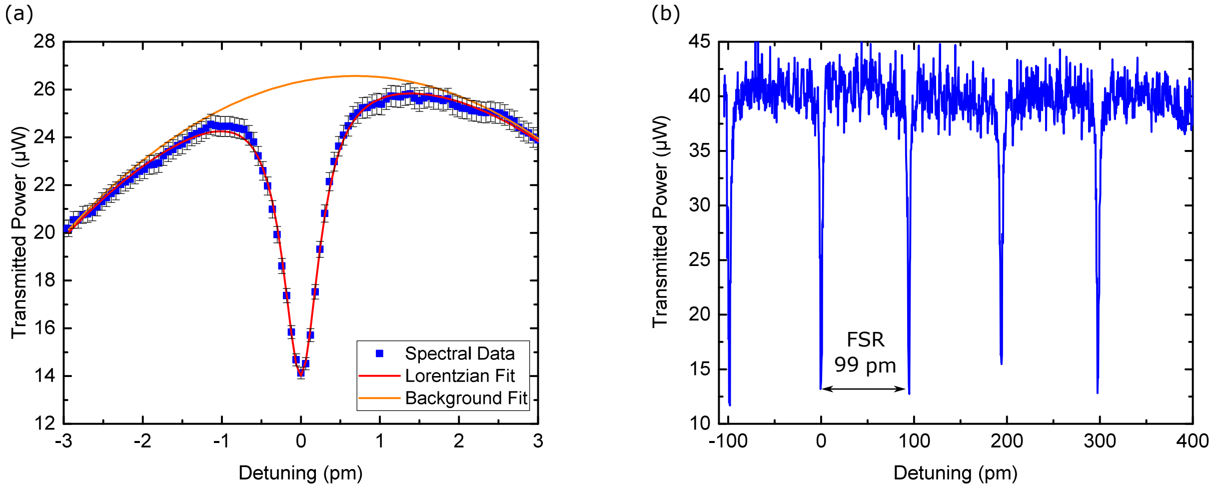

Fig. 1: The transmission spectra of micro-ring resonators. (a) A Lorentzian fit to a resonance peak with a Q value of $(1.38\pm0.04)\times10^6$, this has a Si_3N_4 core 200 nm thick and 1100 nm wide, a bottom cladding 4 μm thick, and a top cladding 900 nm thick. The blue trace is the raw data of a 30 GHz (60 pm) bandwidth transmission spectra centered on 780 nm; the orange trace is the background fit provided by a second degree polynomial; the red trace is the Lorentzian fit. (b) A 250 GHz (500 pm) bandwidth transmission spectra centered on 780 nm of a lower Q micro-ring resonator with the same optical path length showing a free spectral length (FSR) of 99 pm.

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