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Low-loss dispersion-engineered silicon nitride waveguides coated with a thin blanket layer

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Abstract: We demonstrate that coating with a thin blanket layer reduces the propagation loss of silicon nitride dispersion-engineered waveguides featuring strong optical field confinement.

1. Introduction

Silicon nitride (Si_3N_4) is a widely used material for photonic integrated circuits, due to its compatibility with complementary metal oxide semiconductor processes, low optical loss and high nonlinearity [1]. Ultra-high quality-factor (Q) resonators or ultra-low loss Si_3N_4 waveguides have a wide range of applications in e.g. ultra-narrow linewidth lasers [2], optical frequency combs [3], or parametric amplifications [4]. Propagation losses below 0.1 dB/m have been realized through weak confinement [5,6]. However, it is difficult to achieve similar low loss in high confinement Si_3N_4 waveguides because of the higher sensitivity to nanometric sidewall roughness [7–10]. One strategy to reduce the scattering losses in silicon photonics is to deposit a thin (tens of nanometers) titanium dioxide (TiO_2) film by atomic layer deposition (ALD) on lithographically patterned waveguides [11]. A similar strategy has been adapted to low confinement Si_3N_4 waveguides using silicon nitride as the coating layer [6], resulting in improved scattering and absorption losses. In this work, we investigate this strategy in the context of high confinement dispersion-engineered Si_3N_4 waveguides, and demonstrate a significant reduction of the propagation losses, particularly for narrow waveguides, and analyze the impact of the blanket layer on the dispersion.

2. Waveguide fabrication and characterization of microresonators

We fabricated the Si_3N_4 waveguides as shown in Fig. 1(a) using a fabrication flow similar to our prior work [3]. Multipass electron beam lithography was introduced to improve the line edge roughness of the waveguides [12]. Moreover, an additional blanket layer of 8 nm thick (t = 8 nm) Si_3N_4 was deposited by low pressure chemical vapor deposition (LPCVD) using the same recipe as the Si_3N_4 primary core, after high temperature (1200 °C) annealing of the patterned Si_3N_4 devices and prior to the deposition of LPCVD SiO_2 cladding. The Si_3N_4 waveguides have a thickness H of 740 nm and sidewall angle θ ~87º.

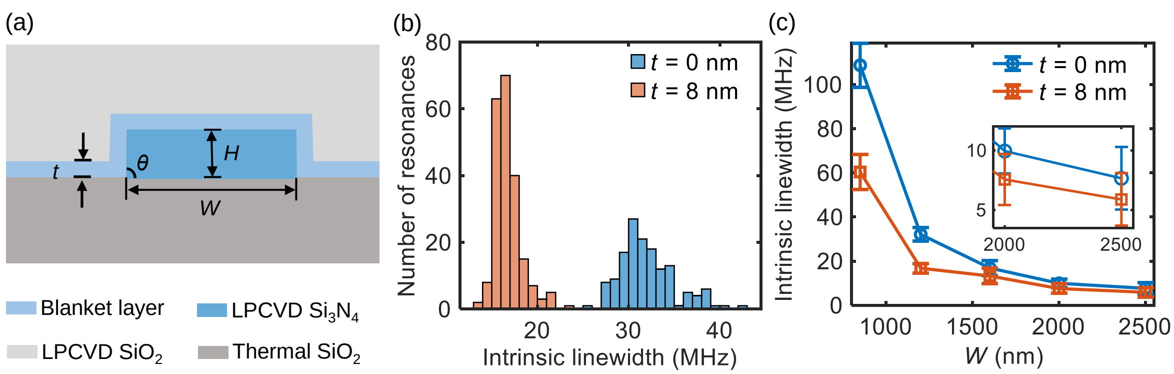

Fig. 1. (a) Schematic diagram of the Si_3N_4 waveguide with a blanket layer. (b) Histograms of intrinsic linewidths from 5 microresonators (W = 1200 nm) with and without the blanket layer. (c) Mean intrinsic linewidth and the standard deviation of the intrinsic linewidth measurement. The inset is a zoom in for W ranging from 2000 nm to 2500 nm.

When characterizing the fabricated microresonators with free spectral range (FSR) ~100 GHz, we swept the wavelength of a tunable laser from 1500 nm to 1600 nm, using a calibrated Mach-Zehnder interferometer to compensate for the nonlinear sweep. In order to avoid the influence of the absorption peak near 1510 nm due to reminiscent N-H bonds, we calculated the linewidths in the wavelength range of 1540–1600 nm. Fig. 1(b) presents two histograms of intrinsic linewidths from microresonators having a width W of 1200 nm, with and without the blanket layer. When the waveguides are coated with an 8 nm thick blanket layer, the highest probable intrinsic linewidth is between 16–17 MHz. This corresponds to a nearly twofold improvement in equivalent losses. However, the relative improvement depends strongly on the width of waveguides. As shown in Fig. 1(c), the larger the width *W*, the lower the impact. For the widest waveguides, the mean intrinsic linewidth changes from 7.66 MHz to 5.88 MHz (equivalent loss is reduced from 1.66 dB/m to 1.27 dB/m). We think that coating with a thin layer can reduce the roughness of the sidewalls, thereby reducing the propagation loss of the Si_3N_4 waveguides. As the width increases, the mode overlap with the waveguide interface decreases, and the influence of the sidewall roughness on the propagation loss is reduced.

3. Dispersion of waveguides

We also measured the dispersion of the Si_3N_4 waveguides. The integrated dispersion $D_{int} = \omega_\mu - \omega_0 - \mu D_1 = D_2\mu^2/2 + D_3\mu^3/6 + \ldots$, where ω_μ is the angular frequency of the μ-th resonance relative to the reference resonance ω_0 [13]. $D_1/2\pi$ is the FSR. As shown in Fig. 2(a), avoided mode crossings are observed at around 1525 nm. The two curves near 1550 nm almost coincide, while at wavelengths far away from 1550 nm, the integrated dispersion has a certain shift. The converted β_2 (group velocity dispersion coefficient) is shifted by ~5 ps^2/km at 1550 nm when the blanket layer is introduced. This small shift is mainly due to the fact that the waveguides feature different geometries in cross section. The effect of the blanket layer is analyzed in more detail in Fig. 2(b), where the β_2 at different wavelengths is computed for two waveguides whose approximately rectangular cross section is identical in size. From these simulations we conclude that the effect of the blanket layer is to modify the third-order dispersion coefficient.

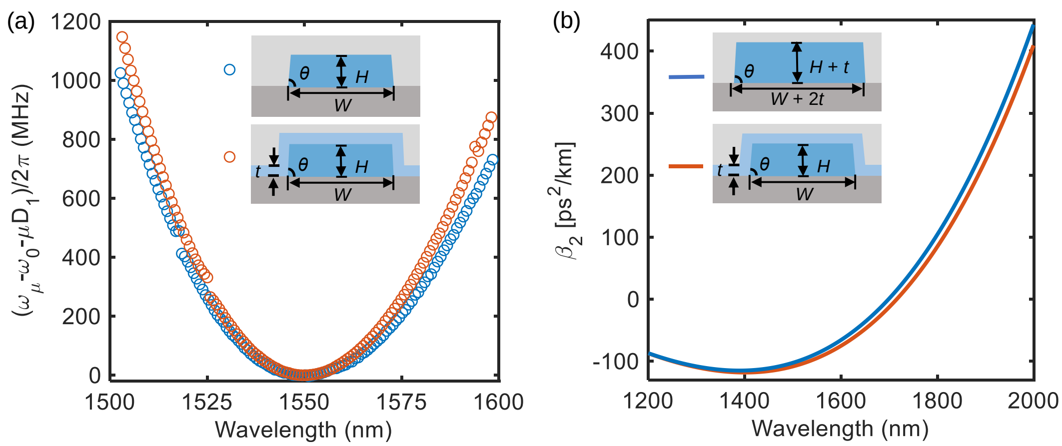

Fig. 2. (a) Measured integrated dispersion of fundamental TE mode. (b) Simulated group velocity dispersion of fundamental TE mode. All waveguide geometries are designed with H = 740 nm, θ = 87º, W = 1200 nm and t = 8 nm.

In summary, we have demonstrated that coating with a thin blanket layer can effectively reduce the propagation losses in high confinement Si_3N_4 waveguides. This effect is more pronounced for narrower waveguides, indicating a significant effect in reducing scattering losses.

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