Photoresist reflow for lithography of lithium niobate on insulator rib waveguides

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Low loss rib waveguides fabricated in lithium niobate on insulator (LNOI) are promising for photonic applications including frequency conversion, electro-optic modulation, and refractometric sensing. The primary source of optical propagation loss in rib waveguides is attributed to surface scattering due to rough sidewalls. Techniques to fabricate rib waveguides with smooth sidewalls include electron beam lithography, the use of metal masks or etch masks such as Si and SiO_2, and chemical mechanical polishing.[1] In this work, we present an alternative photoresist (PR) mask reflow method to etch rib waveguides in LNOI exhibiting subnanometer surface roughness.

The fabrication process is outlined in Fig. 1(a-f). The PR mask undergoes an optimized bake at 200 °C in N_2 ambient to reflow the PR, increase etch resistance, and decrease line edge roughness.[2,3] Compared to bare samples, samples primed with hexamethyldisilazane (HMDS) exhibit a lower change in PR critical feature dimension with baking. Devices are etched using Ar plasma and clad with silicon oxide using plasma enhanced chemical vapor deposition (PECVD). Rib waveguides are fabricated with 240 nm rib depth and widths varying from 1.6 µm to 50 µm. Ring resonators are used to characterize the propagation loss.

We observe smooth sidewalls after etching, consistent with low PR line edge roughness, as shown in the atomic force microscopy (AFM) image in Fig. 1(g). The surface roughness of the etched LN region is measured via AFM to be 0.30 nm rms, as shown in Fig. 1(h), marginally larger than before the etch (0.26 nm rms). Optical micrographs of fabricated resonators are shown in Fig. 1(i, j). Figure 2 shows that rib waveguides with sidewall angles varying from 30° to 14° can be fabricated by increasing the waveguide width and keeping the reflow and etching conditions constant. RMS roughness of 0.49 nm is measured on the sidewall of the waveguide in Fig. 2(d). Intrinsic quality (Q) factor of 10^6 and propagation loss of 0.3 dB/cm is measured on the fabricated device in Fig. 1(j) at 1563 nm wavelength.

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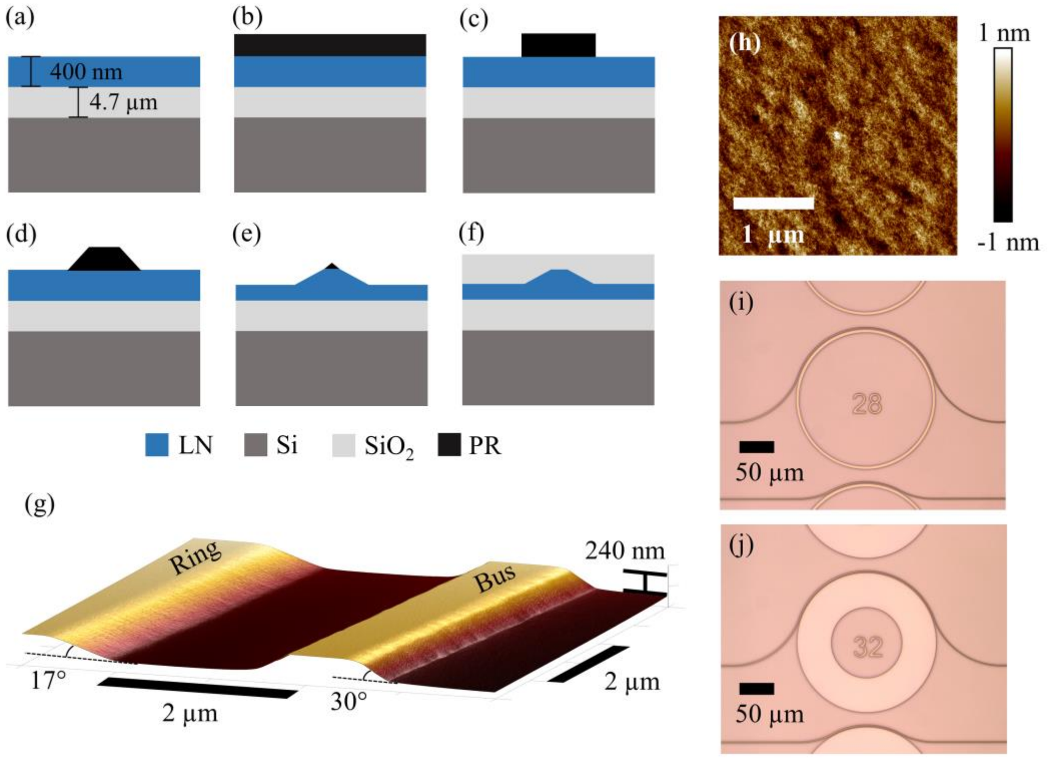

Figure 1. Fabrication of LN rib waveguides using photoresist reflow: (a) HMDS prime of substrate, (b) PR spin coat, (c) PR exposure via 405 nm maskless aligner, (d) PR bake at 200 °C, (e) Ar plasma etch, (f) PR removal and silicon oxide deposition. (g) AFM of rib waveguides in bus coupled ring resonator configuration showing bus and ring sidewalls. (h) AFM scan of plasma etched LN exhibiting a roughness of 0.30 nm rms. Optical micrographs of resonators with 100 µm radius, 250 µm coupling length, and rib widths of (i) 5 µm and (j) 50 µm.

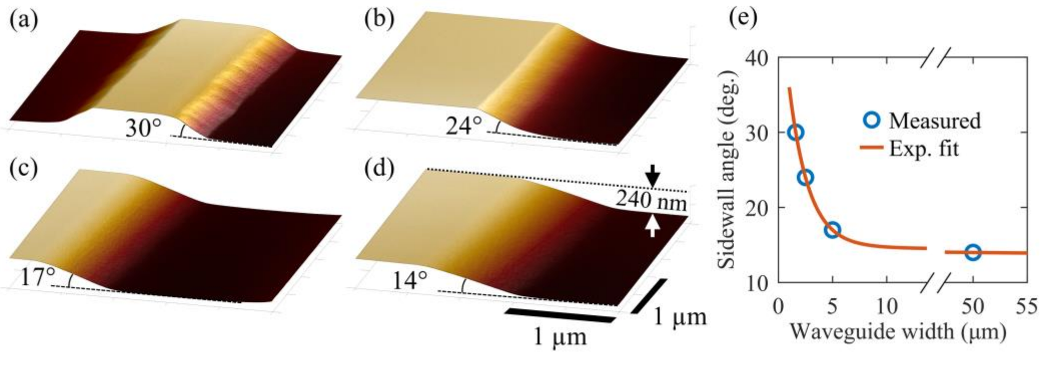

Figure 2. AFM images showing the LN rib sidewall profile and angle for different waveguide rib widths. The rib widths are (a) 1.6 µm, (b) 2.5 µm, (c) 5 µm, and (d) 50 µm. (e) Measured dependence of sidewall angle on the waveguide width with an exponential fit.