Microcombs in Si_3N_4 Microresonators Fabricated via Metal Lift-off: Demonstration of Octave Bandwidth, Dual Dispersive Waves, and Solitons

Gabriel M. Colación,[1,2,*] Lala Rukh,[1,2] Franco Buck,[1,2] and Tara E. Drake,[1,2,3]

[1] *Optical Science & Engineering Program, University of New Mexico, Albuquerque, NM 87106, USA*
[2] *Center for High Technology Materials, University of New Mexico, Albuquerque, NM 87106, USA*
[3] *Department of Physics & Astronomy, University of New Mexico, Albuquerque, NM 87106, USA*

[*] *gcolacion@unm.edu*

Abstract:
We develop thin metal masks via metal lift-off to fabricate Kerr-microring resonators in thick SiN. Nanoscale dimensional accuracy for precise dispersion control is demonstrated by generating octave-spanning frequency combs with dual dispersive waves and solitons.
© 2025 The Author(s)

Nonlinear integrated photonics has ushered in a new era where light-matter interactions are manipulated at the wavelength scale to realize efficient nonlinear phenomena. The ability to realize these phenomena through nanoscale control of device dimensions is key for many nonlinear properties (eg. dispersion control in parametric processes [1], supercontinuum generation [2], photonic crystal microresonators [3]). However, translating processes and tools traditionally developed for microscale MEMS fabrication can lead to difficulties in dimensional control at the nanoscale.

For Kerr-microresonator optical frequency combs formed in dielectric waveguide resonators, nanoscale dimensional accuracy is required to achieve the necessary dispersion for generating low-noise soliton states, octave bandwidths, and dual harmonic dispersive waves. However, the use of polymer-based resists as protective masks for transferring the desired pattern to the thick dielectric layer through etching makes this level of control difficult. Since the etch selectivity (ratio of the dielectric etch rate to that of the resist) is often less than 1:1, etching thick dielectric layers (often required for nonlinear applications) requires even thicker layers of resist. The resulting tall, soft mask pattern often gives rise to incomplete etching, sloped sidewalls, and inaccurate waveguide dimensions.

In this work, we present a solution to the well-known difficulties of creating microresonators with dimensions that support precise dispersion profiles in thick, etch-resistant silicon nitride. Utilizing a straightforward metal lift-off step, we define thin etch masks of chromium metal, neatly avoiding the problems of using thick resist as a mask. We demonstrate microresonators with Q-factors over 1 million, near-vertical sidewalls, and deterministic control of resonator dispersion. Furthermore, we generate octave-spanning frequency combs and solitons as a proof of the efficacy of our fabrication process.

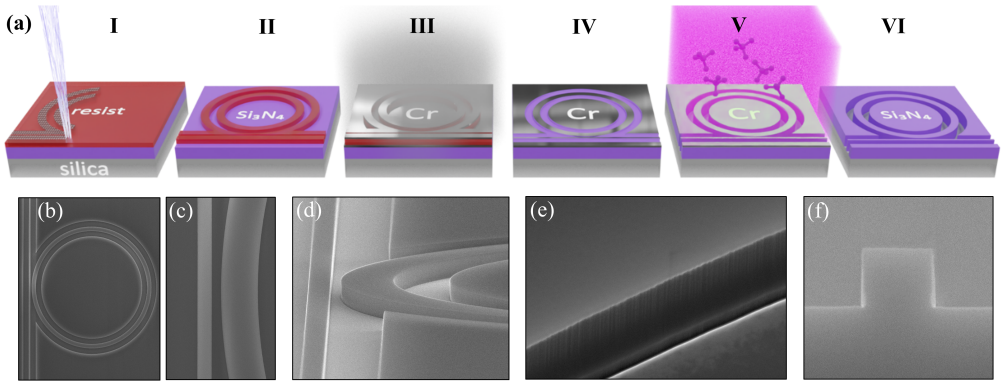

Fig. 1. (a) Illustration of the fabrication process steps: (I) EBL, (II) resist development, (III) metal deposition, (IV) metal lift-off, (V) etching, and (VI) mask removal. (b) Top-down SEM micrograph of etched ring resonator with (c) zoomed view of coupling region. (d) Angled view looking down etched coupling gap. (e) SEM of etched sidewall roughness. (f) Etched waveguide profile showing straight sidewalls. Reproduced from reference [4].

We start our fabrication with chiplets composed of 620 nm thick stoichiometric Si_3N_4 (or SiN) deposited via low-pressure chemical vapor deposition (LPCVD) over SiO_2 on Si. The full fabrication flow is illustrated in Fig. 1a. We first use electron-beam lithography (EBL) to expose a negative of our design in negative-tone EBL resist (Steps I-II). This is followed in Step III with electron-beam physical vapor deposition (EBPVD) of a 50 nm layer

This Article © 2025 The Author(s)

of chromium (Cr). In Step IV, lift-off of the remaining resist (and thus all the metal with resist underneath) leaves behind a thin metal mask for pattern transfer through etching (Step V). After etching, the remaining metal mask is removed to leave behind the completed device (Step VI). Fig. 1b shows our devices which consist of ring resonators with radii of 23.3 μm (1 THz free spectral range or FSR), evanescently coupled to a straight waveguide (Fig. 1c) across a 400 nm gap. This thin metal mask shows 30:1 nitride-to-metal selectivity, facilitating the etching of thick waveguides and high-aspect-ratio features with limited sidewall roughness, straight sidewalls (Fig. 1d-e), and reliable transfer of the design dimensions.

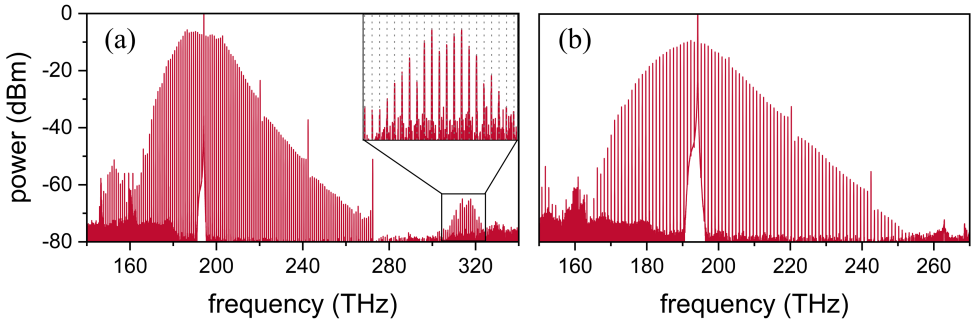

Fig. 2. (a) MI comb spectrum showing dual dispersive waves and spectral bandwidth of an octave. The inset shows the short-wavelength dispersive wave plotted over a grid of the comb spacing, extended from the central comb modes (gray dashed lines). (b) Spectrum for a long-lived soliton state obtained at the same pump power. Reproduced from reference [4].

The resonators fabricated with this method are measured to have intrinsic quality factors over 1 million making them sufficient to support broadband soliton frequency comb generation [4]. Figure 2a shows a frequency comb spectrum for a modulation instability (MI) comb state pumped with 195 mW of coupled CW pump power. Our resonators are designed with dimensions that target needed waveguide dispersion to support octave-bandwidth frequency combs with dual dispersive waves. We achieve this goal and observe dual dispersive waves centered around 152 THz (1965 nm) and 315 THz (950 nm), extending the bandwidth of our comb to over an octave and demonstrating the accurate transfer of design dimensions and geometry afforded by our metal mask. Moreover, many applications benefit from the high coherence and smooth spectral envelope of dissipative Kerr solitons [5]. Utilizing a fast pump frequency sweep method described in detail in reference [6], we access long-lived soliton operation at the same pump power with the resultant soliton spectrum shown in Figure 2b. We believe that improved coupler design will allow us to extract our dual dispersive waves at powers sufficient for stabilization through for f-2f self referencing [5, 7–9]. Further details on this work are available in reference [4].

In this work, we demonstrate that thin metal masks patterned with metal lift-off are viable and advantageous to the fabrication of Kerr-microring resonators in thick layers of SiN. Using this method, we fabricate microrings with accurate dispersion control and demonstrate their ability to generate octave-spanning optical frequency combs with dual dispersive waves, and notably, solitons. Although this work is focused on SiN, a major benefit of the metal lift-off technique is that it's easily transferable to a wide variety of popular, but hard-to-etch photonics materials (eg. silica, tantalum pentoxide, lithium niobate). We believe that etch masks patterned via metal lift-off reduce the barrier for realizing high quality photonic devices, whether for graduate students in a small academic cleanroom or experienced technicians in a high-throughput foundry.

This work was enabled by financial support from AFOSR (FA9550-22-1-0174), NSF EPSCoR (2217786), and UNM Women in STEM awards. We thank the scientists at Sandia National Labs' Center for Integrated Nanotechnologies (CINT) for their expertise and guidance, with particular thanks to John Nogan, Anthony James, and Michael De La Garza for their invaluable insight on process development. Finally, we thank Joseph Yelk for sharing his expertise in scientific illustration and for his contributions to Fig. 1.

1. Black, J. A., Newman, Z. L., Yu, S.-P., Carlson, D. R. & Papp, S. B. Optical synthesis by spectral translation. *arXiv e-prints* arXiv:2112.14251 (2021).
2. Hickstein, D. D. *et al.* Quasi-phase-matched supercontinuum generation in photonic waveguides. *Phys. Rev. Lett.* **120**, 053903 (2018).
3. Zang, J. *et al.* Laser power consumption of soliton formation in a bidirectional kerr resonator. *Nat. Photonics* (2025).
4. Colacion, G. M., Rukh, L., Buck, F. & Drake, T. E. Low-loss silicon nitride Kerr-microresonators fabricated with metallic etch masks via metal lift-off. *arXiv e-prints* arXiv:2503.21301 (2025).
5. Drake, T. E. *et al.* Terahertz-rate Kerr-microresonator optical clockwork. *Phys. Rev. X* **9**, 031023 (2019).
6. Stone, B. D., Rukh, L., Colación, G. M. & Drake, T. E. Reduction of thermal instability of soliton states in coupled Kerr-microresonators. *arXiv e-prints* arXiv:2412.04412 (2024).
7. Moille, G. *et al.* Broadband resonator-waveguide coupling for efficient extraction of octave-spanning microcombs. *Opt. Lett.* **44**, 4737–4740 (2019).
8. Tan, D. T. H., Ikeda, K., Sun, P. C. & Fainman, Y. Group velocity dispersion and self phase modulation in silicon nitride waveguides. *Appl. Phys. Lett.* **96**, 061101 (2010).
9. Briles, T. C. *et al.* Interlocking Kerr-microresonator frequency combs for microwave to optical synthesis. *Opt. Lett.* **43**, 2933–2936 (2018).