Wafer-Scale Fabrication of Ultra-Low Loss Si_3N_4 Photonic Integrated Chips through Nanoimprint Lithography

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Silicon nitride photonic integrated chips (PICs), known for their broad transparent window, ultra-low loss, complementary metal-oxide-semiconductor (CMOS) compatibility, and moderate nonlinearity, have garnered increasing attention and been widely studied in the fields of nonlinear optics [1], ultra-narrow linewidth lasers [2], machine learning [3], and quantum information processing [4]. The conventional fabrication of high-quality SiN PICs typically relies on either time-consuming or expensive methods, such as electron beam lithography (EBL) and deep ultraviolet (DUV) photolithography. In response to these challenges, nanoimprint lithography (NIL) has emerged as a promising alternative [5]. NIL utilizes molds to directly imprint structures onto wafers, offering a simple, efficient, and cost-effective approach for the PICs fabrication. This research fully leverages the advantages of NIL, coupled with an optimized amorphous silicon (a-Si)/SiN hardmask etching strategy, showcasing its potential to streamline the wafer-scale fabrication of high-quality SiN PICs. The highest intrinsic quality (Q) factor Q_i, reaching as high as 15×10^6, is demonstrated. Efficient frequency comb is also generated by engineering the mode dispersion. These performances approach a similar level to state-of-the-art SiN PICs fabricated using EBL or DUV techniques. To the best of our knowledge, this work presents the first realization of high-Q SiN PICs with $Q_i > 10 \times 10^6$ and the generation of frequency combs fabricated by NIL.

The wafer-scale fabrication process of ultra-low loss SiN PICs mainly involves two key steps: NIL and a-Si/SiN hardmask RIE etching. A pre-made crystalline Si mold directly imprints PMMA A4 resist structures onto 4-inch a-Si-on-SiN-on-insulator wafers. By carefully optimizing the relevant fabrication parameters, we achieve high selectivity as well as smooth etching from PMMA to a-Si and then to SiN substrates. In Figure 1(a), the fabricated 4-inch SiN PICs are presented, comprising a total of 9 dies. A high-Q resonance with $Q_i \sim 15 \times 10^6$ is depicted in Fig 2. (c), where the high performance is also evidenced by the smooth SiN waveguide boundary from the SEM images in Fig 2. (b). Figures 2 (d) showcases the statistical distribution of the extracted Q_i of the microring resonator with a radius of 200 um and cross-section of 2.8 um × 0.75 um, demonstrating an average Q_i of 10.2×10^6. The corresponding generated frequency combs are displayed in Figure 2(e).

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3. J. Feldmann, et al. Nature 589, 52–58 (2021)
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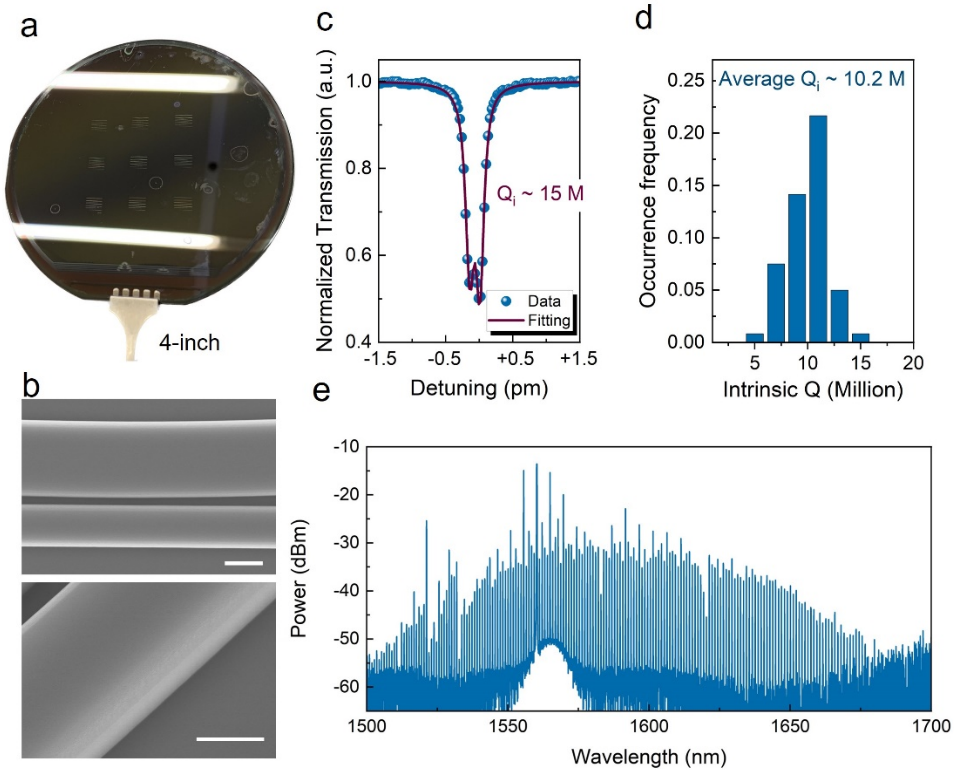

Figure 1: Optical characterization of ultra-low loss Si_3N_4 photonic integrated chips fabricated by NIL and a-Si/Si_3N_4 hard mask etching: (a) Fabricated 4-inch Si_3N_4 wafer; (b) Top-down and tilted-view SEM images of the smooth Si_3N_4 waveguide; Scale bars are 1.5 µm and 500 nm, respectively. (c) Normalized transmission spectrum of a high-*Q* resonance around 1601 nm; (d) Statistical distribution of the extracted intrinsic *Q* factors of the ring resonator with a radius of 200 µm and cross-section of 2.8 µm × 0.75 µm; (f) Generation of frequency combs.