

Direct Growth of Crack-free Stoichiometric Silicon Nitride on Sapphire for Wide-band Photonics

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Primary CNF Tools Used: LPCVD and Anneal Furnaces, Ellipsometry (WOOLLAM), Electron Beam Lithography (JEOL, Stepper (ASML), Reactive Ion Etcher (OXF80), Scanning Electron Microscope

Abstract:

This report summarizes the technical achievements of our research on the growth of silicon nitride (Si_3N_4) films on sapphire substrates. We successfully demonstrated the deposition of crack-free stoichiometric Si_3N_4 films up to 2 μm thick using low-pressure chemical vapor deposition (LPCVD). The residual stress in these films was measured to be only 200 MPa, in contrast to the typically higher stresses observed in Si_3N_4 grown on silicon. This advancement enables the effective fabrication of photonic devices with low optical losses of 0.25-0.37 dB/cm across a wide spectrum, enhancing the viability of Si_3N_4 for broad photonic applications.

Summary of Research:

Silicon nitride on insulator structures has been a pivotal component in the development of photonic integrated circuits, mainly due to its advantageous optical properties. However, the residual tensile stress associated with Si_3N_4 films grown on silicon can lead to cracking, especially at thicknesses above 400 nm. This study focuses on the use of sapphire substrates, which possess a higher coefficient of thermal expansion (CTE) than silicon, to alleviate this stress.

Figure 1 summarizes the growth and stress data. Stress characterization of LPCVD silicon nitride (Si_3N_4) on a sapphire substrate (SiNoSa) shows significantly lower stress levels compared to Si_3N_4 on a silicon substrate (SiNoSi). SiNoSa can be grown crack-free up to at least 2 μm thickness without substrate modification. In contrast, SiNoSi easily cracks for films between 350 nm to 400 nm thick, with cracking occurring beyond 600 nm and making growth challenging without modification at thicknesses over 1000 nm. Various approaches

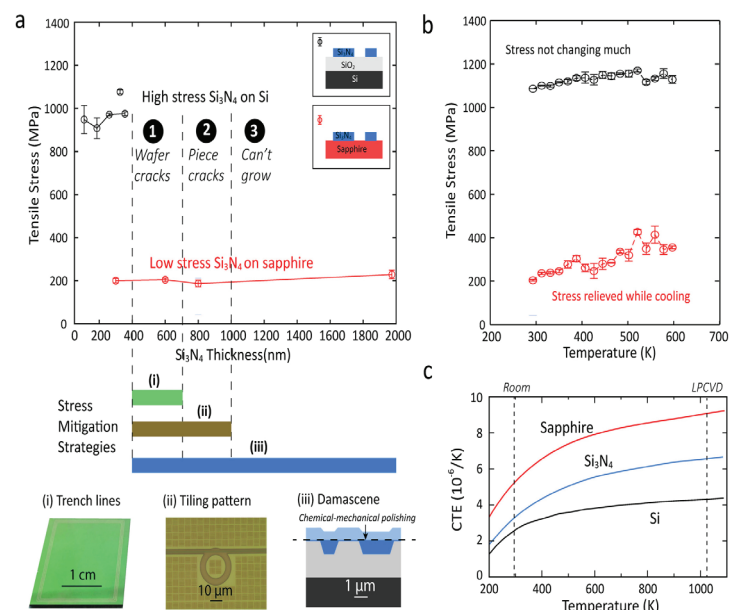


Figure 1.

have been employed for stress mitigation in SiNoSi:

1. Trench lines are effective for film thickness from 400 nm to 700 nm.
2. Tiling patterns incorporating features of 10 μm to 100 μm help reduce stress accumulation in unpatterned areas and facilitate thickness up to 1000 nm with better reproducibility across wafers.
3. Damascene processing allows for the growth of thicker films, reaching levels up to 2 μm , typically followed by chemical mechanical polishing and often used in conjunction with tiling patterns for crack termination.

Temperature-dependent stress measurements for both SiNoSa and SiNoSi indicate notable differences in behavior between the two substrates, confirming that the Sa help to relax the tensile stress and therefore prevent the cracks.

We conducted comprehensive experiments using LPCVD techniques to deposit Si_3N_4 on sapphire. Our results confirmed the ability to grow crack-free films up to 2 μm in thickness. Stress analysis revealed significantly lower residual stress levels when sapphire was utilized as a substrate.

References:

- [1] Z. Ma, X Lu, D. Westly, and K. Srinivasan, "Direct growth of crack-free thick stoichiometric silicon nitride films on sapphire for wide-band photonics" CLEO: Science and Innovations, SM4B. 3 (2026).

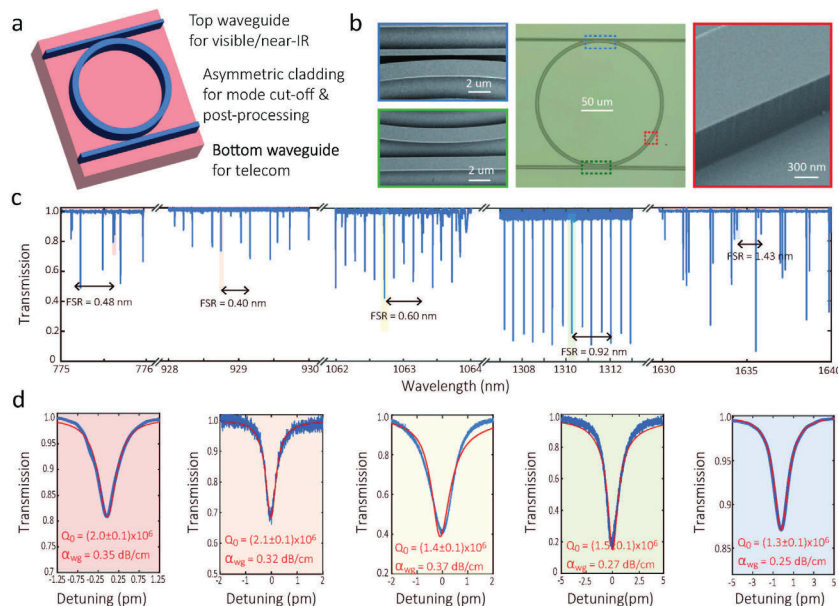


Figure 2.

Figure 2 summarizes the optical characterization of the devices we fabricated. Notably, our findings demonstrate propagation losses of 0.35 dB/cm at 780 nm, 0.37 dB/cm at 1064 nm, and 0.25 dB/cm at 1630 nm, matching or surpassing those of Si_3N_4 on silicon substrates.

Utilizing advanced techniques such as ellipsometry and prism coupling measurements, we characterized the optical properties and confirmed low optical losses across various wavelengths. Device fabrication through microring resonators illustrated the practicality of this growth method, showcasing high intrinsic optical quality factors.