Low-Loss Strip-Loaded SiN Waveguides on Engineered AlN for Quantum Photonic Applications

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Abstract: Aluminum nitride (AlN), integrated with a strip-loaded SiN waveguide, demonstrates low-loss propagation. The engineered AlN Pockels tensor enhances the electro-optic response, advancing efficient photonic devices such as integrated Mach-Zehnder interferometers and nonclassical light sources.

Integrated photonics based on silicon has garnered significant interest for its potential to provide compact and efficient solutions for functional devices. However, silicon has certain limitations, including a low indirect bandgap of 1.1 eV and negligible second-order nonlinear optical properties, which hinder the realization of lossless electro-optic modulators and second-order nonlinear processes.

Aluminum nitride (AlN), a CMOS-compatible material, offers promising solutions to these challenges. AlN possesses a wide bandgap of 6.2 eV, a broad transparency window spanning from ultraviolet to mid-infrared, and a significant second-order nonlinear optical effect. Its intrinsic nonlinearity ($\chi(2)$) enables on-chip photon-pair generation via SPDC and supports low-loss, high-speed electro-optic phase modulation, highlighting the potential of AlN-on-insulator waveguides for integrated quantum photonics.[1,2].

In this work, a SiN strip-loaded AlN waveguide configuration is introduced, demonstrating low losses in a ring resonator structure as shown in Figure 1a. This strip-loaded design features a high-refractive-index Si_3N_4 strip placed on top of a thin AlN layer, deposited by RF magnetron Sputtering, combining efficient light guidance with the advantageous nonlinear and electro-optic capabilities of the AlN substrate.

Two sputtering deposition methods were employed to engineer the columnar structure of the AlN film. As shown in Figures 1b and 1c, vertical and tilted configurations of AlN were achieved.

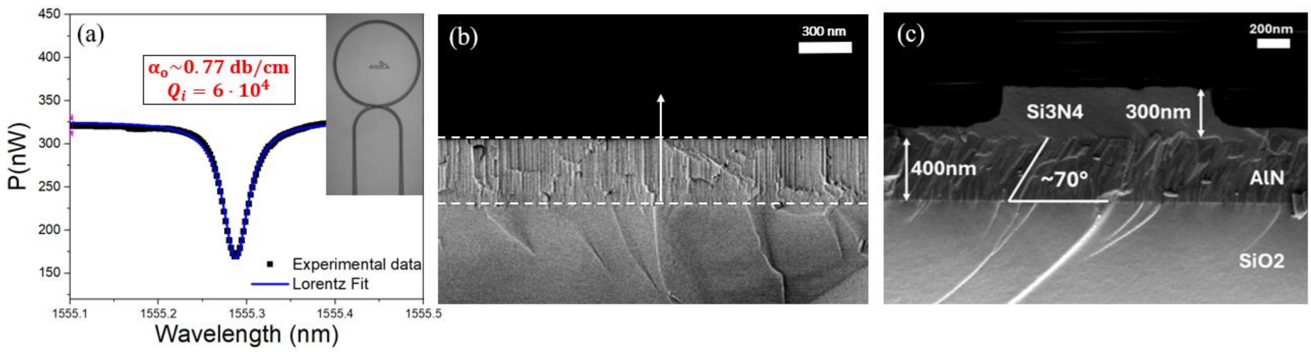

Fig. 1 (a) Power spectrum of a ring resonator in the over-coupling regime using the strip-loaded configuration. Low propagation losses of 0.77 dB/cm are estimated from the resonant peak features around 1555 nm. (b) SEM image of the vertical configuration, where the columnar structure of the AlN aligns perpendicular to the surface, achieved through the sputtering deposition process. (c) SEM cross-section of a strip-loaded Si_3N_4 waveguide on a tilted AlN substrate. The Si_3N_4 and AlN layers are 300 nm and 400 nm thick, respectively, with the AlN columnar structure inclined at approximately 70 degree.

Sputtered AlN maintains crystallinity along the perpendicular direction while remaining isotropic in-plane, rendering many nonlinear tensor coefficients null.

While the preservation of the second-order nonlinear coefficient along the c-axis has been demonstrated, we propose tilted crystal deposition to engineer the nonlinear tensor. This method engineers the nonlinear tensor, enabling novel configurations for in-plane Pockels modulators and creating opportunities for phase-matching in second-order nonlinear phenomena. We effectively demonstrated the versatility of our platform by developing an integrated Mach Zehnder modulator by exploiting the in-plane contact configuration, achieving modulation bandwidth over 1GHz.

References

[1] C. Xiong, W. H. P. Pernice, and H. X. Tang, "Low-Loss, Silicon Integrated, Aluminum Nitride Photonic Circuits and Their Use for Electro-Optic Signal Processing," *Nano Lett.*, vol. 12, no. 7, pp. 3562–3568, Jul. 2012.

[2] X. Guo, C. Zou, C. Schuck, H. Jung, R. Cheng, and H. X. Tang, "Parametric down-conversion photon-pair source on a nanophotonic chip," *Light Sci Appl*, vol. 6, no. 5, pp. e16249–e16249, Nov. 2016.