Sidewall roughness AFM analysis of Lithium Niobate Optical Waveguides

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Thin-Film Lithium Niobate ($LiNbO_3$), referred to as TFLN, represents an appealing platform for the development of novel photonic integrated circuits (PICs) with high bandwidth, small footprint, and low power consumption. It couples the outstanding electro-optic properties of the $LiNbO_3$ crystal with the possibility of fabricating high index-contrast rib waveguides, with stronger light confinement than devices based on bulk $LiNbO_3$. A critical aspect for TFLN-based PICs is minimizing the waveguide propagation losses, mainly arising from rough, irregular sidewalls. Indeed, due to the hardness and inertness of $LiNbO_3$, defining smooth and vertical waveguide sidewalls by standard dry etch techniques is challenging. Different approaches employing additional smoothening steps [1] or double masking for pattern transfer [2] have been employed to define waveguides with propagation losses of 0.21 dB cm^{-1} with AFM-measured quadratic roughness (R_Q) down to 2 nm. Nevertheless, the limited experimental details reported on R_Q calculation, and a lack of a shared AFM measurement protocol, represent a problem for correlating the topological data of the waveguides to their light propagation characteristics.

This talk discusses the effect of AFM experimental setup and processing method on the accuracy and consistency of R_Q measurements of $LiNbO_3$ waveguides sidewall. Firstly, by using a custom inclined holder, we can obtain an accurate map of the waveguide sidewall, where the roughness features can be clearly identified. The post-processing of these maps introduces alterations on the sidewall profile, influencing the calculated R_Q. Roughness calculations on 2D areas accurately quantifying the sidewall irregularities but are more susceptible to these artifacts and tend to be less consistent; calculations on line profiles, conversely, are less affected by these errors but describe less effectively the sidewall features. We also highlight the importance of introducing additional roughness parameters, like skewness, to properly account for the 'waviness' of the sidewall. Indeed, during the transfer of the waveguide profile from the mask to $LiNbO_3$ by dry etch, the hardness difference between the materials can cause an irregular definition of the edge of the structure that is then transferred to the whole sidewall. Lastly, the developed AFM processing method is employed to calculate the on-wafer sidewall roughness of $LiNbO_3$ waveguides etched by an optimized process, achieving $R_Q \leq 1$ nm and propagation losses of 0.5 dB cm^{-1}. These low-loss rib waveguides are the basis of the photonic integrated circuits we develop at AFR Milan.

References:

[1] Siew S. *et al.*, Optics Express 2018, 4421, Vol. 26, No. 4

[2] Luke K. *et al.*¸ Optics Express 2020, 24452, Vol. 28, No.17