Processing Lithium Niobate Coupons for Quantum Applications

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Heterogeneous integration of thin film lithium niobate (TFLN) on silicon and silicon nitride (SiN) platforms have been gaining in popularity over the last few years, especially so, in pursuit of high speed modulators. [1] [2] [3] This work is aimed at using the nonlinear properties of lithium niobate in combination with a low loss platform made in SiN to create devices for quantum optics applications. One target technology for this is to create an on-chip memoryless repeater for QKD. [4] Currently the work has been focused on creating a very low loss transition between the TFLN and SiN material platforms. For this tapers are being developed using a wet etch for lithium niobate. This wet etch enables the manufacturing of tapers with very fine tips and even with some 3D tapering allowing insertion losses that could be as low as 0.02 dB. However, the trigonal crystal system that offers lithium niobate its birefringent quality also creates challenges for processing fine structures using wet etching, as its etching rate depends on the crystallographic axis. This work demonstrates the progress made on developing these taper structures.

Introduction

Highly entangled states are an important resource for quantum key distribution repeaters [4] and quantum computing. [5] However, for each additional photon that is added to such a state, the requirements for low loss, photon indistinguishability and efficient detection also become more stringent. This work is focused on developing the right building blocks to bring this quantum optics technology on chip using the heterogeneous integration of lithium niobate (LN) on silicon nitride (SiN). Lithium niobate is a promising material for this technology owing to its low material loss at telecom wavelengths [6] and its high nonlinear coefficient [7]. By periodically poling LN, efficient nonlinear processes can be realized on-chip such as SPDC [8], and SHG [9].

A major challenge with LN is related to its processing, dry etching LN is reported to have problems with redeposition [10] and is typically not CMOS compatible [11]. This work focuses instead on the wet etching of LN to manufacture low loss tapers and waveguides which is highly selective to hard masks such as SiO_2 and Si and can lead to incredibly fine taper tips and low roughness. [3] This would allow the integration of active LN devices on a low-loss passive SiN circuit. This work aims to optimize the transition from SiN to LN and vice-versa for the realization of quantum circuits on chip.

Integrating the lithium niobate on SiN could be done using micro-transfer printing. [1]

Engineering a low loss transition between SiN and LN

To create waveguides or tapers patterned with wet etching 200nm SiO_2 hard mask is first deposited on a LNOI wafer, after deposition, ARP 6200 ebeam resist is spin coated on

top of the chip. This is then patterned with ebeam lithography followed by an RIE step to etch the hard mask. This sample is now ready for a wet etch in a solution of NH_4 and H_2O_2. After the wet etch, the hard mask can be removed using BHF.
The undercut of the wet etch causes the final structure to have both a very fine taper tip and 3D tapering, it also has a low roughness. The disadvantage is that the etch is not entirely isotropic, as the etching rate depends on the crystallographic axis of the

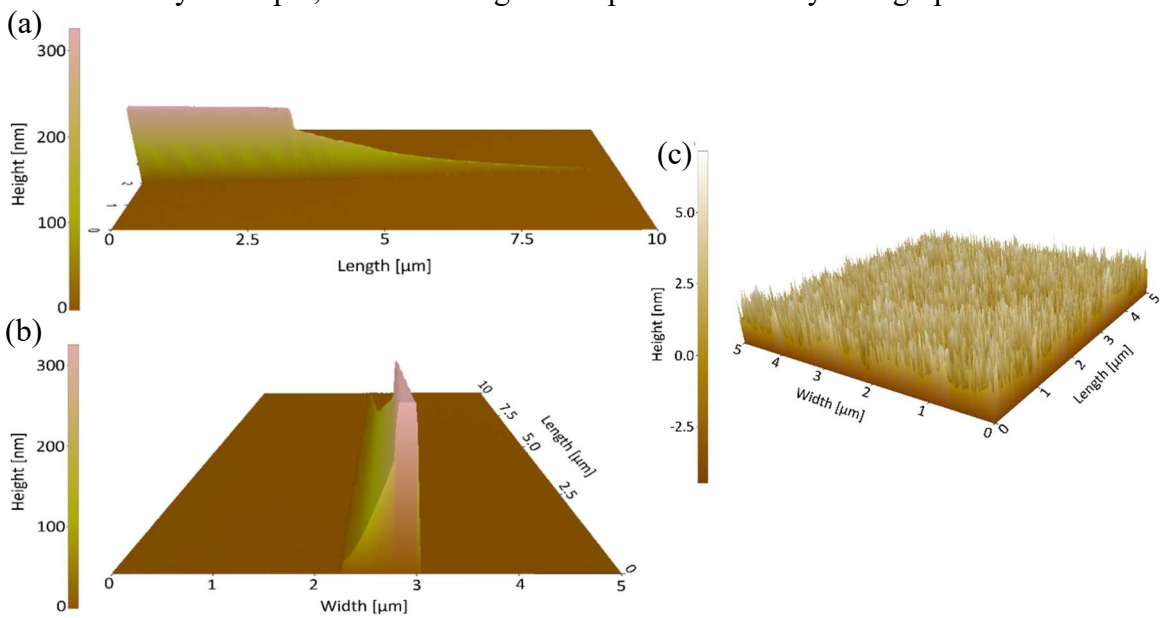

Figure 1 (a) (b) AFM measurement of the taper in front- and side-view (c) surface roughness measurement after the wet etching process with a roughness RMS of 1.361 nm

material. This results in patterned structures with an asymmetric cross-section as seen in the AFM measurements in Figure 1.

An EME simulation environment was made using a 1.5 µm wide SiN waveguide covered by a slab of LN. A taper was introduced to convert the single mode propagation in the SiN waveguide to a hybrid mode in LN and SiN. Assuming an ideal, symmetrical taper, the transmission losses were simulated to be 0.001 dB.

When the asymmetric cross-section is included in the simulation an additional 0.232 dB loss is observed, this can be reduced somewhat by shifting the taper position in relation to the SiN waveguide below as seen in Figure 2.
Shifting the taper position by 275 nm can reduce the loss to 0.126 dB. This can be pushed down even further by adjusting the taper design itself. Additional taper designs were simulated where the central axis of the taper was shifted to compensate for the anisotropy, losses as low as 0.021 dB could be observed for a 200 nm offset. The simulation environment does not account for certain loss factors such as sidewall roughness, but they

indicate that these tapers could have a very high performance with the right design strategy.

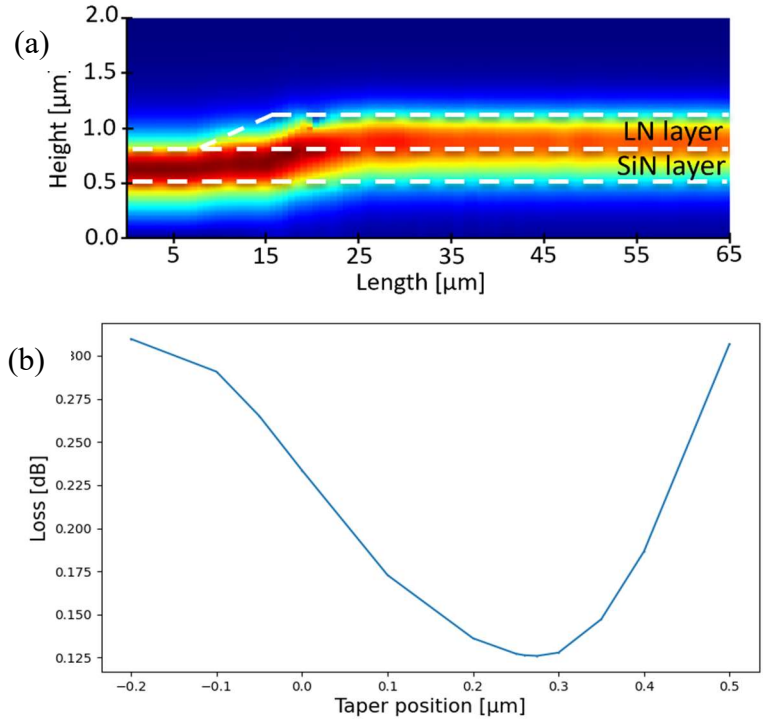

Figure 2 (a) Cross-section of the electric field transitioning from SiN to a SiN and LN hybrid mode (b) Transition loss in relation to the position of the taper tip relative to the center of the SiN waveguide below

Conclusion

By using the wet etching of LN it is possible to generate tapers with very fine tips and 3D tapering that could enable very low-loss transitions between LN and SiN for applications in quantum optics devices. This process is non-isotropic with etch rates that depend on the crystallographic axis of the material, leading to a systematic manufacturing error that results in one taper sidewall to be straight, while the other has a very shallow angle, resulting in some additional losses. It was determined through EME simulations that these losses can be compensated for by tuning the taper position, or its central axis. With the low roughness of the wet etching process and compensated design these tapers could lead to a very low loss transition between SiN and LN. The process to create tapers and waveguides in LN is compatible with LN coupons for micro-transer printing, the next step is to use patterned LN coupons to create heterogeneous LN on SiN devices with the low loss coupling necessary for quantum optics applications.

Acknowledgements

This research is supported and funded by a SBO project BeQuNet based on a collaboration between Belgian universities (UGent, ULB, UHasselt) and research technology organisations (imec).

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