Investigation of the fabrication consistency of lithium niobate ridge waveguides formed by dicing

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Machining of brittle crystalline materials is a topic of growing interest in both optics and quantum applications, as a route to achieving cm-scale structures with nm-scale roughness in formats that are not easily achievable with etching or cleanroom processing. One such material is lithium niobate, which offers high optical transparency, ferroelectric and non-linear properties that make it a popular component for conversion of specific optical wavelengths for telecommunications, atom and ion traps, entangled photon pair generation, and upconversion imaging. In recent works, we have demonstrated a ductile machining approach to fabrication of ridge waveguides in Zn-indiffused periodically poled lithium niobate (PPLN) that enable optical-quality ridges and facets with surface roughness of 0.29 nm Sa in a single pass [1]. These devices enable second harmonic generation (SHG) of 2.5W 780nm at 70% conversion efficiency [2], and broad spectral operation in the UV-blue-green visible range [3]. Fig. 1a. illustrates our fabrication approach of periodic poling, Zn indiffusion, and dicing, while Fig. 1b. shows an SEM image of a resulting waveguide and facet with optical-quality surface finish.

Optimising the performance of non-linear optical waveguides requires precise control of machined features along the entire device (typically 10-40 mm), with a focus on uniformity (ridge straightness and width), minimal chipping, and surface roughness. A width variation of just 150 nm along a 15 mm long ridge waveguide has been shown to have a critical efficiency reduction [4], with more complex local deviations (chips) leading to severe spectral broadening [5]. In a typical device, the SHG spectral shape is expected to be sinc^2, with any broadening or antisymmetry indicating fabrication defects. To link fabrication tolerances in longer-range waveguide uniformity and curvature to overall performance, we have conducted a comprehensive study of waveguide form variation, including straightness, width, chipping, and surface roughness correlated with optical frequency conversion performance. The data was collected using multiple metrology techniques, including coherent scanning interferometry (CSI) and a custom-built, interferometrically referenced confocal profiler that provides accurate information about the straightness of the waveguide.

Central to this study was an experiment where two arrays of ridge waveguides were fabricated using 100 µm and 300 µm wide (kerf) dicing blades, respectively, with a Disco DAD 3430 dicing machine. To ensure consistency in other fabrication factors, periodic poling, zinc diffusion and facet dicing were carried out across one common wafer. Fig. 2 shows the optical frequency conversion efficiency of 1064 to 532 nm SHG in two example waveguides diced with different blade widths. Waveguides machined with a 300 µm wide blade consistently show a better spectral profile with higher efficiency than those cut with 100 µm blades. Fig. 3a depicts the measured ridge width variation across the chip as collected via CSI. While the 100 µm blades have a measured variation of 450 nm, this is reduced to 200 nm when using the wider 300 µm blade. Fig. 3b shows the overall straightness of the 40 mm long waveguides as measured via a confocal scanner, showing an arc variation of 300 nm. We will present the full findings from this study, including analysis of waveguide performance versus ridge form, surface roughness and topside chipping.

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[3] Y.S. Cheng et al., Nature Communications 15, Article 1466 (2024)
[4] M. Chauvet et al., Journal of Optics 17, Number 8 (2016)
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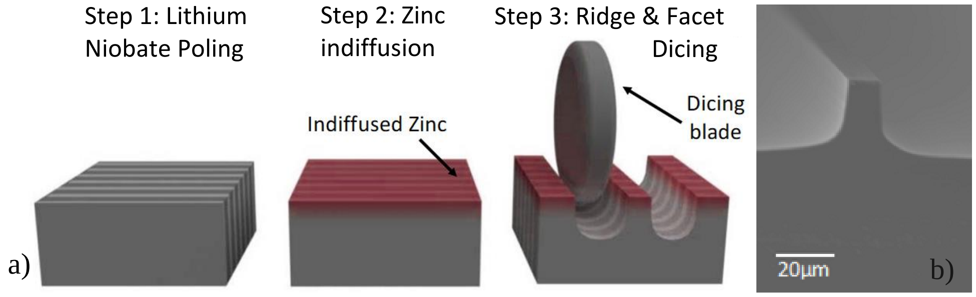

Fig. 1a: Periodically poled lithium niobate ridge waveguide fabrication steps. From left to right, periodic poling to provide the conversion effects, indiffusion to form the planar layer (vertical confinement), and ridge formation to provide the lateral confinement. Fig. 1b: SEM image of a resulting diced waveguide facet and ridge.

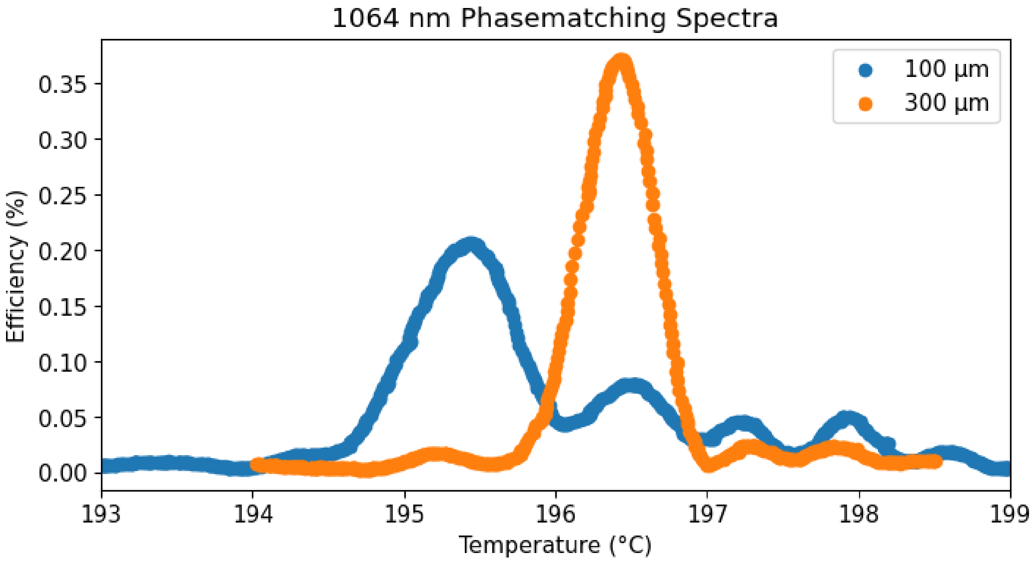

Fig. 2: SHG 1064 nm to 532 nm conversion efficiency spectra of two 40 mm long ridge waveguides machined with 100 μm and 300 μm width blades. The input power was 90 mW.

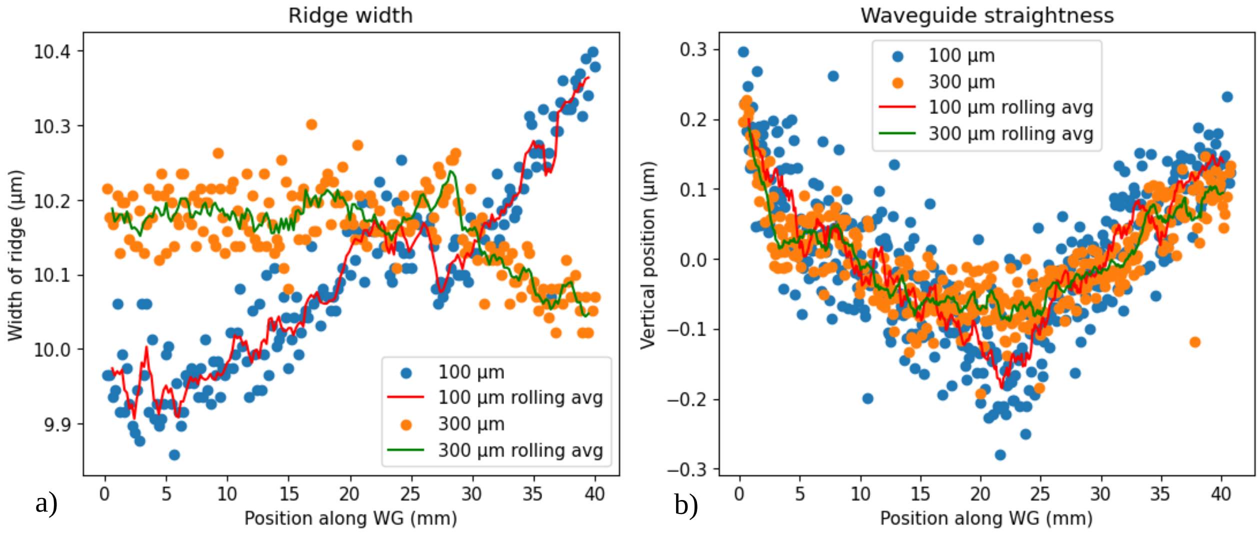

Fig. 3a: Width of the diced ridges measured with CSI along the length of the waveguides.
Fig. 3b: Position of the ridge centers along the length, measured with a custom-built confocal system.