Development of Periodically Poled Lithium Niobate Zinc-Indiffused Ridge Waveguides at Blue Wavelengths

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Abstract: En route to the development of a low-power, cheaper and more-compact UV source via single pass nonlinear generation, we present our developments of a periodically poled lithium niobate (PPLN), zinc-indiffused ridge waveguide operating at blue/UV. Emphasis is placed on manufacturing scalability and optimisation of our diffusion and high-precision dicing processes at <400 nm wavelength generation.

Diced, Zn-indiffused MgO:PPLN Waveguides

- Higher damage threshold in comparison to other PPLN waveguiding platforms, i.e. resistant to photorefractive damage [1,2]
- Guides both TE and TM polarisation modes, enabling the future development of the so-called Type-II nonlinear process
- Reproducible manufacturing process which does not require polishing for optical facets.
- We aim to investigate if this nonlinear waveguiding platform is suitable for operation beneath the typical transmission range of lithium niobate, starting with the generation of 390 nm light.

Why Blue? Yb⁺ Doppler Cooling

- Used for quantum metrology, such as optical clocks. Currently one of the lowest uncertainties in measurements (only beaten by strontium).
- A competitor in the race to a quantum computer, Yb+ ion trapping is chosen due to a long coherence time and (mostly) convenient interrogation laser wavelengths.

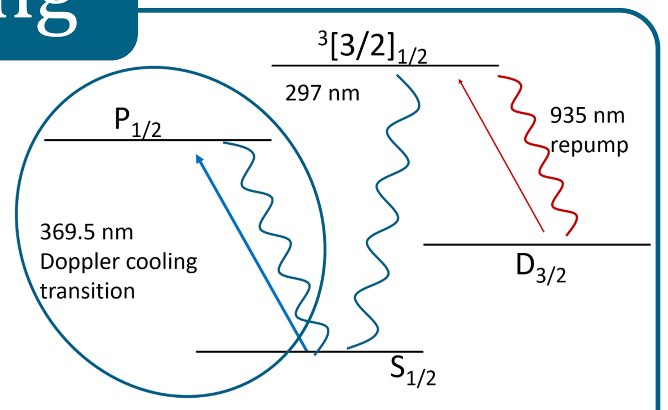
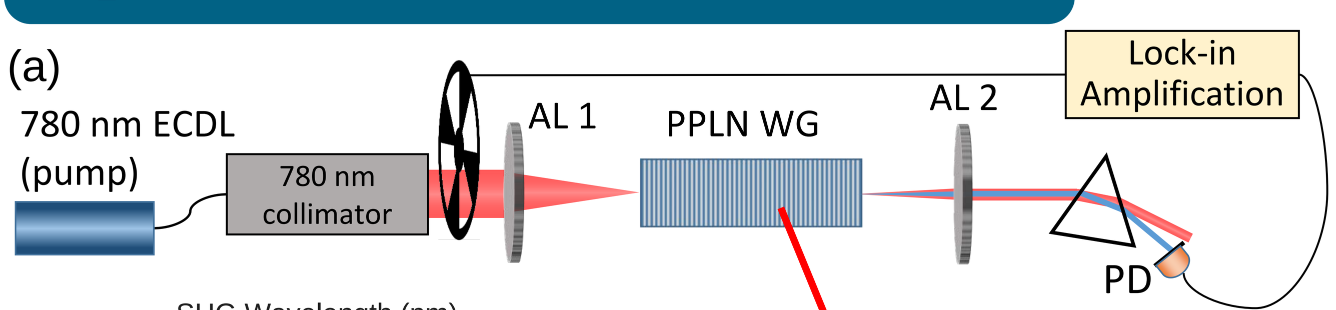
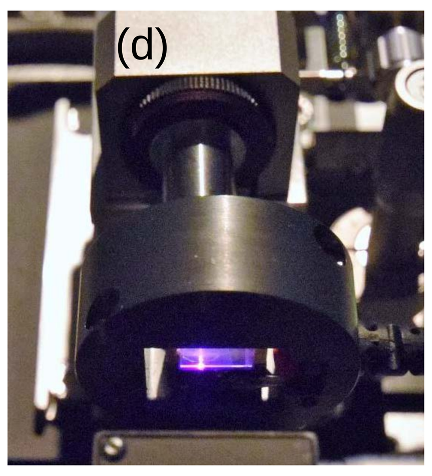
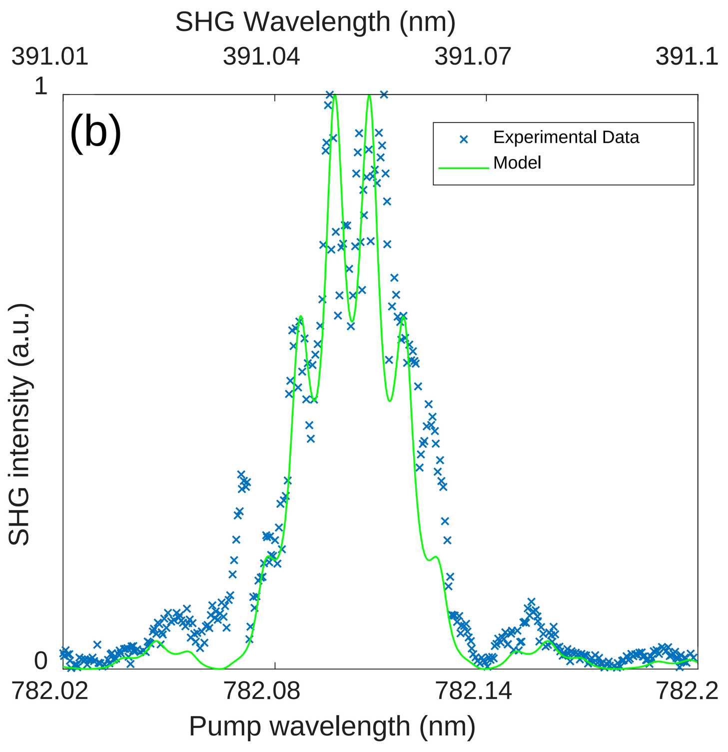


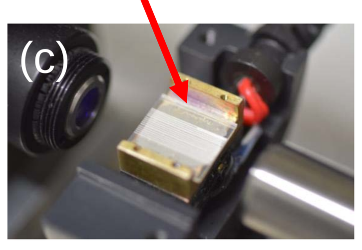
Fig 1: Energy level diagram of Yb⁺. Adapted from Ref. [3].

Optical Characterisation







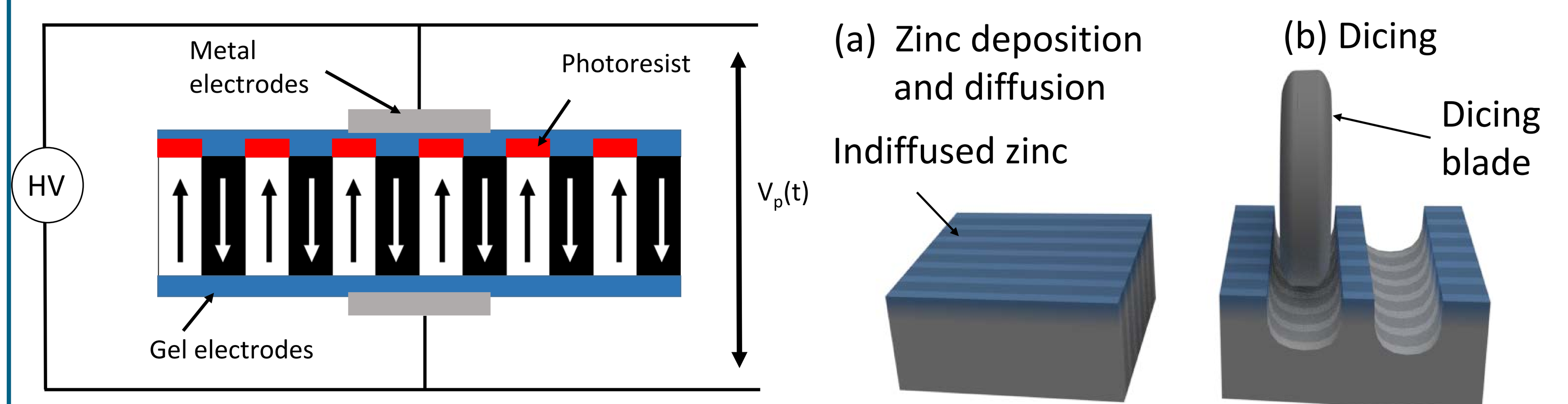


The PPLN waveguides are optically characterised by free space launching of a fibre-coupled, tuneable ~780 nm ECDL with an approximate pump output of 5 mW.

Low-power characterisation allows for the study of phasematching spectrum, to study waveguide uniformity, without the distortion associated with high power nonlinear generation [4]. Given this, we utilise lock-in amplification detection to record the associated phasematching spectrum of second harmonic generation (SHG).

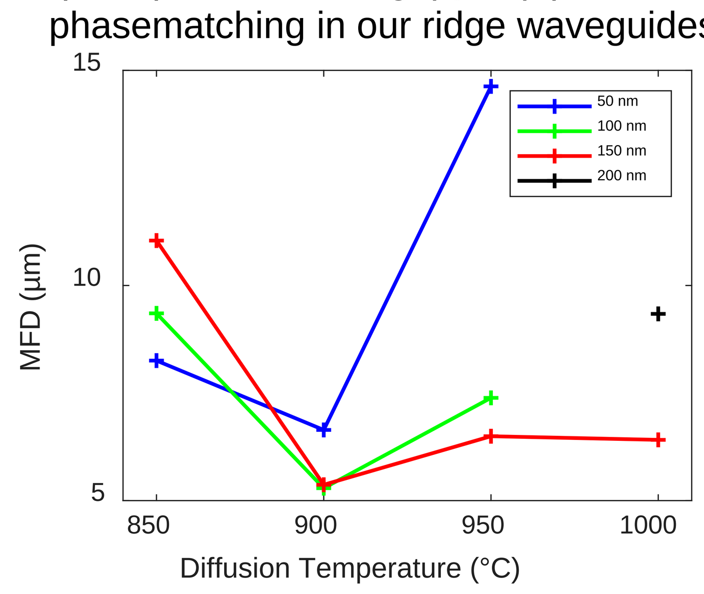
Fig 2: (a) Optical characterisation setup for high resolution characterisation of weak signal power (b) Resultant phasematching spectrum and (c) photograph of the PPLN:WG and (d) blue generation in the waveguide under test.

Waveguide Fabrication



PPLN is fabricated by applying a high potential across a photoresist-patterned lithium niobate wafer. Our waveguides are fabricated via the indiffusion of a zinc layer followed by dicing for ridge and facet definition. For 780-390 nm SHG, a quasi-phasematching (QPM) period of 2.2 µm was used for phasematching in our ridge waveguides.

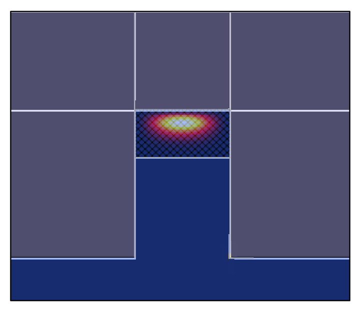
Fig 3: (a) and (b) outline the fabrication process. (c) SEM micrograph of the fabricated waveguides.



Planar waveguide dimensions are investigated to achieve tightly confined pump and signal optical modes. Increasing overlap between the pump and generated modes allows for greater conversion efficiencies. In this case, a 150 nm zinc layer diffused at 900 ° C was chosen as the small MFD at ~780 nm increased the potential for a higher overlap integral of the pump and signal modes.

Waveguide Uniformity Study

An investigation into waveguide uniformity causing the distortion of the phasematching spectra was carried out to further understand the limits of our fabrication capabilities. A commercial white light interferometer (Zemetrics, ZeScope) was utilised in combination with edge-detection algorithms to quantify the width profile along the length of the waveguide.



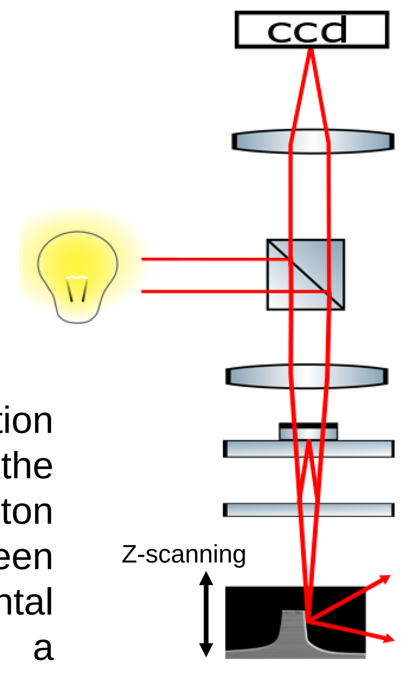
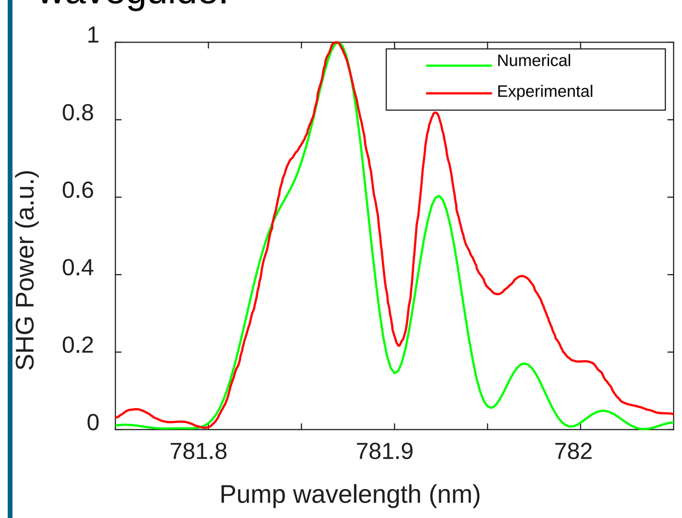


Fig 4: Simplified schematic of a white light interferometer and the concept to explain its use for edge detection in ridge-style integrated waveguides

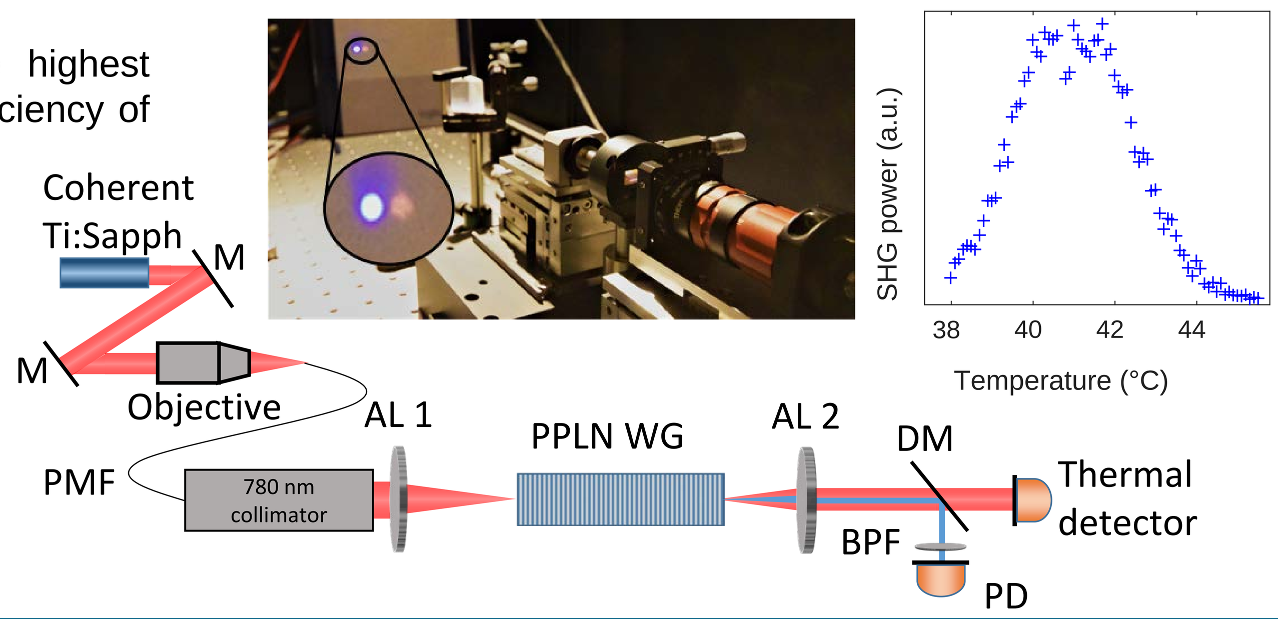


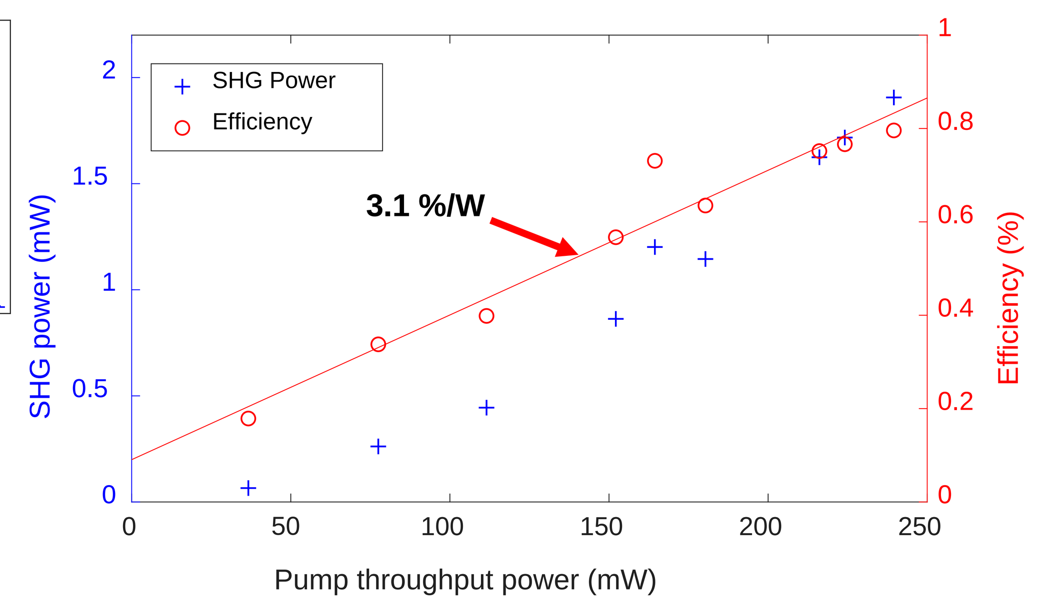
We can evaluate the propagation constant as a function of position in the waveguide (using FIMMWAVE, Photon Design Ltd.) for comparison between numerical and experimental phasematching data; allowing for a study to determine the quality of waveguide fabrication. This is the first demonstration of numerical modelling of nonlinear phasematching spectra [5]. We propose that this method can be used for quickly distinguishing between imperfections in fabrication steps.

Device Efficiency vs Power

A waveguide diced to be 5.6 µm-wide was determined to have the highest conversion efficiency at low power. To further investigate the nonlinear efficiency of this waveguide, we used a Coherent Ti:Sapph at 783 nm in CW mode.

The waveguide was temperature tuned to collect the associated phasematching spectrum and maximum conversion power. A conversion efficiency of 3.1 %/W was achieved over the power range 0-245 mW. No roll-off was observed in this pump power range with a maximum SHG power of ~2 mW. The signal loss at the collection optics was accounted for in this value, approximately 0.36 dB.





Conclusion and Future Work

- Single mode guiding was acheived of the 780 nm pump in a Zn-indiffused PPLN waveguide for nonlinear generation from a short QPM period to ~390 nm light; phasematching occurred for a 2.2 µm QPM period at a temperature of 41 ° C.
- We proved this waveguide platform is capable of deep blue generation; operating close to the absorption band of lithium niobate.
- Further reduction in PPLN QPM period to target the Yb⁺ Doppler cooling line is required; we anticipate a 1.8 µm QPM period for generation of ~369 nm.
- Future research investigating the suitability of other higher power laser sources for compact packaging of the source and PPLN waveguide will be undertaken.

References :

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