3129

Zinc diffused lithium niobate waveguides for high conversion efficiency second harmonic generation.

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Abstract

PPLN waveguides were fabricated using a new technique based on zinc indiffusion of metallic zinc carried out at atmospheric pressure. Single mode channel waveguides at 1550nm were demonstrated to have a conversion efficiency of 59%/Wcm^2. When combined with a pulsed source a conversion efficiency of 80% was achieved for second harmonic generation. This work shows that zinc diffusion is demonstrated to be a viable potential alternative to titanium diffusion and proton exchange as a route for fabricating PPLN waveguides. Advantages of zinc diffused PPLN waveguides are highlighted for visible operation, and limitations on their performance in the visible due to fabrication tolerances will be discussed.

Quasi phase matched devices are seen as an increasingly important tool in providing wavelength conversion solutions for a variety of applications ranging from the mid-infrared generation to the creation of low cost sources for blue and UV regions of the spectrum. The most commonly used material, to date, has been periodically poled lithium niobate (PPLN), which has proved enormously versatile over the last decade. While bulk PPLN is ideal for many applications, it is often desirable to use a waveguide format. In recent years the most popular routes to waveguide fabrication have been annealed proton exchange[1,2,3] and titanium diffusion[4,5]. However, more recently zinc diffusion has emerged as a candidate for fabricating waveguides, both in as-grown PPLN[6] and electrically poled PPLN[7]. In this paper we will discuss recent results on zinc-diffused PPLN that make use of a different fabrication route to the previous work, and will report encouraging results on conversion efficiency that suggest zinc indiffusion could become a realistic alternative to the more widely used proton exchange and titanium diffusion techniques.

Previously reported work by Fujimura et al[7] showed that zinc indiffusion into thin z-cut electrically poled substrates could be carried out without disrupting an existing PPLN grating formed in the sample prior to the indiffusion. This is in contrast to titanium diffusion in which the diffusion process causes repoling, presumably due to the high diffusion temperature (>1000 centigrade). So, it can be seen that zinc diffusion provides a potentially simpler fabrication route than titanium diffusion. As in titanium diffusion the periodic poling must be carried out after the waveguides are formed, and thus suffers the additional complication of needing to pole material that has been significantly chemically modified.

There are essentially two main routes for creating zinc indiffused waveguides making use of either zinc in the vapour phase, or by starting with metallic zinc. In the previous work on metallic zinc it was found that low processing pressure had to be used to prevent unacceptable build-up of residue on the surface during the indiffusion stage. In this work we have shown that by carefully optimising the zinc thickness on the sample it is possible to achieve high quality waveguides without the additional complexity of low pressure processing.

The Zn diffused channel waveguides were formed in PPLN with periods ranging from 18.05--18.6 microns. Zinc strips of 120nm thickness were prepared using photolithography with a 5nm thickness of nickel being used to promote adhesion to the sample surface. Typical diffusion conditions were 930°C for 120 minutes in dry air. The conditions were optimised for low loss and to yield single mode operation at 1550nm. A schematic is shown as figure 1.

The resulting channels were cut, polished and tested for second harmonic efficiency with a cw diode laser. The resulting phase matching curves and mode profiles are shown in figure 2.

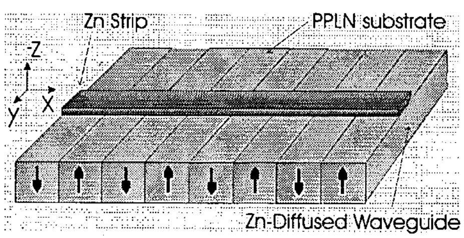

Fig 1 – schematic of waveguide fabrication

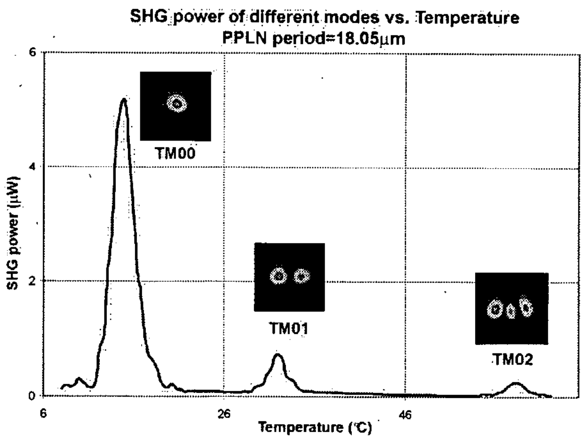

Fig 2 SHG phase matching curves for different modes

The maximum conversion efficiency measured in these devices was achieved by frequency doubling between the fundamental modes of the pump and SHG wavelengths in a 6.2μm wide zinc waveguide in an 18.05μm period PPLN grating at an operating temperature of 14.8°C. The graph of Fig. 4 shows the maximum external SHG power of 5.2μW, as measured for 3.2mW of internal pump power, corresponding to a maximum conversion efficiency of 59%$W^{-1}cm^{-2}$ in the 10mm-long waveguide. In comparison to prior techniques, this SHG conversion efficiency is similar to the 65%$W^{-1}cm^{-2}$ achieved in APE PPLN waveguides[3], and higher than the 9.4%$W^{-1}cm^{-2}$ achieved in titanium-indiffused waveguides[5].

To further investigate the waveguides under high peak power operation, we used a synchronously pumped optical parametric oscillator as a high peak power source at 1556nm. Using this source the higher peak power allows a much greater nonlinear drive and conversion efficiencies of up to 80% were realised with a 3.5mm long waveguide. Figure 3 shows the temperature tuning curve for this waveguide. This OPO source is inherently much broader bandwidth (1.2nm) than the cw diode laser and has a near transform limited pulse lasting 5ps. Previous work in PPLN or PPLN waveguides achieving >70% conversion have generally made use of lasers with carefully tailored "square" temporal pulses to prevent lower conversion occurring during the start and finish of the pulse from reducing the overall efficiency[9,10].

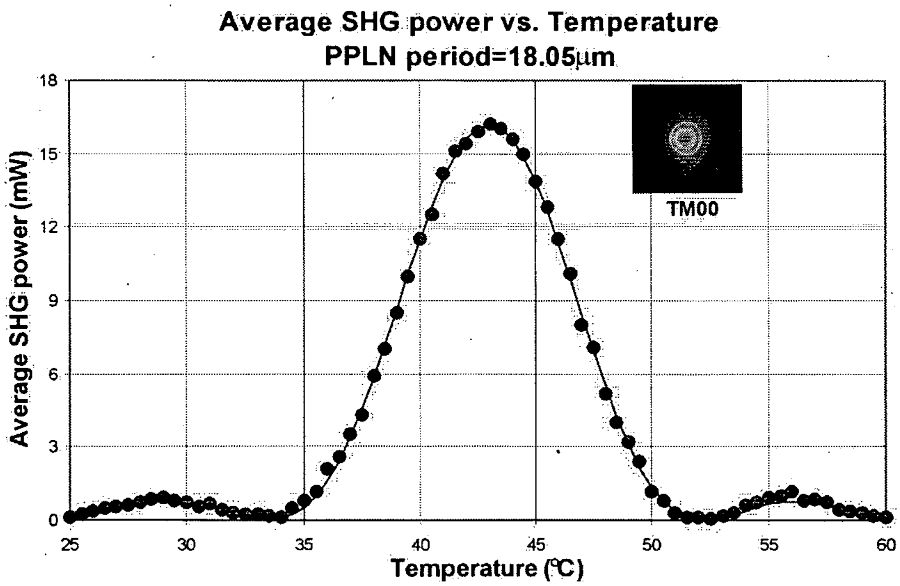

Fig 3. SHG power vs. QPM temperature for PPLN waveguide (period=18.05um) under the high power condition, the solid line is the best sinc fit to the measured data points.

It is also worth pointing out that the zinc indiffused waveguides can be operated at room temperature and even below room temperature, and also in the blue spectral region with significantly reduced photorefractive effect compared to bulk PPLN. Results will be presented on this reduction of the photorefractive effect. However, in our studies we have been unsuccessful in achieving such a high conversion efficiency for blue generation as for the 1550nm waveguides presented here. We will review reasons for this lower efficiency, and we will show that much of the poorer performance can be ascribed to the limitations in our lithographic processing of the zinc strips for diffusion.

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