1-1-2008

Fabrication and characterisation of periodically poled lithium niobate waveguide using femtosecond laser pulses

Shuanggen Zhang
Nankai University

Jianghong Yao
Nankai University

Qing Shi
Nankai University

Yange Liu
Nankai University

Weiwei Liu
Nankai University

See next page for additional authors

Recommended Citation

Zhang, Shuanggen; Yao, Jianghong; Shi, Qing; Liu, Yange; Liu, Weiwei; Huang, Zhangchao; Lu, Fuyun; and Li, Enbang, "Fabrication and characterisation of periodically poled lithium niobate waveguide using femtosecond laser pulses" (2008). *Faculty of Engineering and Information Sciences - Papers: Part A*. 2876.
https://ro.uow.edu.au/eispapers/2876

Fabrication and characterisation of periodically poled lithium niobate waveguide using femtosecond laser pulses

Abstract

We present in this letter the fabrication and characterization of thermally stable type II waveguides in Z-cut periodically poled lithium niobate crystals. The waveguides were fabricated by using a femtosecond laser and were utilized for second harmonic generation. Our experiments have shown that a quasiphase matching wavelength of 1548.2nm, a tuning bandwidth of 2nm, and a tuning temperature range of 150.4±1.6°C can be achieved.

Keywords

characterisation, laser, femtosecond, waveguide, pulses, niobate, fabrication, lithium, poled, periodically

Disciplines

Engineering | Science and Technology Studies

Publication Details

Zhang, S., Yao, J., Shi, Q., Liu, Y., Liu, W., Huang, Z., Lu, F. & Li, E. (2008). Fabrication and characterisation of periodically poled lithium niobate waveguide using femtosecond laser pulses. Applied Physics Letters, 92 231106-1-231106-3.

Authors

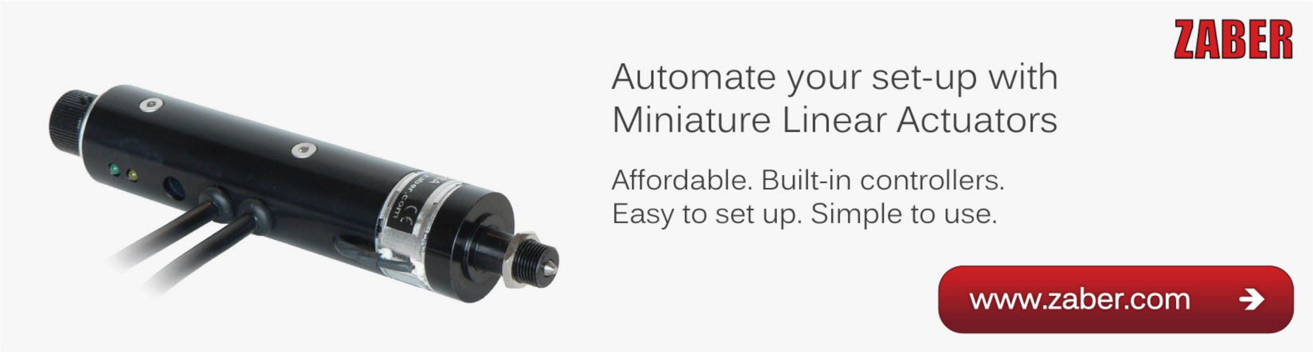
Shuanggen Zhang, Jianghong Yao, Qing Shi, Yange Liu, Weiwei Liu, Zhangchao Huang, Fuyun Lu, and Enbang Li

AIP | Applied Physics Letters

Fabrication and characterization of periodically poled lithium niobate waveguide using femtosecond laser pulses

Shuanggen Zhang, Jianghong Yao, Qing Shi, Yange Liu, Weiwei Liu, Zhangchao Huang, Fuyun Lu, and Enbang Li

Citation: Applied Physics Letters **92**, 231106 (2008); doi: 10.1063/1.2945275
View online: http://dx.doi.org/10.1063/1.2945275
View Table of Contents: http://scitation.aip.org/content/aip/journal/apl/92/23?ver=pdfcov
Published by the AIP Publishing



APPLIED PHYSICS LETTERS **92**, 231106 (2008)

Fabrication and characterization of periodically poled lithium niobate waveguide using femtosecond laser pulses

Shuanggen Zhang,[1] Jianghong Yao,[1] Qing Shi,[1] Yange Liu,[1] Weiwei Liu,[1]
Zhangchao Huang,[1] Fuyun Lu,[1,a)] and Enbang Li[2]
[1]*College of Physical Science and The Key Laboratory of Weak Light Nonlinear Photonics, Nankai University, Ministry of Education, Tianjin 300071, People's Republic of China*
[2]*College of Precision Instrument and Optoelectronics Engineering, Tianjin University, Tianjin 300072, People's Republic of China*

(Received 23 March 2008; accepted 22 May 2008; published online 13 June 2008)

We present in this letter the fabrication and characterization of thermally stable type II waveguides in *Z*-cut periodically poled lithium niobate crystals. The waveguides were fabricated by using a femtosecond laser and were utilized for second harmonic generation. Our experiments have shown that a quasiphase matching wavelength of 1548.2 nm, a tuning bandwidth of 2 nm, and a tuning temperature range of 150.4 ± 1.6 °C can be achieved. © *2008 American Institute of Physics*. [DOI: 10.1063/1.2945275]

Optical waveguides fabricated on lithium niobate (LN) crystals are widely used in integrated optics, and several fabrication methods, including Ti diffusion[1] and proton exchange,[2] are now well established. Although these techniques allow low loss and high quality optical waveguides to be fabricated, they are always involved with complicated processes and only applicable to the fabrication of the two-dimensional waveguides close to the surface of the substrates. With the advent of femtosecond lasers, the above-mentioned disadvantages can be overcome. With the femtosecond laser method, the light is focused to some depth inside a transparent material while the material is translated either along the beam direction (known as longitudinal writing) or perpendicular to the beam direction (known as transverse writing), creating channels of locally modified refractive index, which may act as waveguides under suitable writing conditions. Different kinds of waveguides have been fabricated in glasses and polymers irradiated by the focused ultrashort laser in the past decade.[3,4] Much more interest has been focused on femtosecond laser-written LN waveguide.[5–9] Additionally, the latest work on such waveguides fabricated in periodically poled LN (PPLN) has been initiatively carried out. A type I waveguide has been obtained in PPLN, and a frequency doubling process at 1563 nm has been demonstrated.[10] In this type of waveguides, the nonlinear coefficient can be preserved using a multiscan approach.[11] Another waveguide fabricated in PPLN was achieved using a double line approach, namely, type II waveguide, and efficient second harmonic generation (SHG) at 1064 nm has been reported.[12] Pumped at 1550 nm optical communication band, the SHG wavelength is located around 800 nm, which is the interesting wavelength and has a very wide application such as femtosecond/picosecond laser micromachining. Compact, environmentally stable 800 nm photonic sources are very attractive to replace the conventional solid-state laser.

In this letter, we describe the fabrication of thermally stable type II waveguides in *Z*-cut PPLN crystals utilizing

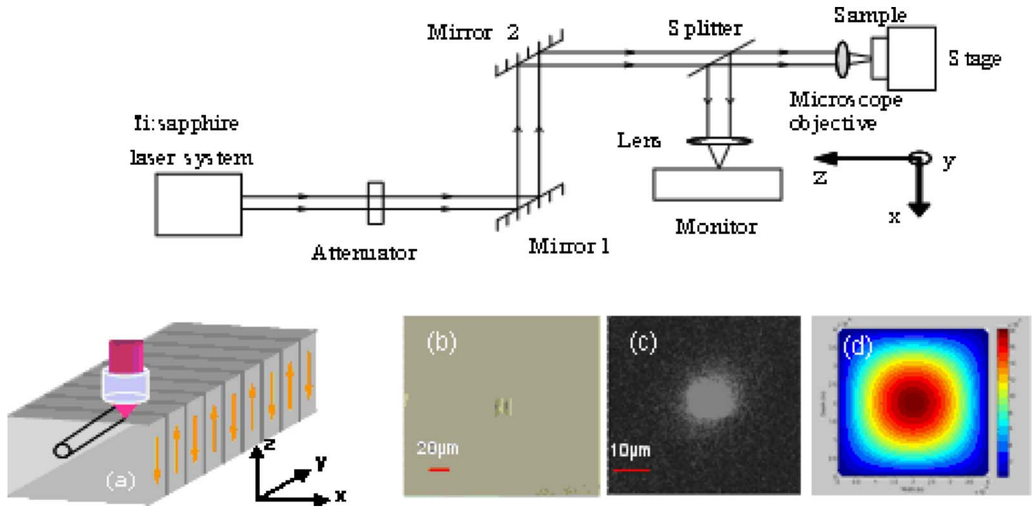


FIG. 1. (Color online) The schematic diagram of waveguide fabrication. (b) is the microstructure of the end face; (c) is the near field mode of SHG after the waveguide by visible camera; (d) shows the simulative mode of SHG by finite element method.

[a)] Electronic mail: lufy@nankai.edu.cn.

0003-6951/2008/92(23)/231106/3/$23.00

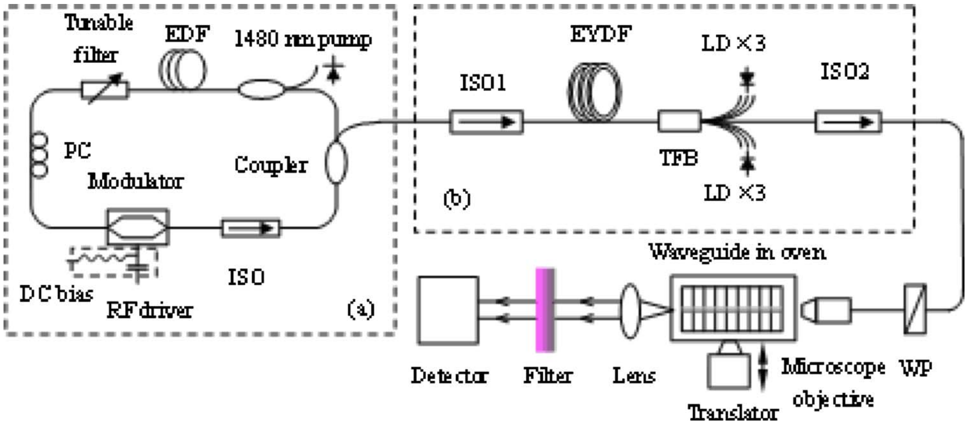


FIG. 2. (Color online) Schematic diagram of the experimental configuration. PC—polarization controller; EDF—erbium doped fiber; ISO—Isolator; EDFA—ytterbium-erbium-doped fiber; TFB—tapered fiber bundle; WP—Wollaston prism.

tightly focused femtosecond laser pulses and the efficient SHG of a high repetition rate wavelength-tunable fiber laser using quasiphase matching (QPM) condition. A normalized efficiency of 4.8% W^{-1} cm^{-2} has been achieved at a QPM wavelength of 1548.2 nm and at an optimal temperature of 150.4 °C. Our work has found that a waveguide width of 10 μm is the optimal width for the single mode propagation.

A schematic diagram showing the PPLN waveguide writing process is depicted in Fig. 1. A Ti:sapphire femtosecond laser (HP-Spitfire, Spectr-Physics Inc.) was used to generate 50 fs laser pulses with a central wavelength of 800 nm at a repetition of 1 kHz. The maximum pulse energy from the laser system was 2 mJ. The laser beam was focused into the sample with a 25× microscope objective [numerical aperture (NA)=0.4] at a certain depth (~200 μm in our work) beneath the surface. A charge coupled device (KA-320) detector was used to monitor the focusing condition. Under the fixed focal spot, the sample mounted on a motorized stage was translated with a velocity of 400 μm/s perpendicular to the *Z* axis direction using a computer-controlled positioner. A 10 mm long and 0.5 mm thick *Z*-cut PPLN sample with a QPM period of 18.6 μm was fabricated using the external pulse field poling technique.[13] In order to produce a thermally stable type II waveguide, we consecutively wrote pairs of straight lines separated by 10 μm in the *X* direction of the sample. Accordingly, through the variable attenuator, the single-pulse energy was adjusted to about 10 μJ, which is the optimum pulse energy for the waveguide fabrication.

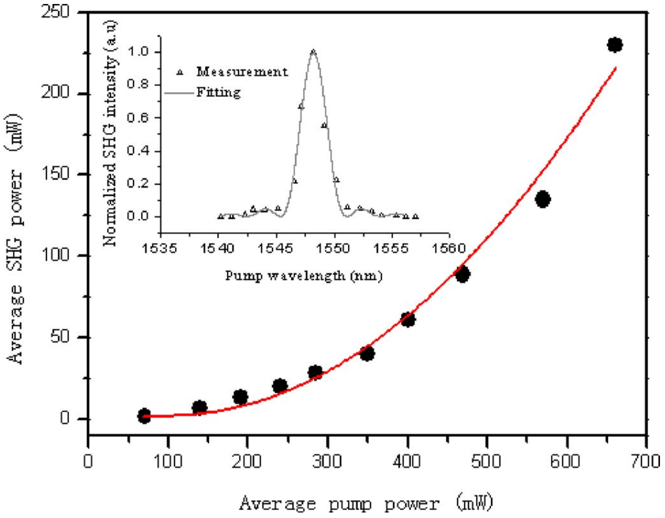


FIG. 3. (Color online) Second harmonic average power vs fundamental power under the optimum wavelength of 1548.2 nm. The inset picture shows the wavelength tuning curve of the SHG output at the temperature of 150.4 °C.

To investigate the guiding properties of the fabricated waveguide, a 1550 nm fiber source (shown in Fig. 2) was coupled into one end of the waveguide using a microscope (NA=0.25), and the output facet was then imaged onto a camera. Figure 1(c) is the corresponding near field image of the guided 774.1 nm mode, together with the simulated mode distribution using finite element method in which the refractive index change was assumed to be about $\Delta n \approx 3\times 10^{-3}$. From our investigations of the guiding properties it was found that only light polarized along the *Z* axis is guided between the laser-written lines.

The experimental setup of the frequency doubling process from such type II waveguide in the PPLN sample is shown in Fig. 2. The light source has a master oscillator-power amplifier (MOPA) architecture, which includes two parts: one is a ring fiber structure based on common single-clad Er-doped fiber and the other is an Er/Yb-doped double-clad fiber amplifier with backward pumps. The master source is a compact fiber laser actively mode locked by a RF driver (HP83711B), and its output signal power is boosted in a double-clad fiber amplifier pumped by a stack of 980 nm diode lasers. Driven at full power, the MOPA system could produce up to 2 W of average power with ~60 ps pulses at a repetition rate of 6.12 GHz over a tunable wavelength range of 1535–1570 nm.

The *Z*-axis polarized fiber laser was coupled to the PPLN waveguide with a 10× microscope objective (NA=0.25). Both end faces of the waveguide were polished after fabrication, but without antireflection coating. The waveguide was placed inside a temperature-controlled oven (HC Photonics), in which the operation temperature can be controlled up to 200 °C with an accuracy of 0.1 °C, allowing for precise thermo-optic tuning.

Following the collimation and separation from residual fundamental frequency light, the waveguide SHG was fed to a spectrometer or an optical power meter. The picture of the

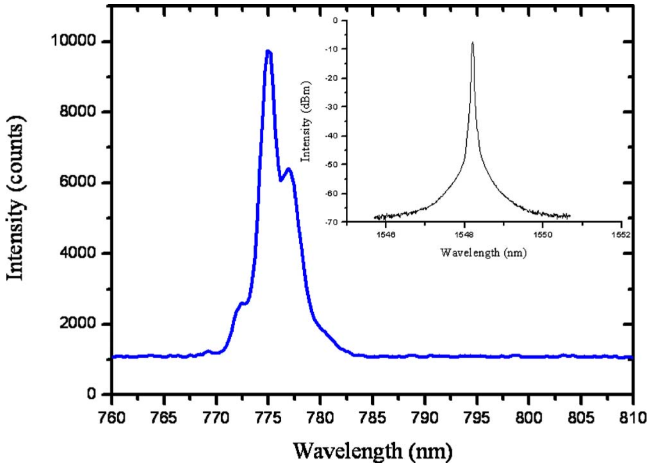


FIG. 4. (Color online) The spectra of the second harmonic wave after the waveguide pumped at 1548.2 nm.

inset in Fig. 3 shows the fundamental tuning wavelength range, together with the fitting curve of the experimental data. As can be seen, there is an excellent agreement between the data and the characteristic sinc^2 phase matching profile. A phase matching peak can be found at 1548.2 nm. The measured full width at half maximum (FWHM) spectral acceptance is about 2 nm.

At an optimum wavelength of 1548.2 nm, the power of the fundamental wave was varied and the SHG power was measured, as shown in Fig. 3. With the fundamental wave power increases, the second harmonic power increases accordingly as a quadratic trend. At an incident average power of 660 mW in the waveguide, a second harmonic power of 230 mW is obtained, yielding maximum conversion efficiency of 34.8%. It is much higher than that of bulk conversion efficiency of 23.4% under the same experimental parameters. The normalized efficiency of 4.8% $\mathrm{W}^{-1}\,\mathrm{cm}^{-2}$ was obtained by $\bar{\eta}=P_{2\omega}/P_{\omega}^2L^2$, where L is the sample length. At the maximum input power, there is still no evidence of saturation in SHG efficiency. We expect that with the use of antireflection-coated front and end facets, it is possible to further enhance the second harmonic output power and to increase the efficiency.

Figure 4 shows the spectra of the harmonic light measured using a high-resolution spectrometer (Ocean Optics). The corresponding pumping wavelength is located at 1548.2 nm, as displayed in the inset of Fig. 4. The profile distortion is caused by the dispersion and nonlinear effects during the picosecond pulse train propagation along the waveguide.

At the optimum emission wavelength of 1548.2 nm, the measured SHG intensities as a function of PPLN waveguide temperature are shown in Fig. 5. The optimum temperature is found to be around 150.4 °C, and the corresponding temperature acceptance bandwidth is about 1.6 °C.

In conclusion, we have demonstrated the maskless nonlithographic fabrication of thermally stable type II waveguides in periodically LN with tightly focused femtosecond laser pulses. Efficient SHG has been achieved in such waveguides by using a high repetition rate wavelength-tunable fiber source. At the QPM wavelength of 1548.2 nm, a conversion efficiency of 34.8% has been achieved at an optimal temperature of 150.4 °C. The waveguides written with femtosecond laser pulses have a number of advantages including ease fabrication, flexible patterning, and excellent stability. These waveguides are promising candidates for three-dimensional nonlinear functional elements in integrated optics.

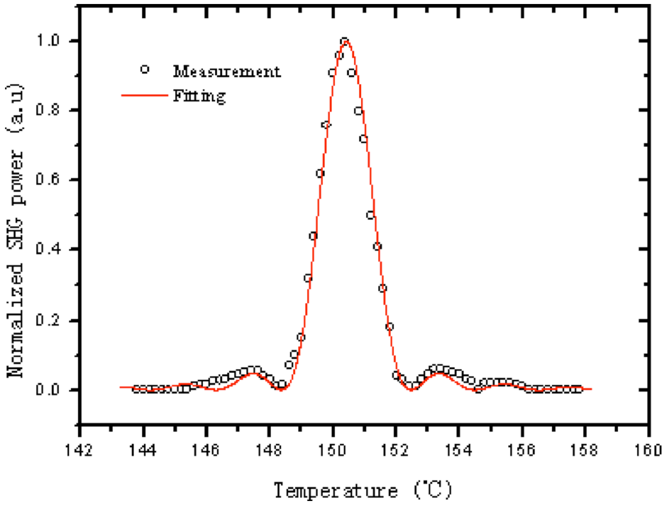


FIG. 5. (Color online) Measured thermal tuning curve for SHG at the center phase matching temperature of 150.4 °C. The dotted line represents the normalized SHG average power, and the solid line is the fitting curve. The FWHM acceptance bandwidth is about 1.6 °C.

This work was supported by the National Natural Science Foundation of China (60677013), the Specialized Research Fund for the Doctoral Program Foundation of Institute of Higher Education of China (20060055021), and the Chinese National Key Basic Research Special Fund (2006CB921703).

[1] R. V. Schmidt and I. P. Kaminow, Appl. Phys. Lett. **25**, 458 (1974).
[2] J. L. Jackel, C. E. Rice, and J. J. Veselka, Appl. Phys. Lett. **41**, 607 (1982).
[3] D. Homoelle, S. Wielandy, Alexander L. Gaeta, N. F. Borrelli, and C. Smith, Opt. Lett. **24**, 1311 (1999).
[4] G. Cerullo, R. Osellame, S. Taccheo, M. Marangoni, D. Polli, R. Ramponi, P. Laporta, and S. D. Silvestri, Opt. Lett. **27**, 1938 (2002).
[5] L. Gui, B. Xu, and T. C. Chong, IEEE Photonics Technol. Lett. **16**, 1337 (2004).
[6] R. R. Thomson, S. Campbell, I. J. Blewett, A. K. Kar, and D. T. Reid, Appl. Phys. Lett. **88**, 111109 (2006).
[7] J. Burghoff, C. Grebing, S. Nolte, and A. Tünnermann, Appl. Phys. Lett. **89**, 081108 (2006).
[8] H. T. Bookey, R. R. Thomson, N. D. Psaila, A. K. Kar, N. Chiodo, R. Osellame, and G. Cerullo, IEEE Photonics Technol. Lett. **19**, 892 (2007).
[9] A. H. Nejadmalayeri and P. R. Herman, Opt. Express **15**, 10842 (2007).
[10] Y. L. Lee, N. E. Yu, C. Jung, B.-A. Yu, I.-B. Sohn, S.-C. Choi, Y.-C. Noh, D.-K. Ko, W.-S. Yang, H.-M. Lee, W.-K. Kim, and H.-Y. Lee, Appl. Phys. Lett. **89**, 171103 (2006).
[11] R. Osellame, M. Lobino, N. Chiodo, M. Marangoni, G. Cerullo, R. Ramponi, H. T. Bookey, R. R. Thomson, N. D. Psaila, and A. K. Kar, Appl. Phys. Lett. **90**, 241107 (2007).
[12] J. Thomas, M. Heinrich, J. Burghoff, S. Nolte, A. Ancona, and A. Tünnermann, Appl. Phys. Lett. **91**, 151108 (2007).
[13] M. Yamada, N. Nada, M. Saitoh, and K. Watanabe, Appl. Phys. Lett. **62**, 435 (1993).