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Red and blue light generation by frequency doubling and tripling in periodically-poled $LiNbO_3$

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Abstract

Efficient frequency-doubling and tripling of a diode-pumped Nd:YAG laser (670mW at 1320nm) generates 360mW red (660nm) and 35mW blue (440nm) light in a single pass through two cascaded periodically-poled $LiNbO_3$ gratings. Photorefractive effects are negligible.

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Periodically-poled $LiNbO_3$ (PPLN), with its high optical nonlinearity and non-critical phase-matching, is an attractive nonlinear material for generating high-power visible output via frequency up-conversion of existing infrared sources. In this work we demonstrate second and third harmonic generation of a Nd:YAG laser (1320nm) to produce red (660nm) and blue (440nm) wavelengths with high spatial beam quality, in a simple single-pass arrangement. Samples of PPLN were prepared for this experiment using the electric-field poling technique [1].

The fundamental infrared laser source was a Nd:YAG laser end-pumped by a single, beam-shaped 20W diode-bar [2]. The experimental arrangement is shown in figure 1. A folded resonator design was used with an intracavity etalon to select the 1320nm lasing wavelength, and an acousto-optic modulator to Q-switch the laser. The laser was operated at a pulse repetition rate of 17kHz, producing Q-switched pulses of energy 60µJ and 170ns duration (FWHM) corresponding to a peak power of 353W in a linearly polarised fundamental transverse mode (beam quality factor, $M^2 < 1.2$). After collimation and focusing, an average power of 780mW (275W peak) was incident on the first PPLN sample.

Second harmonic generation (SHG) was achieved using PPLN of period 12.34µm, thickness 0.5mm and length 20mm. The grating period was chosen to allow first-order quasi-phase matched (QPM) SHG at an elevated temperature of 140°C in order to suppress photorefractive effects. The fundamental infrared (1320nm) beam was focused to a spot of radius 42μm inside the uncoated crystal sample. An average (internal) fundamental power of 670mW resulted in the generation of 360mW (141W peak) of second harmonic red (660nm) in a single-pass, representing a conversion efficiency of 54%. Figure 2 shows how the conversion efficiency depends upon the fundamental power. The output red beam had a circular profile with $M^2 = 1.1$ indicating successful suppression of photorefractive effects and no optical damage at these operating power levels.

The generated second harmonic and the remaining unconverted fundamental were then combined in a second (uncoated) PPLN sample to achieve sum frequency generation (SFG) of 440nm blue light - the third harmonic of the Nd:YAG source. This PPLN sample had a period of 11.62μm, thickness 0.3mm and length 25mm, designed for third-order QPM SFG, again at 140°C. The use of a third-order grating through a 0.3mm sample permitted the optimisation of a 50:50 mark-to-space domain inversion ratio both to maximise the third-order conversion efficiency to the blue and to minimise photorefractive effects. With average internal powers of 174mW at 1320nm and 246mW at 660nm, 35mW (13.7W peak) of blue light was generated in a single-pass (conversion efficiency 8%), figure 3. The output blue beam also had a circular spatial profile with $M^2 = 1.1$.

These results demonstrate the capability of SFG, even in a third-order interaction, to generate significant powers of blue (440nm) light in PPLN. Additionally, results show that photorefractive effects can be successfully eliminated in undoped $LiNbO_3$ at this short wavelength. Provision of anti-reflection coatings for optics and crystals, and optimisation of beam overlap in the frequency-mixing process, should all offer a significant improvement in performance.

References

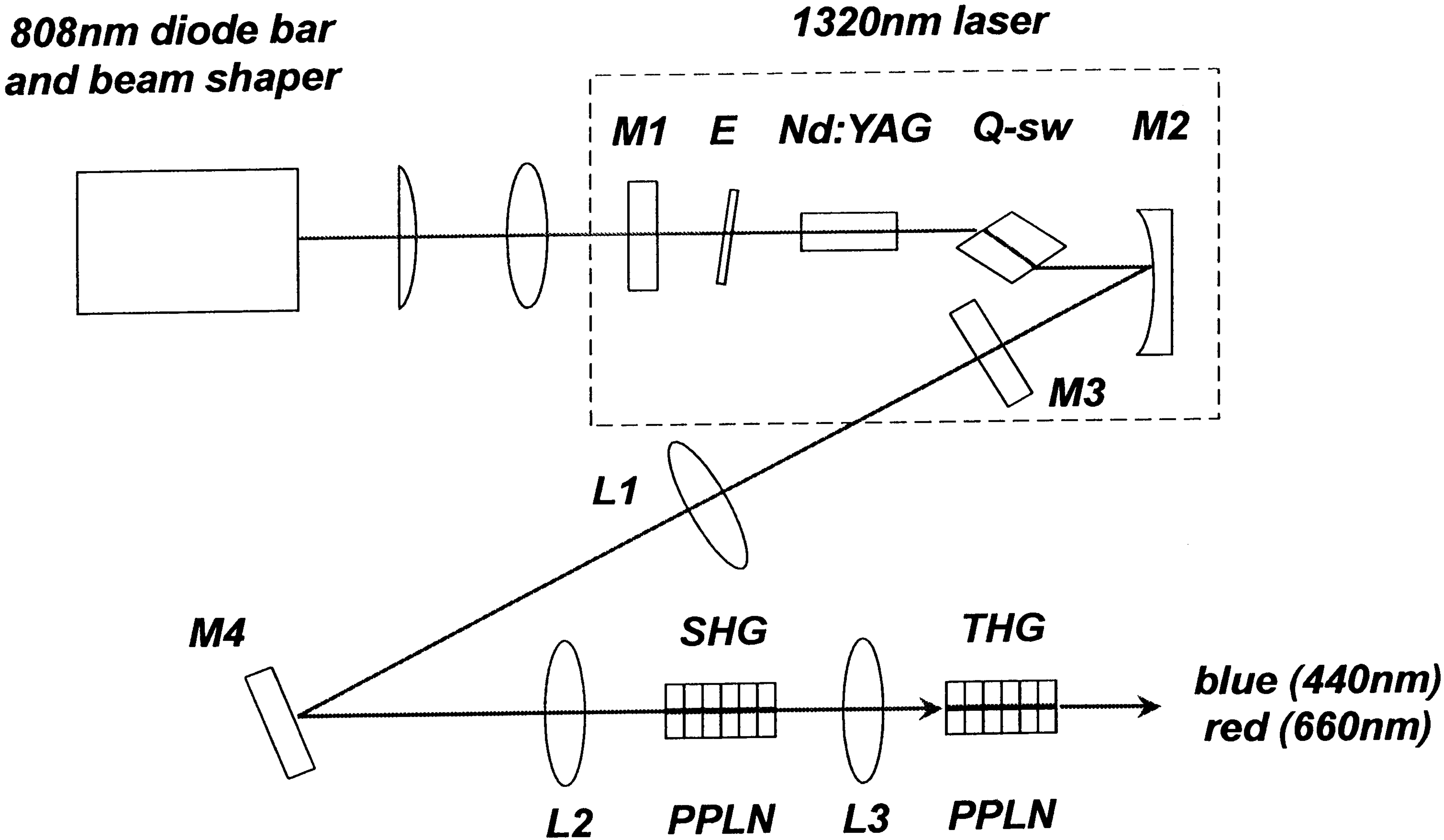
1. J.Webjörn, V.Pruneri, P.St.J.Russell, J.R.M.Barr & D.C.Hanna, Electron.Lett. **30**, 894 (1994)
2. W.A.Clarkson and D.C.Hanna, Opt.Lett. **21**, 869 (1996)

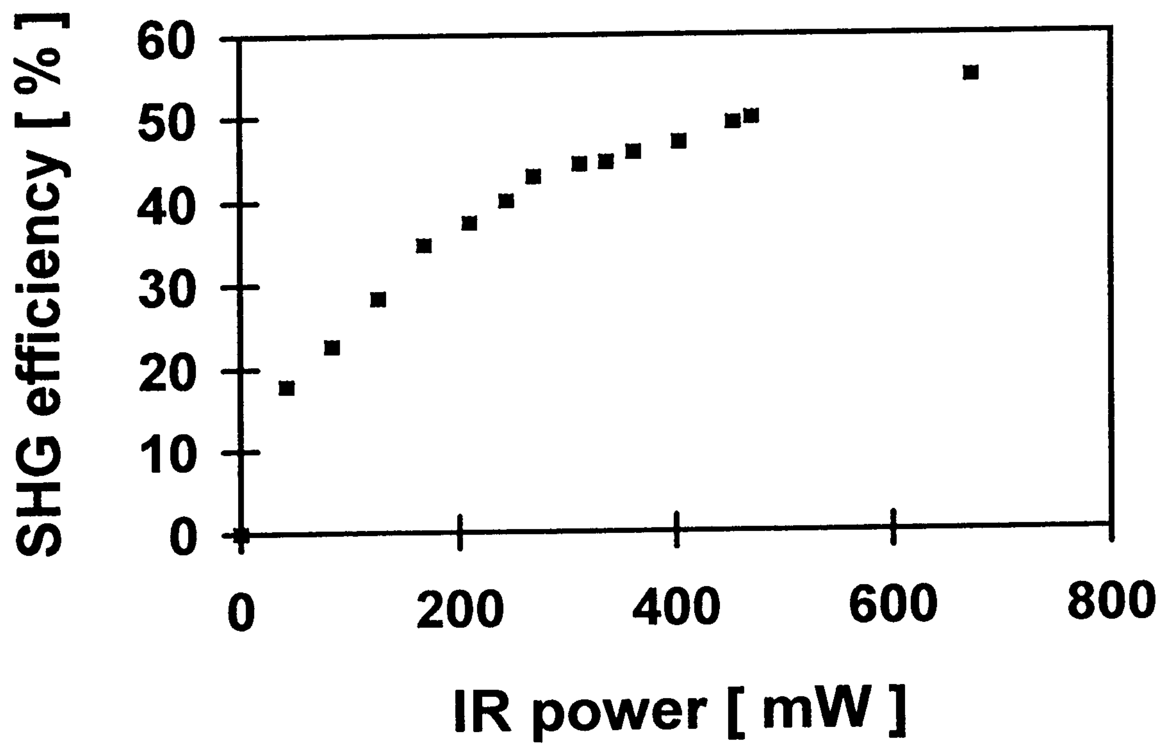
Figure Captions

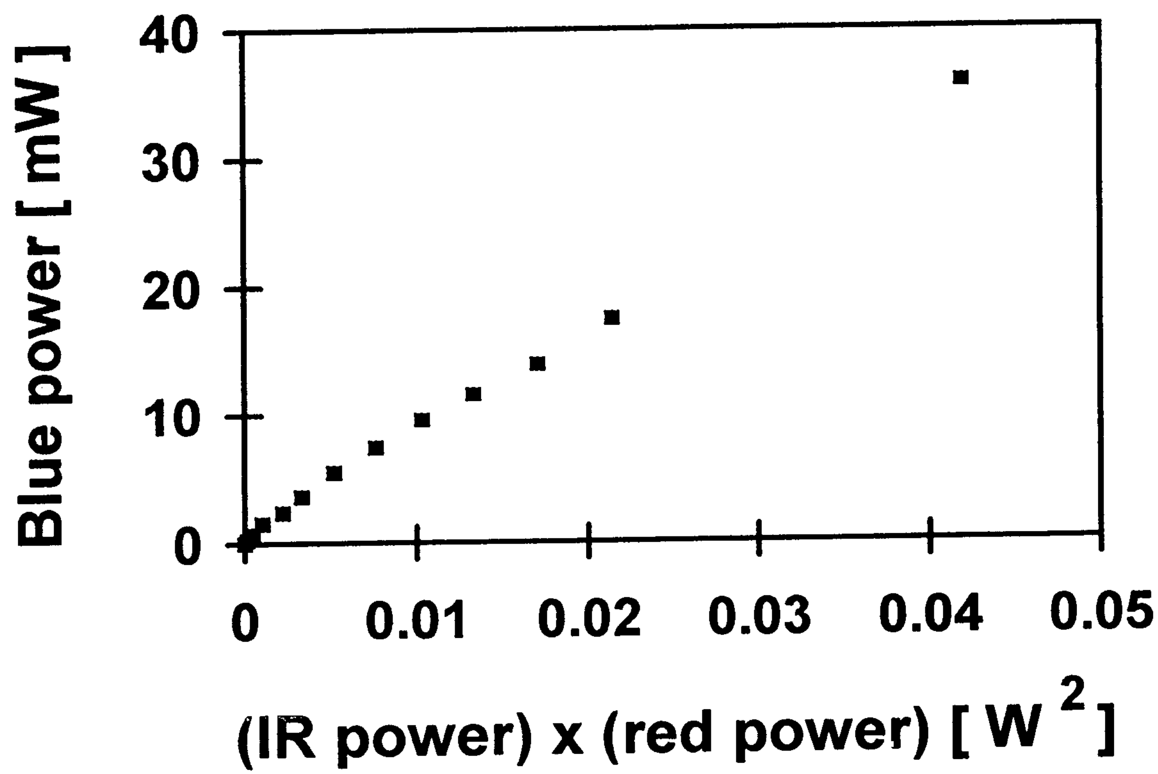
Figure 1 The experimental arrangement. M1,3,4 are plane mirrors. M2 is a curved mirror ROC 50mm. E is an 100μm thick etalon. Q-sw is acousto-optic modulator Q-switch and L1-3 are lenses with focal lengths 300mm, 150mm, 50mm respectively.

Figure 2 Red (660nm) light generation in the first PPLN crystal by SHG. Graph of SHG conversion efficiency vs average fundamental power.

Figure 3 Blue (440nm) light generation in the second PPLN crystal by SFG. Graph of blue vs (fundamental)×(second harmonic) average powers.


808nm diode bar
and beam shaper
1320nm laser
M1
E
Nd:YAG
Q-sw
M2
M3
L1
M4
SHG
THG
blue (440nm)
red (660nm)
L2
PPLN
L3
PPLN


SHG efficiency [%]
60
50
40
30
20
10
0
0
200
400
600
800
IR power [mW]


Blue power [mW]
40
30
20
10
0
0
0.01
0.02
0.03
0.04
0.05
(IR power) x (red power) [W 2]