Broadcast wavelength conversion based on cascaded $\chi^{(2)}$ nonlinearity in MgO-doped periodically poled LiNbO$_3$

F. Lu, Y. Chen, J. Zhang, W. Lu, X. Chen and Y. Xia

The first experimental demonstration of broadcast wavelength conversion is reported, based on the cascaded second-order nonlinearity in 5% MgO-doped periodically poled LiNbO$_3$ with type I quasi-phase matching. A broad second-harmonic generation bandwidth up to 27 nm was obtained. Using the device, a free three-channel converter with no crosstalk in the communication band was demonstrated.

Introduction: The all-optical wavelength converter has increasingly been promoted in recent years for both continuous wave (CW) [1] and pulsed [2] lasers by employing a quasi-phase-match (QPM) technique [3] owing to the maturity of the electric poling technique at room temperature. Based on the cascaded second-harmonic generation (SHG) and difference frequency generation (DFG) interactions, the grouped wavelength converter is realised on periodically poled LiNbO$_3$ (PPLN), through which multiple channels are converted simultaneously with equal efficiency [1, 4, 5]. However, this kind of converter, which we call an N × N converter, has an intrinsic limit on conversion choice, i.e. each of the N input signals can be converted into only one output wavelength, owing to the rather narrow SHG bandwidth for conventional type 0 QPM interactions using d_{33}.

The N × M broadcast wavelength converter is more attractive for future all-optical DWDM communication systems. By designing structures with a phase-reversal sequence superimposed upon a uniform QPM grating, Chou *et al.* first implemented this kind of device with the simultaneous use of M pump wavelengths in 1999 [6]. In 2003, a multiple QPM LiNbO$_3$ wavelength converter with a continuously phase-modulated domain structure [7] was designed, which has the potential function of N × M conversion owing to the tunable pump wavelength. In addition to the above engineered QPM structures, we notice that in 2002 broadband QPM SHG in MgO-doped PPLN in the communication band was demonstrated by type I QPM using d_{31} [8]. So, the wavelength converter with broadband SHG based on a uniform QPM grating would be another scheme to realise broadcast wavelength conversion. In this Letter, by continuously tuning pump wavelengths, we propose and experimentally demonstrate a novel mechanism for N × M broadcast wavelength conversion employing type I QPM based on the cascaded $\chi^{(2)}$ interactions in 5% MgO-doped PPLN crystal.

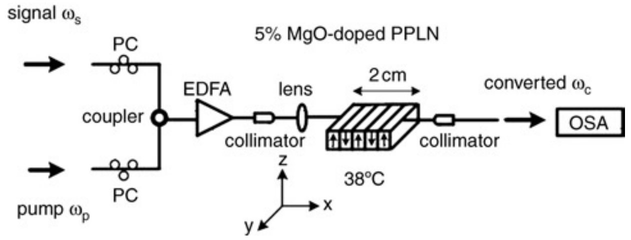

Fig. 1 *Experimental setup*

PC: polarisation controller; MgO-doped PPLN: MgO-doped periodically poled LiNbO$_3$; EDFA: erbium-doped fibre amplifier

Experiments: The principle of the cascaded $\chi^{(2)}$ wavelength conversion comprises two steps. First, the pump light ω_p is upconverted to frequency $2\omega_p$ by SHG. Then, when the signal light ω_s is launched into the MgO-doped PPLN crystal, the converted light $\omega_c = 2\omega_p - \omega_s$ will be generated by DFG. Phase matching between interacting waves for both SHG and DFG is required, and can be accomplished in the communication band by choosing a suitable grating grid and temperature of the crystal.

Fig. 1 shows the experimental setup. Both pump and signal lights are launched into a 5% MgO-doped PPLN crystal after being amplified by a powerful C-band EDFA, since the conversion efficiency is much lower in bulk crystal than in the waveguide. The size of the z-cut MgO-doped PPLN crystal is 20 × 10 × 0.5 mm, and the grating period is 20.4 µm, which decides conversion occurs at the 1.5 um band. The optimum conversion temperature is 38°C. Two polarisation controllers are used to adjust the polarisation of pump and signal lights at the ordinary direction. Therefore, the double-frequency wave should be an extraordinary light and the converted wave is an ordinary light for type I QPM.

Results: Fig. 2 shows the broad SHG bandwidth for pump light in our experiment. The peak normalised SH efficiency is 0.1%/W with incident pump power of 300 mW when the pump wavelength is 1562 nm. The SHG bandwidth is as wide as 27 nm in 20 mm long-crystal, which is much broader, about 0.8 nm, than that with type 0 QPM [9]. So, we can tune the pump at an arbitrary wavelength within the 27 nm band, which makes the broadcast wavelength conversion possible. A broader SHG bandwidth can be expected by neglecting the amplification bandwidth of the C-band EDFA. As well as pump light, signal light also has to be amplified by the EDFA, so we did not measure the conversion bandwidth, which would be wider than about 70 nm [1] in type 0 QPM because we have such wide SHG bandwidth.

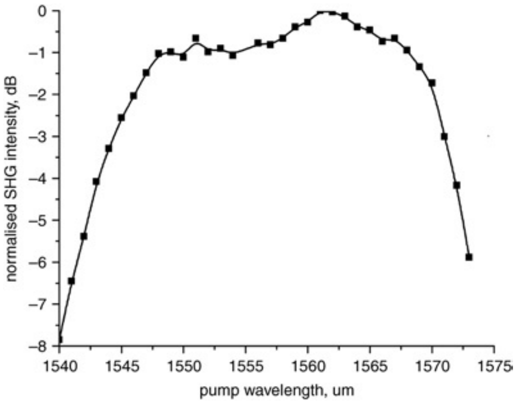

Fig. 2 *27 nm broad bandwidth of SHG for type I QPM*

Fig. 3 shows a combination of two individual measured traces of conversion. Since we did not have two pumps input simultaneously, by this way we demonstrated such a 1 × 2 broadcast wavelength converter. The wavelengths of the signal, two pumps and two converted lights are: 1546.92 nm (signal, 193.8THz); 1561.42 nm (pump 1, 192.00THz), 1562.23 nm (pump 2, 191.9THz); 1576.20 nm (converted 1, 190.20THz), 1577.86 nm (converted 2, 190.0THz) (ITU standard), respectively. The low conversion efficiency (−66 dB) is mainly due to using the nonlinear coefficient d_{31} for type I QPM, which is much smaller than d_{33} for type 0 QPM, and no waveguide fabricating. Other factors include the size of the focusing spot, no antireflective coating, polarisation control and optical loss owing to the many optical passive components used.

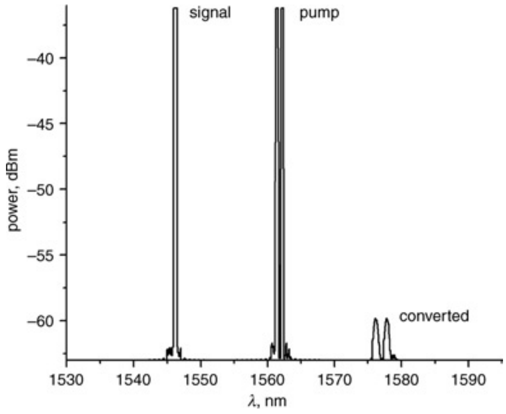

Fig. 3 *Measured trace of 1 × 2 broadcast wavelength conversion in 5% MgO-doped PPLN*

By launching several pump lights with different wavelengths while the signal wavelength is fixed, a broadcast wavelength conversion at the communication band has been demonstrated conceptually. Furthermore, we have demonstrated a free three-channel wavelength converter, which would convert three signal lights (193.4, 193.8, 194.2 THz) to another three (190.0, 190.1, 190.2 THz) at an arbitrary sequence each time with three pump lights on. As shown in Fig. 4, crosstalk between channels can be eliminated with proper selection of different frequency grid for signal and converted lights. Here nine pump lights, 191.7, 191.75, 191.80, 191.90, 191.95, 192.00, 192.1, 192.15, 192.2 (THz) are employed, which are all within the SHG band shown in Fig. 2.

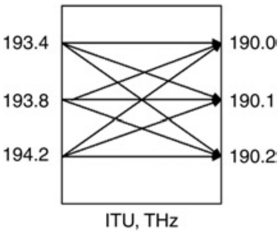

Fig. 4 *Model of free three-channel wavelength converter with no crosstalk*

Conclusion: We have presented a broadcast wavelength conversion device at the communication band in a 20 mm-long 5% MgO-doped PPLN crystal. By employing type I QPM for both SHG and DFG interactions, 27 nm broad bandwidth of pump light has been obtained. A free three-channel wavelength conversion has also been demonstrated. The low conversion efficiency would be improved by adopting waveguide devices, facet coating, etc. Our research shows a promising application in future all-optical DWDM communication systems.

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