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Efficient Ti:PPLN multi-wavelength converter for high bitrate WDM-transmission systems

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Abstract: Wavelength conversion by cascaded difference frequency generation (cDFG) in a fully packaged Ti:PPLN-waveguide converter with an efficiency of -8dB, up to -3dBm of converted output and simultaneous multichannel conversion without depletion has been demonstrated. A converted 40Gbit/s RZ-channel has been transmitted error-free over 5×100km of NZDS-fibre without penalty.

Introduction

Wavelength conversion based on parametric difference frequency generation (DFG) in periodically poled $LiNbO_3$ (PPLN) waveguides has attracted considerable interest /1/, because it meets numerous requirements of fibre optical communications such as strict transparency, independence of data rate and -format, low cross talk and no intrinsic chirp. Its conversion bandwidth not only covers the gain bandwidth of standard EDFAs but can be easily shifted into the S- or L-band or even further. The $\chi^{(2)}$ nonlinearity of $LiNbO_3$ can be used twice in a cascaded process to generate the pump for the DFG-process inside the converter (cDFG) /2/. cDFG allows to utilize laser sources in the 3rd window for pumping and simplifies fundamental mode excitation.

In this paper we report for the first time highly efficient single- and multi-channel wavelength conversion by cascaded difference frequency generation (cDFG) in a fully packaged Ti:PPLN-waveguide converter with converted output power levels close to 1mW. Error-free transmission over 500km of non zero dispersion-shifted (NZDS-) fibre has been achieved using λ-converted data.

Device fabrication and packaging

The structure of the converter together with the measured near field intensity distribution of the fundamental TM-mode is shown in Fig. 1.

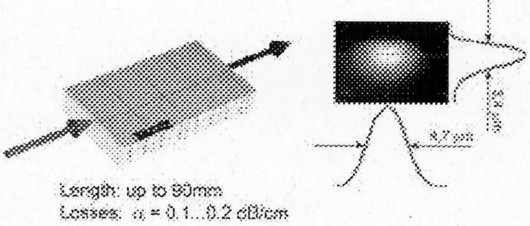

Figure 1: Left: structure of the Ti:PPLN-waveguide with microphotograph of the selectively etched surface; right: intensity distribution of the TM-mode

On a commercially available 0.5mm thick, 4"-diameter Z-cut Lithium Niobate wafer strip waveguides were fabricated by indiffusion (8.5h @ 1060°C) of photolithographically defined 7μm wide, 82mm long Ti-stripes along the X-axis of the crystal. Afterwards, the microdomain structure of 16.6μm periodicity was generated by electric field assisted poling. Details of the field-assisted poling process are reported elsewhere /3/. Finally, the endfaces of the waveguide were polished to allow endfire coupling of signal- and fundamental waves, respectively. In addition, the endfaces have been AR-coated to avoid Fabry Perot interference effects. The ends of the fibre pigtails are mounted on micromanipulators with a separation of fibre- and waveguide endfaces of a few micrometers. In this way the Ti:PPLN-converter and the pigtails are thermally decoupled allowing sample temperatures up to 200°C. Such elevated temperatures have been used to avoid photorefractive damage. Moreover, epoxy-free coupling does not limit the power levels of both, pump and signal. Typical fibre-to-fibre insertion losses of the device after alignment are about 5dB for TM-polarization (3.5dB for TE-polarization).

Single channel conversion

Single channel conversion has been performed using two external cavity lasers (ECLs), one as the fundamental source at 1556.1nm and the other one as the signal source at 1559.8nm wavelength. The power of both was boosted with EDFAs. Pump and signal radiations were multiplexed using an arrayed waveguide grating (AWG) of 200GHz channel spacing with about 3dB insertion loss. 175mW of fundamental power and 10mW of signal power were fed to the input pigtail of the Ti:PPLN-wavelength converter operated at 188.5°C. The TM-polarization was adjusted using polarization controllers.

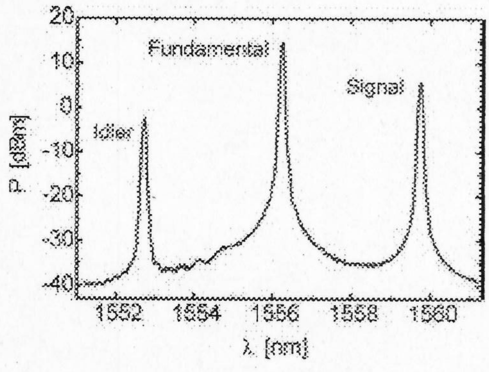

Figure 2: Output spectrum of the Ti:PPLN-wavelength converter for single channel conversion

Fig. 2 shows the measured output spectrum of the converter. 0.5mW of idler (converted signal) power at 1552.8nm wavelength have been generated. This is to our knowledge the highest power level of a wavelength converted signal reported to date. The conversion efficiency defined as the ratio of generated idler power to transmitted signal power is -8dB compared to -6dB of numerical simulations.

Multi-channel conversion

To demonstrate simultaneous multi-channel conversion we multiplexed two DFB-lasers (1549.4nm, 1551.1nm), one ECL (1547.6nm), and an actively modelocked fibre laser (1552.8nm, 4.5ps pulse width (FWHM) at 10GHz pulse repetition frequency) as four signal channels together with another boosted ECL (1556.3nm) as fundamental source (all are at ITU-wavelengths). This time a conversion to longer wavelengths was performed. Fig. 3 shows the output spectrum of the converter. A slightly lower conversion efficiency of -10dB was achieved. By switching individual signal channels no measurable change in efficiency was observed. There was also no difference in conversion efficiency for cw- and pulsed channels. The conversion bandwidth is about 55nm (FWHM).

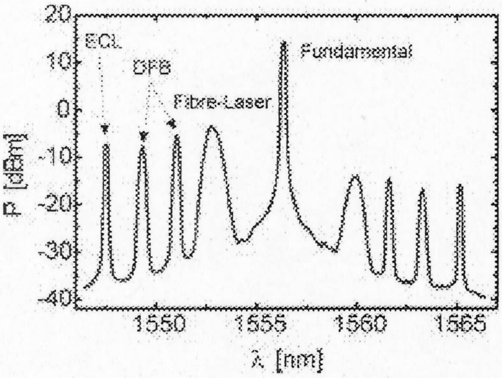

Figure 3: Output spectrum of the Ti:PPLN-wavelength converter for multi-channel conversion

Transmission of converted 40Gbit/s RZ-data

The excellent performance of the device enabled a transmission experiment using converted data from a 4×10Gbit/s OTDM-transmitter (1561.1nm wavelength, 4.5ps pulses of 0.3 time-bandwidth-product, 2^7-1 pseudo-random bit sequence) as signal. The λ-converter was operated at 194.2°C to adjust phase matching for SHG at 1557.8nm, the wavelength of the ECL used as fundamental source. Amplified and filtered (to reduce ASE-noise) data and the fundamental radiation were combined using a 3dB coupler, then commonly amplified in a single EDFA and launched after polarization control into the converter. To allow an adjustment of the relative power levels of the signal and the fundamental radiations a variable attenuator was inserted in the signal branch in front of the 3dB coupler. With 21.1dBm (129mW) of fundamental power and 18.7dBm (74mW) of average signal (data-) power incident to the converter -0.85dBm (0.82mW) of converted signal at 1554.4nm was generated. The converted signal was bandpass filtered to block the transmitted unconverted signal and fundamental radiations and to suppress amplifier ASE. Then the converted data were launched into a fibre transmission line comprised of 5 spans of 100km of NZDS-fibre. A 100% compensation of the chromatic dispersion was achieved by means of dispersion compensating fibres (DCF). The input power level to each fibre span was set to +8dBm. At the receiver side after clock recovery one 10Gbit/s channel was selected using an electro-absorption modulator as gate (see eye diagrams as inset in Fig. 4). The demultiplexed data were investigated in terms of bit-error-ratio (BER) and compared to the back-to-back (btb) BER of the unconverted and of the converted data.

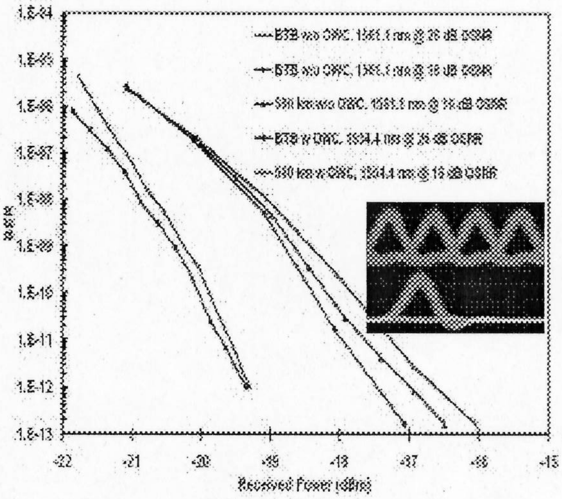

Figure 4: Bit-error-ratio as function of the received optical power, details see legend; inset: eye-diagrams after 500km of transmission before and after demultiplexing

In Fig. 4, the different BER-graphs correspond to the following situations: btb-configuration of the converted data (circles) for an OSNR of 26dB (@ 2 nm resolution bandwidth), btb of unconverted data at the same 26dB OSNR (crosses), btb at 16dB OSNR (diamonds) and after the line for both, unconverted (triangles) and converted data (stars). No BER-penalty between the btb-measurements of the converted and unconverted data was observed. After 500km the penalty at BER = 10^{-13} remains below 1dB for both, the converted and unconverted channel.

This very promising result confirms that the conversion is completely transparent and does not affect the signal quality. Moreover, simultaneous transmission of several converted data channels over 500km of NZDS-fibre should be possible.

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references

/1/ I. Brener et al., Electron. Lett. 36 (2000) 1788

/2/ M. H. Chou et al. IEEE Photonics Technol. Lett. 11 (1999) 653

/3/ G. Schreiber et al. accepted for publication in Appl. Phys. B (2001)