Proc. 2004 Annual Meeting IEEE Laser & Electro-Optics Society (LEOS 2004), Puerto Rico, November 2004, paper ThL2

Direct Measurement of the Diffraction Relation in Waveguide Arrays

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Abstract: High quality one-dimensional waveguide arrays were fabricated and characterized. Second-harmonic generation in the array waveguides proved to be an ideal tool for a direct measurement of the discrete diffraction relation.

OCIS codes: (190.2620) Nonlinear Optics, frequency conversion; (130.3120) Integrated optics devices

1. Introduction

Recently one- and two-dimensional waveguide arrays were used as host for studying nonlinear localization phenomena in lattices [1, 2]. The reliability and quality of the results of these experiments depend strongly on the quality of the waveguide arrays. Particularly critical are the uniformity of the linear coupling between the array waveguides and a minimization of any coupling defects. For quadratic nonlinear systems with multi-wavelength parametric interactions also the uniformity of the wavevector mismatch in the waveguides is an important parameter for the successful investigation of nonlinear beam dynamics. Taking advantage of the unique discrete diffraction properties for light propagation in arrays [3] in combination with second-harmonic generation (SHG) in the individual waveguides we characterized both, the linear array properties like diffraction relation and the spatial uniformity of the nonlinearity. We fabricated arrays with properties in excellent agreement to the theoretical predictions. The measurement methods provide information on the spatial distribution of the array properties without destruction of the sample. The technique is restricted to quadratic nonlinear arrays.

2. Samples and experimental conditions

On 5- and 7-cm-long Z-cut lithium niobate crystals arrays of linearly coupled waveguides were fabricated by in-diffusion of 7-µm-wide and 98-nm-thick titanium stripes for 8.5 hours at a temperature of 1060 °C. Each array consists of 101 waveguides. Arrays with waveguide separations between 12 and 15 µm have coupling lengths between 4 and 16 mm. For phase-matching SHG between the fundamental wave (FW) and the second-harmonic (SH) TM_{00} waveguide modes a QPM grating with a period of 16.751 µm was written in the sample by electric field poling. The sample could be heated in an oven up to 250 °C to study also index disturbances and resulting inhomogeneities of the linear coupling and the wavevector mismatch distribution due to photorefractive and pyroelectric effects. The array waveguide modes were excited with a cw laser diode with a tunable wavelength between 1460 and 1590 nm. The input beam was elliptically shaped with variable widths from 3.5 to 64 µm (FWHM) and 3.5 µm high and focused onto the polished front facet of the waveguide array. In order to manage the discrete diffraction properties an adjustable phase-difference of the FW modes in adjacent waveguides was realized by appropriate tilting the input beam [3]. A phase difference of π of the modes in neighboring waveguides corresponds to a beam tilt of ~3 degree. The array output was separated by wavelength and imaged on cameras. FW and SH output pictures and powers were measured for varying input beam width, input beam tilt and wavelength.

3. Experimental results

From the diffraction pattern at the output of the arrays with single waveguide excitation we determined the coupling lengths of each array. A typical discrete diffraction pattern is shown in Fig. 1a. These patterns do not change dependent on the position in the array and agree very well with theoretical predictions, which is an indication for an excellent uniformity of the coupling in the whole sample with no coupling defects. Fig. 1b shows the dependence of the coupling length between waveguides versus wavelength for different arrays. An excitation of the array with Gaussian beams with adjustable tilt allows to check indirectly the dispersion relation by observing the output beam position and shape. For an input phase difference of $\pi/2$ between modes in adjacent waveguides discrete diffraction disappears in first order. Fig. 1c shows the output of a diffraction-less propagating beam. The observed asymmetric beam distortion is caused by higher-order diffraction terms.

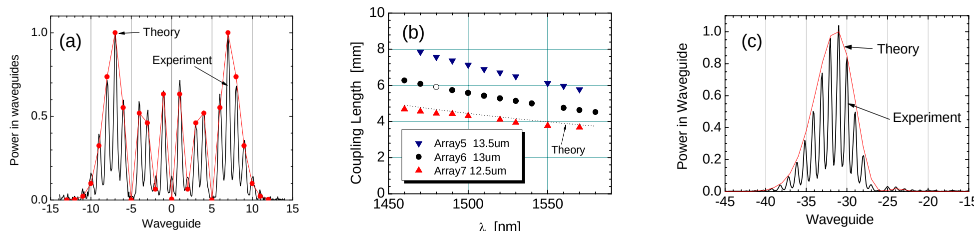

Fig. 1. a) Diffracted output of a waveguide array with single waveguide excitation. b) Coupling length of different arrays versus wavelength. c) Diffraction-less beam output with distortions due to higher-order diffraction (beam input at pos. 0).

A proper plot of SHG tuning curves with a Gaussian input beam dependent on the input beam tilt provides directly the dispersion relation of the array. Because the tightly confined SH modes in the individual array waveguides are not coupled the wavevector β_{SH} of the SH is independent on the beam tilt. In contrast, the FW Gaussian beam has a wavevector β_{FW} that is dependent on the beam tilt according to the dispersion relation of the array. Therefore, the phase-matching wavelength (vanishing wavevector mismatch $2\beta_{FW}$-β_{SH}=0) can be transformed into the dispersion relation which describes β_{FW} versus the transverse wavevector. The transverse wavevector is directly connected to the phase difference between modes in neighboring waveguides. Fig. 2a shows a typical result that resembles the well known cosine-shaped diffraction curve of an array. The agreement to the diffraction relation that was measured indirectly by beam shift and beam broadening is excellent.

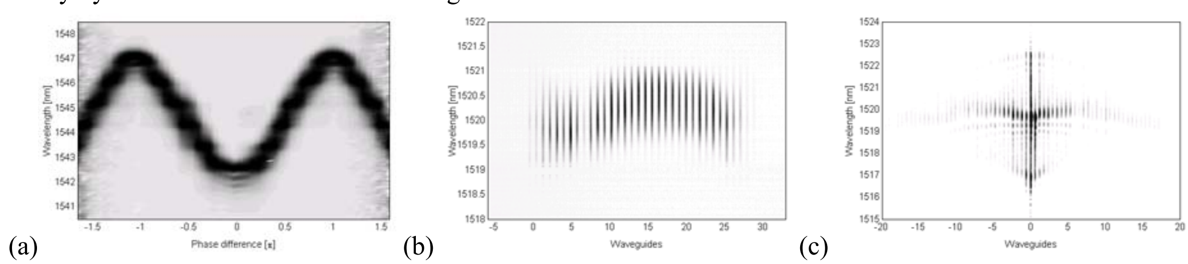

Fig. 2. a) SHG tuning curves for Gaussian beams in the array dependent on the phase-difference between modes in adjacent waveguides. b) SHG tuning curves in the individual array waveguides for diffraction-less beam propagation. c) SHG tuning curves in the individual array waveguides for single channel excitation.

Measuring SH tuning curves in all individual array waveguides separately provides information on the spatial uniformity of the wavevector mismatch in the sample. Exciting a diffraction-less beam that crosses the array, SH output from different waveguides is generated at different positions along the propagation. Therefore phase-matching at positions inside the sample can be measured and complete phase-matching maps of the arrays were obtained. Fig. 2b shows a phase-matching profile in a part of an array. Fig. 2c shows a result of a similar experiment. With a single excitation the whole spectrum of eigenmodes of the array is excited. The SHG tuning curves in the individual waveguides provide also insight in the phase-matching distribution in the array, however, the analysis of this result is more complex.

4. Conclusion

We found new concepts for the characterization of the quality, i.e. the homogeneity of linear and nonlinear properties of waveguide arrays. For the first time the diffraction relation of discrete diffraction was measured directly. The authors gratefully acknowledge support by the European Commission (IST/FET) and an U.S. Army Research Office Multidisciplinary University Research Initiative.

5. References

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