A new method of second harmonic generation based on light tunneling between waveguide channels

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***Abstract*— A new method for obtaining second harmonic generation is proposed. Tunneling between coupled waveguides provides the required quasi-phase matching. Its simple technological implementation and high conversion efficiency make this novel approach a competitive alternative to existing methods.**

Keywords-component; second harmonic generation; quasi-phase matching; channel waveguides; coupled waveguides

I. Introduction

Phase matching is key for efficient nonlinear frequency conversion. As material dispersion usually breaks the phase matching condition, different quasi-phase matching (QPM) procedures have been developed, usually based on a periodical or chirped variation of the nonlinear susceptibility [1,2]. An efficient technique to get QPM is by periodically poled structures, although it requires the poling of the crystal, either during its growth or in the device fabrication process [3,4]. Also, periodic poling presents some interferences with waveguides fabrication techniques [5].

In this paper, a different approach is taken for second harmonic generation (SHG). Instead of varying the material parameters, the intensity of the fundamental beam is modulated to avoid the destruction of the generated harmonic, thus providing QPM. This modulation can be obtained thanks to the light intensity transfer between two sufficiently close waveguides.

II. Theoretical background

A. Second harmonic generation

When a fundamental wave with frequency ω_1 and wavelength λ_1 interacts with the second-order nonlinear susceptibility of a material a polarization wave at the second-harmonic frequency $\omega_2 = 2\cdot\omega_1$ is produced. Since the polarization wave is forced by the fundamental wave, it travels with the same velocity, determined by n_1, the index of refraction at the fundamental wavelength. The polarization wave generates a second-harmonic wave which travels at a velocity determined by its index of refraction (n_2). In general $n_2 > n_1$ because of dispersion in the material, so that the fundamental and second-harmonic waves travel at different phase velocities [2]. So the field intensities of the fundamental wave and the second harmonic are coupled. The coupling system of equations is obtained from the nonlinear wave equation and is the following:

$$\frac{dA_1}{dz} = \frac{2i\omega_1^2 d_{eff}}{k_1 c^2} A_2 A_1^* \; e^{-i\Delta kz}$$
$$\frac{dA_2}{dz} = \frac{i\omega_2^2 d_{eff}}{k_2 c^2} A_1^2 e^{i\Delta kz} \qquad (1)$$
$$\Delta k = 2k_1 - k_2$$

where $A_{1,2}$ are the field amplitude of the fundamental and the second harmonic, respectively, d_{eff} the nonlinear coefficient of the material and k the wave vector. [6].

B. Waveguide tunneling

It is known that when two identical channel waveguides are sufficiently close to each other, the electromagnetic field of the light traveling across one of the channels reaches the other one. Then, energy transfer between the channels takes places resulting in a periodic transfer of light from one channel to the other one. So the field amplitude of the light in one channel as it travels in the z-direction can be expressed as:

$$\frac{dA}{dz} = -\frac{2\pi}{L}\sin\left(2\pi\frac{L}{z}\right) \qquad (2)$$

where A is the field amplitude and L the period of the light in one channel. L depends on the characteristics of the waveguides (index profile, index depth, distance between channels, etc.)

C. Quasi-phase matching via channel waveguides coupling (CWG QPM).

The SHG of a waveguide can be improved dramatically by using two channel waveguides to obtain QPM. In this paper we have solved the system of equations shown in (1) but taking

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into account a change of the field amplitude of the fundamental beam as shown in (2).

With this configuration the fundamental wave is traveling between the two channels periodically. When the spatial frequency of the fundamental wave matches the second harmonic we obtain QPM and the intensity of the second harmonics increases. It is important to notice that both channels produce second harmonic and the second harmonic efficiency at the output is the addition of both channels.

The equations shown here are general and can be used with any nonlinear optical material. However, in the next section the parameters of the lithium niobate are used to show the ratio A_1/A_2 that can be obtained with this new method.

III. RESULTS

For the sake of generality the data will be shown as a function of L. However, the other parameters must be set. In order to obtain some results we have chosen the values of the parameters of $LiNbO_3$.

TABLE I. $LiNbO_3$ parameters

Parameter	***Value***
$d_{eff} = d_{33}$	30x10-6 μm/V
λ_1	1.064 μm
n_1, n_2	2.175, 2.251
I_1	$3\cdot10^7$ W/m^2
Propagation length	5 cm

In Fig. 1 the values of the coherence length for the best QPM can be observed. CWG and PPLN QPM for the parameters mentioned above are compared. CWG QPM and first order PPLN QPM occur at the same coherence length, detail of these peaks can be seen in Fig 1b. The maximum SHG is obtained for the PPLN at 6.9 μm but this configuration is very difficult to achieve experimentally [6]. The following maximum is the one obtained with CWG QPM. The next one is obtained with the PPLN at second order.

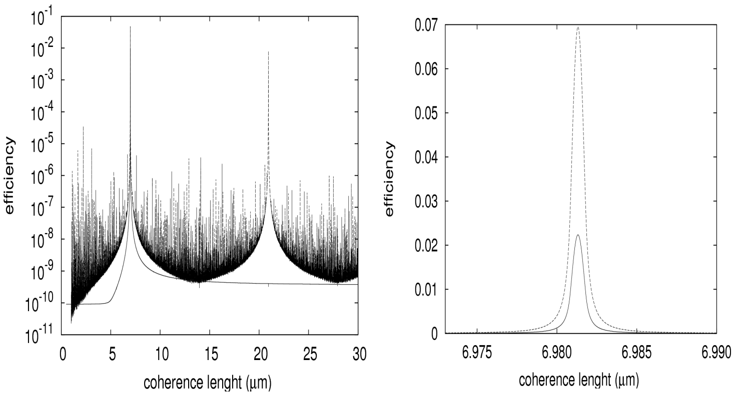

Figure 1. Efficiency of SHG as a function of coherence length in CWG-QPM (continnous line) and first and third order of PPLN-QPM (dashed line).

In Fig 2, the amplitude of SHG is shown as a function of the propagation length (z) for the first-order PPLN, CWG and second-order PPLN, respectively. Fig 2b shows a small range of z to see how the second harmonic grows. The first-order PPLN always increases while the second-order PPLN exhibits a decay at each domain region. It must be noted, however, that obtaining first-order PPLN presents technical challenges that are difficult to overcome [6]. The CWG QPM grows monotonically and offers a second harmonic efficiency remarkably better than second-order PPLN, while being technically more feasible than first-order PPLN.

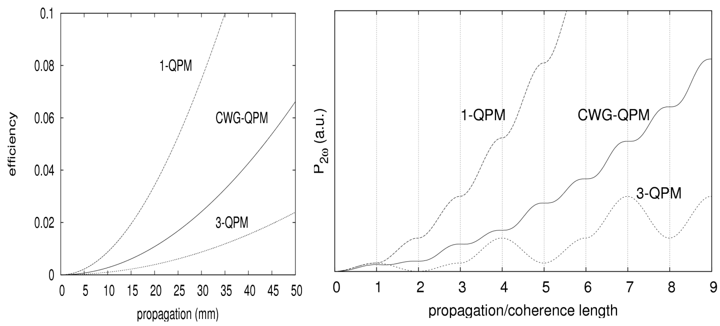

Figure 2. Efficiency for SHG for the first coherence lengths for CWG-QPM and first and third order of PPLN-QPM.

IV. CONCLUSION

We propose a new method for SHG in waveguides, very easy to implement from a technological point of view and with a high conversion efficiency. When compared with PPLN SGH, our novel method shows conversion efficiencies that are lower than those corresponding to first-order PPLN but significantly higher than those of second-order PPLN.

These results and the technical difficulties associated to first-order PPLN, make our proposed method a very competitive alternative for the design of waveguide frequency-doubling devices.

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