



HAL
open science

C-Band Translation by Second-Harmonic Generation in an Orientation-Patterned Gallium Phosphide Waveguide

Brieg Le Corre, Antoine Lemoine, Abdelmounaim Harouri, Luc Le Graciet, Bruno Gérard, Sylvain Combrié, Arnaud Grisard, Grégoire Beaudoin, Isabelle Sagnes, Konstantinos Pantzas, et al.

► **To cite this version:**

Brieg Le Corre, Antoine Lemoine, Abdelmounaim Harouri, Luc Le Graciet, Bruno Gérard, et al.. C-Band Translation by Second-Harmonic Generation in an Orientation-Patterned Gallium Phosphide Waveguide. Optica Advanced Photonics Congress, OPTICA, Jul 2024, Québec (Canada), Canada. hal-04711999

HAL Id: hal-04711999

<https://hal.science/hal-04711999v1>

Submitted on 27 Sep 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

C-Band Translation by Second-Harmonic Generation in an Orientation-Patterned Gallium Phosphide Waveguide

B. Le Corre^{1,2}, A. Lemoine², A. Harouri¹, L. Le Gratiet¹, B. Gérard³, S. Combrié⁴, A. Grisard⁴, G. Beaudoin¹, I. Sagnes¹, K. Pantzas¹, G. Patriarche¹, Y. Léger²

¹Centre de Nanosciences et de Nanotechnologie, CNRS, 91120 Palaiseau, France

²Univ Rennes, INSA Rennes, CNRS, Institut FOTON - UMR 6082, F-35000 Rennes, France

³III-V Lab, 91767 Palaiseau, France

⁴Thales Research and Technology, 91767 Palaiseau, France
brieg.le-corre@c2n.upsaclay.fr

Abstract: Orientation-patterned gallium phosphide (OP-GaP) is studied for frequency combs conversion from C-band to visible. Simulations of periodic and chirped OP-GaP waveguides nonlinear response are presented. Design rules for future developments are established using this study. © 2024 The Author(s)

1. Introduction

Many applications, such as spectroscopy [1], require frequency combs centered in the visible range. Technologically mature combs are centered around 1.55 μm . Translating these combs from the infrared to the visible using non-linear optics is a promising way of overcoming this bottleneck. Thanks to its intrinsic properties, such as its high non-linear coefficients of order 2 and 3 and its wide transparency range (0.5 - 12 μm), OP-GaP is of particular interest in integrated photonics, for the conversion of frequency combs to the visible: in periodic structuring, OP-GaP allows efficient spectral translation from a telecom frequency to the visible [2]. However, the bandwidth of the conversion spectrum remains limited to a small range centered around a main frequency. In the present contribution, we propose to modulate the spectral response of the OP-GaP, by widening the conversion bandwidth of the device in order to achieve an optimal translation from the C-band to the visible. Numerical simulations are carried out to compare two OP-GaP guide designs. An optimization criterion is established to guide the fabrication of OP-GaP waveguides for comb translation. Initial designs for new OP-GaP guides are discussed.

2. C-band translation by second-harmonic generation

The OP-GaP waveguides considered here are suspended, shallow ridge, 3 μm high, with a lateral etch depth of 1.6 μm , and 4.5 μm wide. The two designs under consideration differ in the quasi-phase matching (QPM) criterion. In a periodic OP-GaP guide, the QPM period, noted Λ , required to generate a maximum second harmonic (SH) signal at a fundamental wavelength λ , is given by $\Lambda\lambda^{-1} = 2\Delta n/\lambda$, where Δn is the difference between the indices seen by the fundamental and the SH. In chirped guides [3], the QPM period, depends on the position in the guide and varies from $\Lambda_{1.565} = 5.22 \mu\text{m}$ to $\Lambda_{1.53} = 4.88 \mu\text{m}$, as follows:

$$\Lambda^{-1}(z) = \frac{\Lambda_{1.53}^{-1} - \Lambda_{1.565}^{-1}}{L_{\text{wg}}} z + \Lambda_{1.565}^{-1} \quad (1)$$

In order to evaluate the efficiency of SH generation in these guides, we numerically solve the system of equations that couples the complex amplitudes of the fundamental and SH modes during propagation, as reported in [4], but taking into account propagation losses in the medium. In our model, the propagation losses of the fundamental and the SH will be considered as equal to each other [2].

To achieve our goal, we need to maximize both the bandwidth (BW) of the conversion spectrum and the average SH signal on the C-band. In order to obtain a compromise between these two parameters, we will target the maximization of the product of these two parameters. Figure 1(a, b) show a graphical representation of the product of the average SH signal and the BW for 500 μm long guides with losses of 15 dB/cm. Figure 1(c – h) groups together maps showing the evolution of the average SH signal, the BW and the product of the two as a function of two parameters: propagation losses in the guide and guide length. We note that, for both types of guides, an increase in guide length combined with a decrease in losses leads to an increase in the average SH signal. However, the average SH signal of the periodic OP-GaP is lower than that of the chirped OP-GaP, even at negligible losses. Furthermore, at a fixed non-zero loss level, the average SH signal in a periodic guide reaches its maximum at a lower critical guide length than in a chirped guide. While the conversion BW of a periodic waveguide is always very low, regardless of losses, that of a chirped waveguide shows a dependence on losses. The length of the chirped guide

must therefore be sized according to the losses. For example, a chirped guide with a loss level of 30 dB/cm sees its conversion BW degraded from 60% to 40% of the C band, when its length exceeds 1 mm.

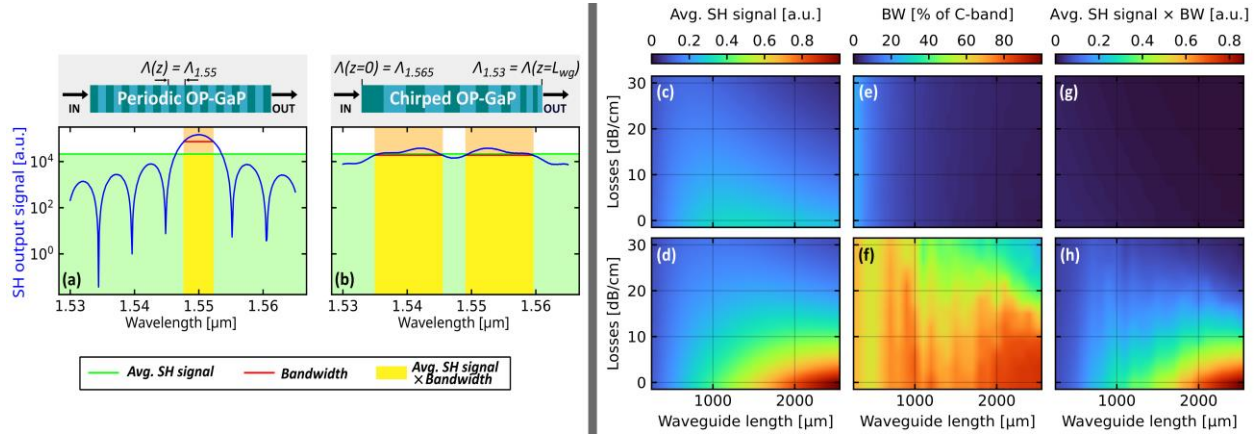


Fig. 1. Graphical representation of the average SH signal - bandwidth product, for a 500 μm long (a) periodic and (b) chirped guide with losses of 15 dB/cm. Average SH signal in (c) periodic, (d) chirped waveguides. Bandwidth in (e) periodic, (f) chirped waveguides. Average SH signal - bandwidth product in (g) periodic, (h) chirped waveguides.

3. Fabrication process

First, GaP membranes are grown by metalorganic vapor phase epitaxy (MOVPE) on gallium arsenide (GaAs) substrates. The two membranes are then bonded by thermal compression bonding. In this way, the orientation of the upper GaP membrane is reversed with respect to the lower membrane's one. After top GaAs substrate removal, the QPM period is defined by electron lithography and the membranes are etched to expose the two orientations in alternating and chirped fashion, thus fabricating the OP-GaP template for chirped waveguides. MOVPE regrowth is done to obtain the desired thickness. Finally, this step is followed by a polishing step to flatten the OP-GaP surface. Shallow ridge waveguides are then designed from OP-GaP template according to the steps described in Figure 2. A first deep etching step is used to reach the layer beneath the GaP. This is followed by a second etching step to define the guide. Finally, the GaP is under-etched to obtain the suspended chirped OP-GaP waveguide.

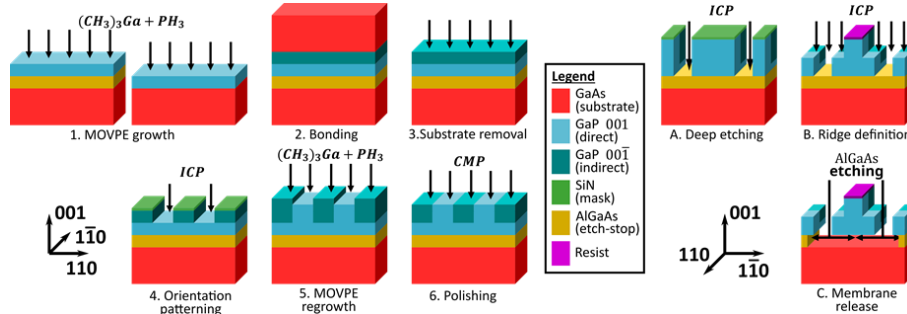


Fig. 2. Step 1 to 6 – Fabrication of an OP-GaP template. Step A to C – waveguide definition.

4. Acknowledgement

The authors acknowledge RENATECH for technological support. This research was supported by "France 2030" with the French National Research agency OFCOC project (ANR-22-PEEL-0005) and by the EUROPEAN Union (ERC-2022-COG, PANDORA, 101088331).

5. References

- [1] R. A. McCracken *et al.*, "A decade of astrocombs: recent advances in frequency combs for astronomy". *Opt. Express*, vol. 25, no 13, pp. 15058-15078, 2017.
- [2] K. Pantzas *et al.*, "Continuous-Wave Second-Harmonic Generation in Orientation-Patterned Gallium Phosphide Waveguides at Telecom Wavelengths", *ACS Photonics*, vol. 9, no 6, pp. 2032-2039, 2022.
- [3] T. Suhara and H. Nishihara, "Theoretical analysis of waveguide second-harmonic generation phase matched with uniform and chirped gratings", *IEEE J. Quantum Electron.*, vol. 26, no 7, pp. 1265-1276, 1990.
- [4] Y. Jeong and B. Lee, "Matrix analysis for layered quasi-phase-matched media considering multiple reflection and pump wave depletion", *IEEE J. Quantum Electron.*, vol. 35, no 2, pp. 162-178, 1999.