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Linear and Nonlinear Characterization of Vertical Orientation-Patterned Gallium Phosphide Waveguides for Second Harmonic Generation

A. Lemoine¹, B. Le Corre^{1,2}, L. Morice¹, A. Harouri², L. Le Gratiet², G. Beaudoin², J. Le Pouliquen¹, A. Grisard³, S. Combr  ³, B. G  rard⁴, C. Cornet¹, Y. Dumeige¹, K. Pantzas², I. Sagnes², Y. L  ger¹

¹Univ Rennes, INSA Rennes, CNRS, Institut FOTON - UMR 6082, F-35000 Rennes, France

²Centre de Nanosciences et de Nanotechnologie, CNRS, 91120 Palaiseau, France

³Thales Research and Technology, 91767 Palaiseau, France

⁴III-V Lab, 91767 Palaiseau, France

Author e-mail address: antoine.lemoine@insa-rennes.fr

Abstract:

1. Introduction

Non-linear photonics is now ubiquitous in many application fields such as telecommunications and quantum technologies. In the framework of octave-spanning spectral conversion, where second-order processes are most relevant, the ability to pattern periodically the nonlinear response of waveguides, achieving the so-called quasi-phase matching (QPM) condition, has led to the demonstration of the highest second harmonic generation (SHG) efficiencies in integrated structures [1,2], at the cost of elaborate fabrication process or limited poling capabilities. The main alternative to QPM in nonlinear photonic waveguides consists in modal phase matching which generally suffers from a small mode overlap, strongly impacting the SHG efficiency. Recently, novel designs of nonlinear waveguides were proposed, based on the vertical control of the material susceptibility rather than its periodic modulation along the propagation length, unlocking modal phase matching configurations with large mode overlap [3,4]. Here we present the realization of vertical orientation-patterned gallium phosphide (VOP-GaP) waveguides by direct bonding, and the first linear and nonlinear characterization for such structures in the framework of SHG.

2. Design and realization of a VOP-GaP waveguide.

In this work, we developed VOP-GaP nano-waveguides for SHG, allowing us to investigate the conversion of a TE₀₀ pump mode into a TM₁₀ SH mode. In the absence of crystal polarity engineering, this non-linear process has a negligible efficiency due to the odd vertical profile of the SH mode (fig 1.a). Reversing the crystal orientation of the material between the lower and upper parts of the waveguide allows the nonlinear polarization profile to match with the TM₁₀ symmetry of the output mode (fig 1.b), resulting in a mode overlap close to the optimal value. To fabricate such a device, two GaP thin films were grown by MOVPE on a GaAs substrate, bonded by direct adhesion and transferred onto insulator. The guides were then defined using electron lithography and dry etching [1] (fig 1.c).

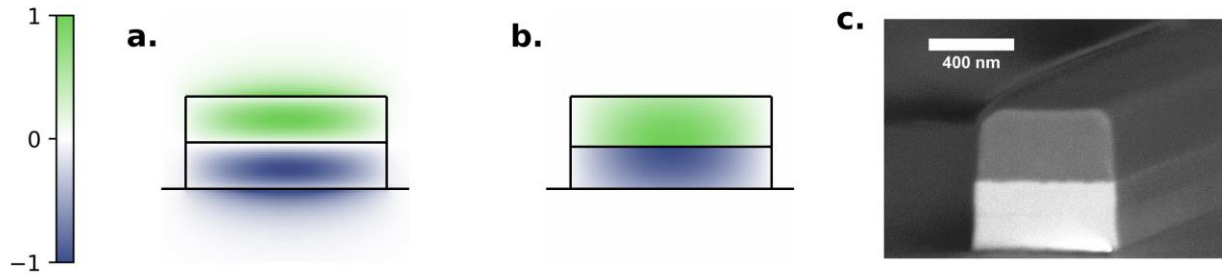


Figure 1 a. Mode $TM_{10,y}$ propagating in a VOP-GaP waveguide b. Non linear polarization in a VOP-GaP waveguide c. SEM image of a clived VOP-GaP waveguide

3. Linear and nonlinear characterization

We used Fabry-Perot (FP) fringe contrast measurements [5] to assess the propagation losses in the VOP-GaP guides at telecom wavelength. The FP fringes shown in figure 2.a were obtained by recording the output signal of the waveguides while scanning the wavelength of the CW injection laser. Their contrast is directly linked to the losses in the cavity, allowing us to estimate the propagation losses to 50 dB/cm. This value is higher than the one of OP-GaP waveguides [1] but remains competitive given the sub-micrometer dimensions of the guides. Losses in the visible range were estimated by imaging the light scattered at the surface of the sample under laser injection at 780nm (fig 2.b). Losses around 50 dB/cm are also measured in this wavelength range. Taking these values into account and based on the dispersions of the TE₀₀ and the TM₁₀ modes of a VOP-GaP waveguide with optimized dimensions, the theoretical SHG conversion efficiency of such devices can be estimated to a 6300 %/Wcm². Experimentally, three SHG phase-matching configurations were observed in these VOP-GaP waveguides at 1320, 1400 and 1488nm under pulsed excitation, the SH power dependence of the latter being presented on Fig 2.d. These different phase matching configurations will further be discussed and compared with state-of-the-art quasi-phase matching efficiencies in more mature photonic platforms like PPLN integrated waveguides [2].

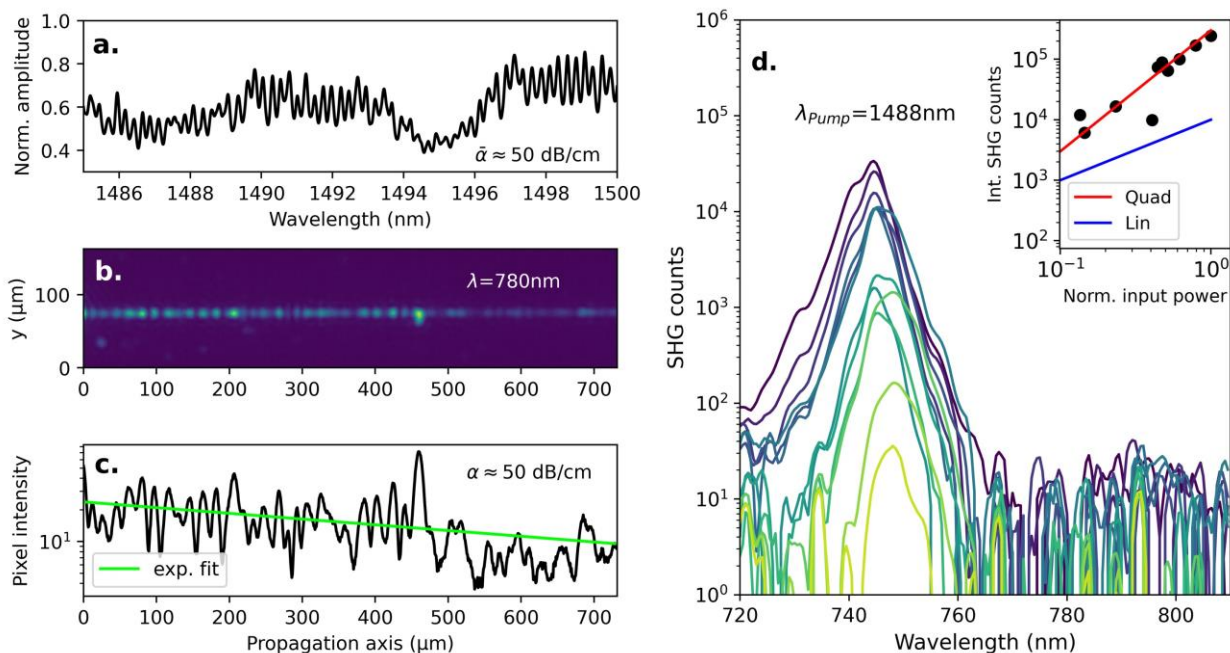


Figure 2 a) FP fringes of the cavity formed by the VOP-GaP waveguides with cleaved facets at telecom wavelength. b) Top view image of the light scattered from the propagating mode in a VOP-GaP waveguide at 780nm. c) Line profile of b) for loss evaluation. d) SH spectrum observed under pulsed excitation at 1488nm. The insert shows the quadratic evolution of the SH power with pump power, typical of 2nd order non-linear effects.

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4. References

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