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Gallium Phosphide Platforms for Integrated Photonics

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Abstract: Here we compare different Gallium Phosphide photonic platforms in the framework of non-linear photonic integration. This comparison is firstly carried out through the evaluation of propagation losses within nano-waveguides in the near infrared. © 2024 The Author(s)

1. Introduction

Gallium Phosphide (GaP) is a III-V semiconductor with many advantages for integrated non-linear photonics thanks to its wide transparency band (visible, NIR, MIR) pushing the absorption threshold to two photons below 1100 nm, its high refractive index ($n_0 > 3$), its indirect gap, its non-centrosymmetric geometry which results in a second-order non-linearity $\chi^{(2)}$ as well as a large third-order non-linearity $\chi^{(3)}$ ($n_2 = 1.2 \times 10^{-17} \text{ m}^2/\text{W}$ [1]).

GaP photonic devices can be produced from the growth of GaP on different substrates like Gallium Arsenide (GaAs [2]), Silicon (Si [3]) or on native substrates [4]. The GaP/GaAs platform shows good crystal quality despite a high rate of dislocations due to the lattice mismatch between the two materials. The growth of GaP on Si induces fewer dislocations but shows structural defects specific to the use of a nonpolar substrate [5]. For photonic applications purpose, the refractive index of GaAs and Si being larger than that of GaP ($n_0 = 3.27$ for GaAs and 3.5 for Si against 3.05 for GaP at 1.55 μm) the transfer of the GaP membranes to a material with a smaller refractive index such as silica is mandatory, so-called GaP-on-insulator (GaPOI). In contrast, GaP/Al_{0.7}GaP/GaP epilayers can be straightforwardly used as a monolithic photonic platform ($n_0 = 2.88$ for Al_{0.7}GaP at 1.55 μm) but this advantage is mitigated by the fluctuating quality and high cost of GaP substrates.

In this work, we investigate the impact of the photonic platform used on the propagation losses of GaP nano-waveguides and evaluate their relevance in the development of advanced GaP photonic circuits. The propagation losses in the near infrared were measured on these structures by two distinct methods: vertical diffusion imaging and Fabry-Perot fringe contrast measurement [6].

2. Fabrication processes

To fabricate GaPOI waveguides, the GaP membrane is flipped upside-down and transferred by bonding with a polymer on an insulating substrate (SiO₂/Si). The growth substrate (GaAs or Si) is then removed. Lithography and etching steps can then be similar for GaPOI nano-waveguides (Fig. 1. (a)) and GaP/AlGaP/GaP ones (Fig. 1. (b)). The waveguides are then cleaved at both sides for butt-coupling injection.

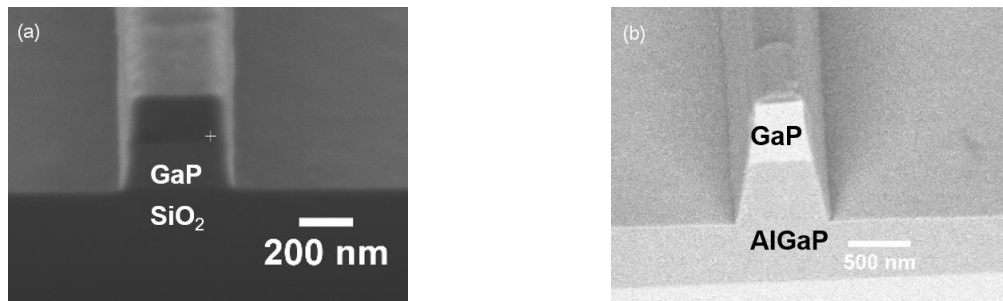


Fig. 1. (a) SEM image of GaP nanowaveguide on insulator. (b) SEM image of a monolithic structure on GaP/AlGaP/GaP.

Prior to this technological workflow, the GaP/Si platform requires an additional fabrication step. The large roughness of GaP/Si epilayers due to emerging anti-phase boundaries is typically about 8 nm RMS (Fig. 2. (a)) which is detrimental to the fabrication of low-loss waveguides. Chemical Mechanical Polishing (CMP) is thus first carried out to decrease the surface roughness of the epilayer down to 1nm RMS (Fig. 1. (b)). The technological

workflow is then identical to the case of GaP/GaAs. In these GaP/Si membranes, chemical treatment can be used to reveal the distribution of antiphase domains within the layer, that should strongly impact 2nd order non-linear properties but have negligible effect on third-order properties or linear ones (Fig. 1. (c)).

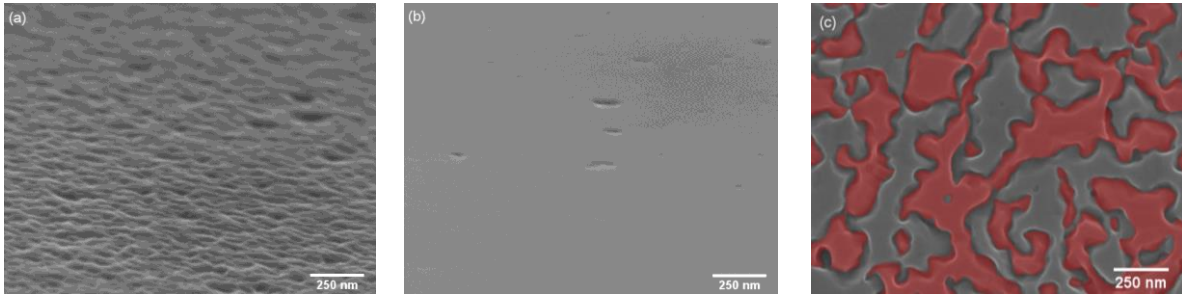


Fig. 2. (a) SEM image of the surface of a GaP membrane grown on Si. (b) SEM image of the surface of GaP after 30 min of CMP. (c) SEM image of the GaP/Si membrane after CMP and chemical treatment etching preferentially emerging anti-phase boundaries. [3]

3. Losses measurement at 800 nm

A first assessment of the propagation losses in the nanowaveguides was performed by recording the exponential decay of the light scattered along the guides under butt-coupling injection at 800nm. Due to the length of the waveguides of about 1mm, the precision of this measurement is limited and similar losses are estimated for waveguides from the GaP/GaAs and GaP/AlGaP/GaP platforms (50 ± 10 dB/cm). To obtain more quantitative measurements, the Fabry-Perot fringes of the cleaved-waveguides were analyzed by recording the output power from the guides while scanning the wavelength of the injection laser. The fringes in the output signal (Fig. 3. (a)) are in good agreement with the theoretical Free Spectral Range (FSR) of the cavity. As reported in [6], the fringe contrast then allows us to extract the spectral evolution of the propagation losses (Fig. 3. (b)). In this first generation of devices, losses are larger for GaAs-based GaPOI waveguides (48dB/cm) than for GaP/AlGaP/GaP waveguides (41dB/cm), mostly due to a large roughness of the GaP/GaAs interface (2nm RMS). These measurements are now being extended towards telecom wavelengths and on GaPOI waveguides based on the GaP/Si platform.

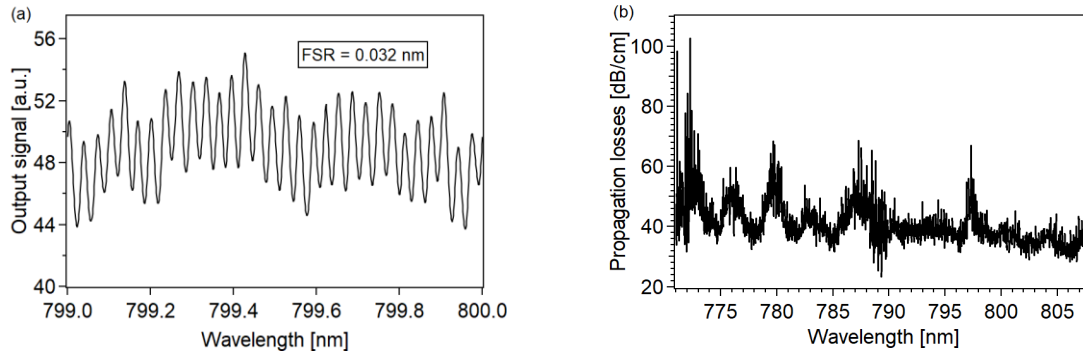


Fig. 3. (a) Signal measured at the output of a GaP/AlGaP guide at 800nm (b) Propagation losses in function of wavelength for GaP/AlGaP waveguide.

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