Frontiers in Optics + Laser Science 2023 (FiO/LS) © Optica Publishing Group 2023

Large size gallium phosphide micro-transfer printing for integrated nonlinear photonics

**Luis Reis,[1,2,*] Maximilien Billet,[1] Tom Vandekerckhove,[1,2] Fabrice Raineri,[3]
Isabelle Sagnes,[3] Konstantinos Pantzas,[3] Grégoire Beaudoin,[3] Günther Roelkens,[1]
François Leo,[2] and Bart Kuyken[1]**

[1] *Photonics Research Group, Ghent University-IMEC, 9052 Ghent, Belgium*
[2] *OPERA-Photonique, Université libre de Bruxelles, CP 194/5 Brussels, Belgium*
[3] *Centre de Nanosciences et de Nanotechnologies, CNRS, Université. Paris Sud. Paris Saclay, Palaiseau, France*

[*] *luis.reis@ugent.be*

Abstract: Gallium Phosphide has unique material properties suitable for telecom and mid-infrared applications. Using micro-transfer printing, we demonstrate a low-loss Gallium Phosphide-on-insulator integrated platform with an arbitrarily large coupon area enabling the generation of on-chip supercontinuum generation.

1. Introduction

Integrated photonics has provided the tools to realize complex optical systems in a small footprint. Most of the systems use silicon-based materials, but they are limited in terms of functionality due to material properties. They lack optical gain and second order nonlinearities. To expand the capabilities of the photonic integrated circuits (PICs), III-V semiconductors and other advanced materials are being integrated into the silicon-based PICs. One of those materials, gallium phosphide (GaP), has gathered attention recently due to its unique material properties that are particularly suitable for telecom [1] and mid-infrared [2] applications. It has a high refractive index, large second and third order nonlinear coefficients. However, current solutions for integration using die-to-wafer or wafer-to-wafer bonding [3] are limited by process constraints and it wastes expensive material. Our approach uses micro-transfer printing for heterogeneous integration, which is a back-end process, and it can be scaled for mass production. When it comes to thin films of materials such as GaP, micro-transfer printing is a versatile technique [4], but typically it can only be used to integrate small structures due to the low stiffness of the suspended coupons, or due to the limited chemical resistance required for long etch times. Here, we demonstrate a low-loss gallium phosphide-on-insulator integrated platform that can be used to transfer an arbitrarily large coupon area.

2. Micro-transfer printing of large coupons

Micro-transfer printing (µTP) [5] is an innovative technique that allows for the heterogeneous integration of micro and nanostructures made from various materials onto different target substrates. The pre-fabricated structures are picked with a PDMS stamp and printed onto the target surface with minimal post-processing requirements that are CMOS-compatible. With µTP it is possible to do mass production of integrated devices with ± 0.5 µm 3σ alignment accuracy and arrays of devices can be transferred in a single step, to achieve a high throughput.

To accommodate the requirements of applications using large structures such as spirals and racetrack resonators, large areas of thin-films are needed. To prevent the collapse of these large thin-film coupons with low stiffness, we developed a new process that keeps the coupons suspended regardless of size, by using auxiliary pillars to make the suspended distances shorter similar to a work done previously in lithium niobate [6]. Next to the support pillars there are holes to allow the hydrofluoric acid (HF) to penetrate and etch the release layer within minutes. This detail is essential because HF attacks the defects in the GaP epitaxy creating small holes if etched for too long. The process is shown in figure 1.

3. Results

A batch of 256 coupons with dimensions of 520x520 µm was produced where all of them were successfully suspended. One of them is shown on the left side of figure 2. From those 256, 48 coupons were printed onto a SiO_2 substrate without any issues. These printed coupons were used to fabricate microring resonators, spiral waveguides and optical grating couplers like the ones on the center of figure 2 used for testing measurements.

The measured waveguide loss from the fabricated structures is about 6 dB/cm. The loss was extracted from measuring the input/output power relation from waveguides with different lengths using identical grating couplers

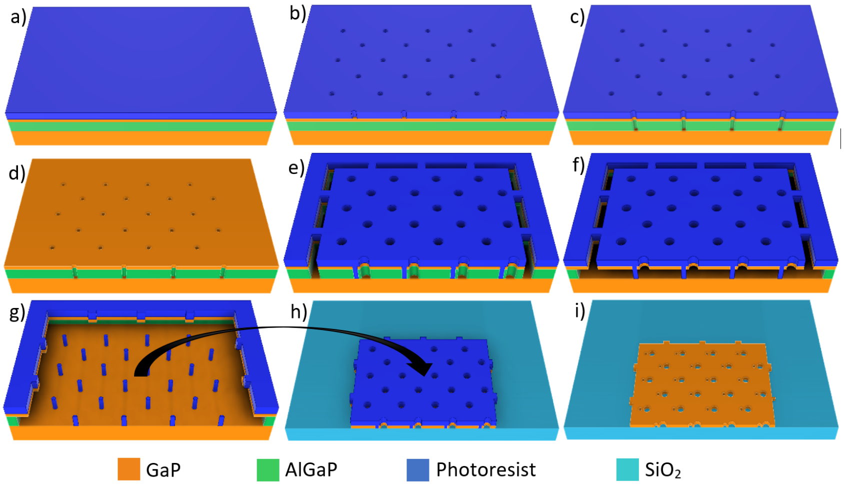

Fig. 1. Schematic cross-section view of the fabrication and transfer printing process flow. a) GaP source wafer epitaxy stack with spin coated photoresist on top. b) Holes patterned using UV lithography to allow the creation of pillars. c) Holes dry-etched with an ICP plasma tool. d) Photoresist stripped using acetone/alcohol/DI water and O_2 plasma. e) Photoresist spin coating, UV lithography patterning and ICP dry-etching to create lateral tethers and etching holes. f) AlGaP release layer etched with HF. g) and h) µTP one coupon from the source wafer to the target SiO_2 substrate. i) Photoresist stripped using acetone/alcohol/DI water and O_2 plasma.

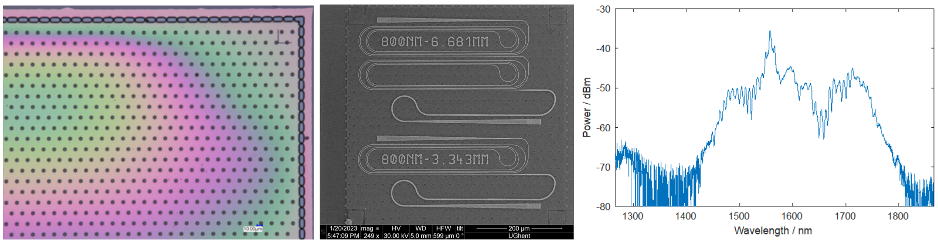

Fig. 2. Optical microscope picture of a suspended coupon still attached to the source wafer (left). SEM picture of one of the 520x520 µm printed coupons with two spirals (center). Measured supercontinuum spectrum of a GaP waveguide with dimensions l = 13 mm, w = 750 nm and h = 300 nm (right).

and also from the Q-factor of microrings. One spiral with a length of 13 mm and 750x300 nm cross-section was also used to test the nonlinearity of the GaP. Due to the anomalous dispersion of the waveguide, we coupled 270 fs pulses at 1550 nm and we were able to observe supercontinuum generation during a quick test. A peak power under 100 W inside the waveguide was sufficient to generate the spectrum shown on the right side of figure 2.

References

1. H. Wang, H. Chai, Z. Lv, Z. Zhang, L. Meng, X. Yang, and T. Yang, “Silicon photonic transceivers for application in data centers,” J. Semicond. **41**, 101301 (2020),”
2. R. Soref, ”Mid-infrared photonics in silicon and germanium.” Nature Photon **4**, 495–497 (2010),”
3. V. Snigirev, A. Riedhauser, G. Lihachev, M. Churaev, J. Riemensberger, R. N. Wang, A. Siddharth, G. Huang, C. Möhl, Y. Popoff et al., “Ultrafast tunable lasers using lithium niobate integrated photonics,” Nature **615**, 411–417 (2023),”
4. M. Billet, L. Reis, Y. Léger, C. Cornet, F. Raineri, I. Sagnes, K. Pantzas, G. Beaudoin, G. Roelkens, F. Leo, B. Kuyken, ”Gallium phosphide-on-insulator integrated photonic structures fabricated using micro-transfer printing,” Opt. Mater. Express **12**, 3731-3737 (2022),”
5. T. Vanackere, M. Billet, C. O. de Beeck, S. Poelman, G. Roelkens, S. Clemmen, and B. Kuyken, “Micro-transfer printing of lithium niobate on silicon nitride,” in 2020 European Conference on Optical Communications (ECOC), (IEEE, 2020), pp. 1–4,”
6. T. Vandekerckhove, T. Vanackere, J. De Witte, S. Cuyvers, L. Reis, M. Billet, G. Roelkens, S. Clemmen, and B. Kuyken ”Reliable micro-transfer printing method for heterogeneous integration of lithium niobate and semiconductor thin films.” arXiv preprint arXiv:2304.13760 (2023).”