Gallium phosphide transfer printing for integrated nonlinear photonics

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Integrated nonlinear photonics has drawn an increased interest as it provides scalable, compact, and low cost solutions for a large range of applications. Indeed, the high confinement of the light in integrated waveguides allows for enhanced nonlinear effects. However, mature highly nonlinear platforms such as silicon-on-insulator (SOI) circuits suffer from nonlinear losses at telecom wavelengths caused by two-photon absorption. Moreover, the platform lacks a second order nonlinear susceptibility, which is not the case for wide bandgap III-V semiconductors. Recently, gallium phosphide-on-insulator (GaP-OI) has been proposed as an efficient platform for second and third order nonlinear applications [1] and last year we demonstrated as a proof of concept the transfer printing of GaP as a versatile technique for GaP hetero-integration [2].

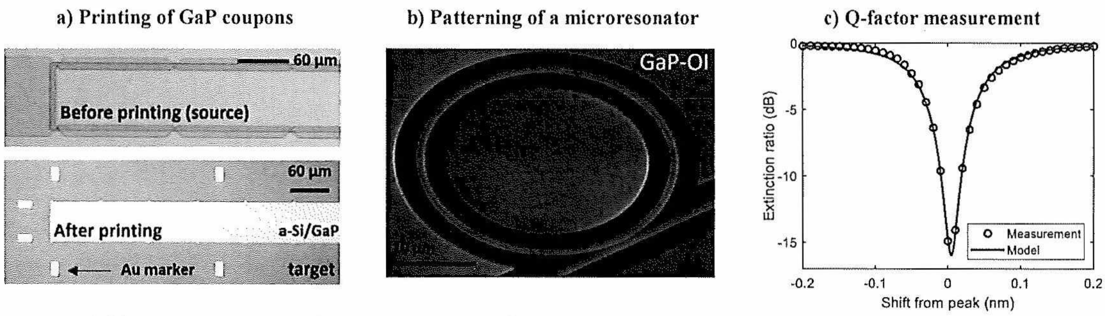

Fig. 1 (a) Process of GaP transfer printing on an insulator target. The top picture shows a suspended source coupon anchored to the epitaxial substrate via a-Si tethers and the bottom one shows a printed GaP coupon. (b) SEM picture of a microring resonator patterned on a GaP printed coupon (the ring diameter is 30 µm). (c) Measurement of a microring resonance line.

In this work we show an improved process for GaP transfer printing by using a new design of encapsulated MOCVD-grown GaP coupons allowing for drastically lower propagation losses. Here, hydrogenated amorphous silicon (a-Si) tethers are anchored into the GaP epitaxial substrate. The coupons are patterned, released and printed on an insulator target following the method described in reference [2]. Then, the encapsulation is removed with dry and wet etching and microring resonators are patterned using electron beam lithography and dry etching techniques. The oxide hard mask used for the lithography is chemically etched in a HF solution. Figure 1.(a) shows the result of the printing process. Figure 1.(b) shows a microring patterned on a printed GaP coupon. The resonances of the ring are measured at telecom wavelengths using a continuous wave tunable laser. The best Q-factor extracted from extinction ratio measurements, as shown in Figure 1.(c) for a ring-waveguide of 1 µm width and 300 nm height, is around 25 000, corresponding to propagation losses of 1.2 dB/mm for the fundamental TE mode [3]. These results pave the way for highly versatile hetero-integration of GaP as a nonlinear material on complex integrated photonic circuits.
To prove the efficiency of our platform for nonlinear applications, we will show experimental results of quasi-phase-matched (QPM) second harmonic generation (SHG).

This work has been funded by the "European Research Council (ERC)", the Belgium "Fonds de la Recherche Scientifique (FNRS)", the French ANR-17-CE24-0019 ORPHEUS and the French RENATECH network.

References

[1] D. J. Wilson, K. Schneider, S. Hönl, M. Anderson, Y. Baumgartner, L. Czornomaz, T. J. Kippenberg, and P. Seidler, Integrated gallium phosphide nonlinear photonics, Nat. Photonics **14**, 57–62 (2020)
[2] M. Billet, Y. Léger, C. Cornet, F. Raineri, I. Sagnes, G. Roelkens, G. Roelkens, F. Leo, B. Kuyken, and B. Kuyken, Gallium phosphide on insulator photonics enabled by micro-transfer printing, OSA Advanced Photonics Congress, paper **ITu2A.6**, (2020)
[3] W. Bogaerts, P. D. Heyn, T. V. Vaerenbergh, K. D. Vos, S. K. Selvaraja, T. Claes, P. Dumon, P. Bienstman, D. V. Thourhout, and R. Baets, Silicon microring resonators, Laser & Photonics Reviews **6**, 47–73 (2012)

978-1-6654-1876-8/21/$31.00 ©2021 IEEE

ROOM 7

CJ-8.3 FRI 11:45

Q-Switched Rod-Type Multicore Fibre Laser Delivering 3.1 mJ Pulses

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A custom rod-type multicore Yb-doped fibre is used in Q-switched operation, achieving 3.1 mJ pulse energy. The fibre design, laser performance, and prospects for further power scaling in multistage MCF amplifiers will be discussed.

CJ-8.4 FRI 12:00

The contribution has been withdrawn.

ROOM 8

factors exceeding 30 millions and wafer-level yield.

CK-8.4 FRI 11:45

AlGaAs-on-insulator Waveguides for Highly Efficient Photon Pair Generation

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We demonstrate the generation of correlated photon pairs in AlGaAs-on-insulator waveguides through spontaneous four-wave mixing at telecom wavelengths with a generation efficiency of 0.096 × 10^12 pairs/(s×W^2), one of the highest achieved in integrated structures.

CK-8.5 FRI 12:00

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EE-5.4 FRI 11:45

Role of dispersion and compression ratio on the temporal contrast of SPM-broadened post-compressed pulses

•*E. Escoto[1], A.-L. Viotti[1,2], S. Alisauskas[1], H. Tünnermann[1], M. Seidel[1], K. Dudde[1], B. Manschwetus[1], I. Hartl[1], and C.M. Heyl[1,3,4]; [1]Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany; [2]Department of Physics, Lund University, Lund, Sweden; [3]Helmholtz-Institute Jena, Jena, Germany; [4]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany*

We explore the effects of dispersion and compression ratio on pulse post-compression. We show by numerical simulations, supported by experimental data, that ultrashort pulses with high temporal contrast can be produced at high compression ratios.

EE-5.5 FRI 12:00

Efficient tunable UV pulse generation from a green pumped fs-OPCPA

•*T. Lang, S. Alisauskas, M. Kazemi, A. Tajalli, and I. Hartl; Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany*

We present highly efficient up-conversion schemes for broadband SH-pumped OPCPAs. Utilizing the Yb-pump in a cascaded-SFG, 69% conversion efficiencies to 300nm were obtained without degradation. The tunable UV pulses are compressed in glass to 75fs.

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EH-5.4 FRI 11:45

Overcoming optical performance and diffusion issues in thermally tunable phase-change metasurfaces

•*J. Shields, C. Ruiz de Galarreta, J. Bertolotti, and C.D. Wright; College of Engineering Mathematics and Physical Sciences, Exeter, United Kingdom*

We experimentally demonstrate how thermally activated diffusion can irreversibly degrade the optical performance of thermally tunable phase-change material based metasurfaces to unacceptable levels, and validate a way to address such a fundamental issue via incorporating ultrathin Si3N4 barrier layers.

EH-5.5 FRI 12:00

Anomalous Resonance Frequency Shift in Liquid Crystal-Loaded Metamaterials

•*E. Perivolari[1], V. Apostolopoulos[1], M. Kaczmarek[1], and V.A. Fedotov[2]; [1]Physics and Astronomy, University of Southampton, Southampton, United Kingdom; [2]Optoelectronics Research Centre & Centre for Photonic Metamaterials, University of Southampton, Southampton, United Kingdom*

We show that Babinet complementary patterns of metamaterials may not exhibit the same frequency tun-

ROOM 11

in GaAs-based THz-QCLs. We present a novel fabrication-scheme for $ZnO/Zn_{0.88}Mg_{0.12}O$ THz-QCL structures, yielding the first observation of THz-electroluminescence in ZnO.

CC-7.4 FRI 11:45

Terahertz intersubband electroluminescence from n-type germanium quantum wells

•*D. Stark[1], M. Mirza[2], L. Persichetti[3], M. Montanari[3], S. Markmann[1], M. Beck[1], T. Grange[4], S. Birner[4], M. Virgilio[5], C. Ciano[3], M. Ortolani[6], C. Corley[7], G. Capellini[3,7], L. Di Gaspare[3], M. De Seta[3], D.J. Paul[2], J. Faist[1], and G. Scalari[1]; [1]Institute for Quantum Electronics, Department of Physics, ETH Zürich, Zürich, Switzerland; [2]James Watt School of Engineering, University of Glasgow, Glasgow, United Kingdom; [3]Dipartimento di Scienze, Universita Roma Tre, Roma, Italy; [4]nextnano GmbH, München, Germany; [5]Dipartimento di Fisica "E. Fermi," Universita di Pisa, Pisa, Italy; [6]Sapienza University of Rome, Department of Physics, Rome, Italy; [7]IHP - Leibniz-Institut für innovative Mikroelektronik, Frankfurt (Oder), Germany*

We report the observation of intersubband electroluminescence from n-type Ge/SiGe quantum cascade structures at THz frequencies. This is an important step towards an integrated THz quantum cascade laser on silicon.

CC-7.5 FRI 12:00

All-Optical Control of Quantum Cascade Random Lasers Enhanced by Deep Learning

•*B. Limbacher[1,2], S. Schönhuber[1,2], N. Bachelard[3], M.A. Kainz[1,2], A.M. Andrews[2,4], H. Detz[5], G. Strasser[2,4], J. Darmo[1,2], S. Rotter[3], and K. Unterrainer[1,2]; [1]Photonics Institute, TU Wien, Vienna, Austria; [2]Center for Micro-and Nanostructures, TU Wien, Vienna, Austria; [3]Institute for Theoretical Physics, TU Wien, Vienna, Austria; [4]Institute for Solid-*

ROOM 12

JSIV-3.4 FRI 11:45

Forecasting turbulence in a passive resonator with supervised machine learning

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Chaotic dynamics implies an exponential magnification of any inaccuracy in the initial conditions. Consequently, long-term forecasting becomes an elusive task. Here, we address the predictability of experimental extreme events through the machine learning.

JSIV-3.5 FRI 12:00

Metasurface-based Polarization-insensitive Beam Splitter with Deep Learning

•*F.C. Savas[1], Y.A. Yilmaz[1], I.A. Atalay[1], and H. Kurt[1,2]; [1]TOBB University of Economics and Technology, Ankara, Turkey; [2]Korea Advanced Institute of Science and Technology, Daejeon, South Korea*

In this study, all-dielectric metasurface-based beam splitter is realized by a deep neural network to split the beam at the angle of ±46.8° and achieve more than 0.97 transmission value for TE and TM polarizations.

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