Rethinking Sensing – Developing Next Generation Camera Technology

(Invited paper)

Johannes Bütow[1], Jörg S. Eismann[1,2,3], Varun Sharma[1], Dorian Brandmüller[1], and Peter Banzer[1,2,3,*]

[1]Institute of Physics, University of Graz, NAWI Graz, Austria
[2]Max Planck Institute for the Science of Light, Erlangen, Germany
[3]Institute of Optics, Information, and Photonics, University Erlangen-Nuremberg, Germany
*corresponding author, e-mail: peter.banzer@uni-graz.de

We discuss the utilization of reconfigurable photonic integrated circuits for the measurement of spatial phase, polarization, and intensity distributions of light beams. The fundamental principle as well as the main building blocks of this novel detector platform will be discussed.
Keywords: *silicon photonics, photonic integrated circuits, superpixels, structured light*

INTRODUCTION

Conventional detectors like cameras or photodiodes are usually 'blind' for parameters different than intensity or power. Additional optical elements, more complicated architectures, or completely different approaches are necessary to make them 'see', for instance, the phase and polarization of a light field or beam. All-integrated photonic circuits are also well suited for the aforementioned task of measuring (and shaping) light fields. They hold great potential as actively controllable on-chip detectors, inherently sensitive to intensity, phase and polarization, if constructed and calibrated appropriately.

DISCUSSION AND RESULTS

The structure of electromagnetic fields in general and light in particular plays a crucial role in many fields of research and applications, ranging from light steering and management at the nanoscale [1-3], (nano-)metrology [4-6], advanced spectroscopy [7,8], endoscopy [9] all the way to free-space (quantum) communications [10]. However, although very important, the direct and simultaneous measurement of light's spatial degrees of freedom (intensity, phase, and polarization) is far from trivial. We now propose, implement and apply a novel route towards the spatially resolved measurement of said parameters. The corresponding novel detector consists of a reconfigurable photonic integrated circuit (PIC; see figure). Grating couplers, meshes of waveguides and Mach-Zehnder interferometers serve as an all-integrated platform – also referred to as Super-Pixels – for on-chip light processing [11-14]. After calibration of the system based on a known input field, the relative intensity and phase information between all pixels can be measured for arbitrary input beams [13]. The chosen architecture and layout of the input grating couplers (free-space interface) also provide for additional information about the polarization of input light fields. In addition, the PIC can also be ran in reverse to not only detect but also emit sculpted beams of light [14], with potential applications in beam steering, shaping, and optical communications.

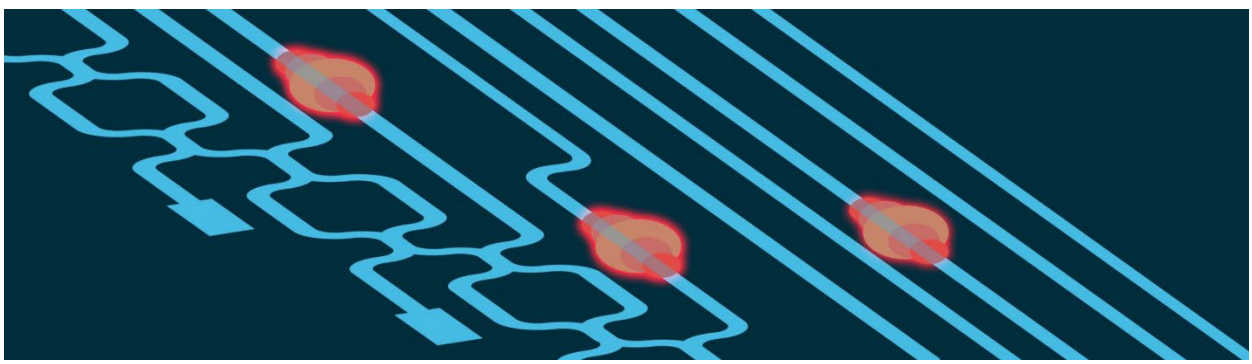

Fig. 1. Artistic impression of a photonic integrated circuit (PIC) consisting of silicon waveguides, on-chip interferometers, etc. Grating couplers arranged in a desired manner act as an input interface sampling a light beam in a spatially resolved manner (not shown). If combined with electronic phase-shifters (heaters), the waveguide modes can be manipulated selectively, eventually allowing for the retrieval of intensity, phase, and polarization information of the light field impinging on the PIC.

CONCLUSION

Novel integrated detectors capable of simultaneously measuring lights spatial intensity, phase and polarization distributions constitute a powerful addition to the existing detector toolbox. They pave the way towards intriguing applications in nano-optics, imaging, endoscopy, and optical communication. With their unique ability to also re-emit and shape the light field they are extremely versatile and flexible. In this presentation, we plan to introduce the corresponding photonic integrated architecture of superpixels, their building-blocks, and discuss selected applications.

Acknowledgement: We thank the Super-Pixels consortium for very valuable support and countless fruitful discussions. This project has received funding from the European Commission Horizon 2020 research and innovation programme under the Future and Emerging Technologies Open Grant Agreement Super-Pixels No. 829116.

References

[1] S. Nechayev, J. S. Eismann, M. Neugebauer, P. Woźniak, A. Bag, G. Leuchs, P. Banzer, Huygens' dipole for polarization-controlled nanoscale light routing, Phys. Rev. A 99, 041801, 2019

[2] M. F. Picardi, A. V. Zayats, F. J. Rodríguez-Fortuño, Janus and Huygens dipoles: near-field directionality beyond spin-momentum locking, Phys. Rev. Lett. 120, 117402, 2018

[3] J. E. Vazquez-Lozano, A. Martinez, F. J. Rodriguez-Fortuno, Near-Field Directionality Beyond the Dipole Approximation: Electric Quadrupole and Higher-Order Multipole Angular Spectra, Phys. Rev. A. 12, 024065, 2019

[4] M. Neugebauer, P. Wozniak, A. Bag, G. Leuchs, P. Banzer, Polarization-controlled directional scattering for nanoscopic position sensing, Nature Commun. 7, 11286, 2016

[5] A. Bag, M. Neugebauer, P. Wozniak, G. Leuchs, P. Banzer, Transverse Kerker scattering for Angström localization of nanoparticles, Phys. Rev. Lett. 121, 193902, 2018

[6] J. S. Eismann, M. Neugebauer, K. Mantel, P. Banzer, Absolute characterization of high numerical aperture microscope objectives utilizing a dipole scatterer, Light: Science & Applications, 10(1), 1-7, 2021

[7] S. Grosche et al., Towards polarization-based excitation tailoring for extended Raman spectroscopy, Optics Express 28, 7, 2020

[8] P. Woźniak and P. Banzer, Single nanoparticle real and k-space spectroscopy with structured light, New Journal of Physics 23, 10, 2021

[9] P. Jákl et al., Endoscopic Imaging Using a Multimode Optical Fibre Calibrated with Multiple Internal References, Photonics 9, 1, 2022

[10] M. P. J. Lavery et al., Free-space propagation of high-dimensional structured optical fields in an urban environment, Science Advances 3, 10, 2017

[11] D. A. B. Miller, Self-aligning universal beam coupler, Opt. Express 21, 6360-6370, 2013

[12] D. A. B. Miller, Self-configuring universal linear optical component, Photonics Res. 1, 1-15, 2013

[13] J. Bütow, J. S. Eismann, M. Milanizadeh, F. Morichetti, A. Melloni, D. A. B. Miller, P. Banzer, Spatially resolving amplitude and phase of light with a reconfigurable photonic integrated circuit, Submitted, 2022

[14] M. Milanizadeh, F. Toso, G. Ferrari, T. Jonuzi, D. A. B. Miller, A. Melloni, and F. Morichetti, Coherent self-control of free-space optical beams with integrated silicon photonic meshes, Photon. Res. 9, 2196-2204, 2021