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LASER & PHOTONICS REVIEWS

Editorial

Integrated optics – new material platforms, devices and applications

The objective of the two special issues of Lasers and Photonics Reviews (LPR) on Integrated Optics (of which this is the second part) is to get an idea of the state-of-the-art of this fascinating field through reports of leading scientists and engineers about the latest developments. Our intention is that the broad range of materials, devices, circuits and applications of Integrated Optics is represented by selected examples. We shall not repeat what has already been said in our editorial for the first special issue, which appeared in January 2012. Instead of this, we move immediately to commentary on the content of this second special issue with essential parts of the review abstracts printed in italics.

For a number of years, nonlinear integrated optics based on quasi-phase-matched second order nonlinear interactions in materials such as periodically poled lithium niobate (PPLN) and other ferroelectrics, but also in periodically orientation patterned semiconductors, has become progressively more important. It is possible nowadays to convert, with a high efficiency level, the frequency of coherent radiation in integrated nonlinear devices almost arbitrarily – and only limited by the fundamental absorption bands of the substrate materials. Considerable flexibility has been achieved by "ferroelectric domain engineering", which is usually carried out by applying structured external fields to the materials to be poled. However, light-mediated methods can also be used – with major advantages for the fabrication of sub-micrometer domain structures. This exciting development is reviewed by Charlie Y. J. Ying, Alistair C. Muir, Christopher E. Valdivia, Hendrik Steigerwald, Collin L. Sones, Robert W. Eason, Elisabeth Soergel, and Sakellaris Mailis (University of Southampton, United Kingdom; University of Bath, United Kingdom; Cyrium Technologies Inc., Canada; University of Bonn, Germany) in their article on **"Light-mediated ferroelectric domain engineering and micro-structuring of lithium niobate crystals".** They also show that domain patterns can be transferred into topographical structures by domain selective etching. In this way a wide range of micro-structures of excellent quality has been demonstrated.

The state-of-the-art of high-refractive-index-contrast single-crystalline thin lithium niobate ($LiNbO_3$, LN) films as a new platform for high-density integrated optics is reviewed by Gorazd Poberaj, Hui Hu, Wolfgang Sohler, and Peter Günter (ETH Zürich, Switzerland; University of Paderborn, Germany). In their paper on **"Lithium niobate on insulator (LNOI) for micro-photonic devices"** the authors show how sub-micrometer thick, single-crystalline LN films can be fabricated, even as a full wafer of 3 inch (75 mm) diameter, by "ion-slicing" and crystal- or PCB-bonding to a SiO_2-coated LN substrate. Moreover, several micro- and nano-structuring techniques have been used to develop micro- and nano-photonic devices. Among them are LNOI photonic wires (cross-sectional area $< 1\ \mu m^2$) with very special dispersion properties, periodically poled structures for nonlinear interactions such as second harmonic- and sum frequency-generation, electro-optically tunable micro-ring resonators, free standing micro-rings for hybrid integration – and photonic crystal structures.

Another class of materials is presented by Christos Grivas and Markus Pollnau (University of Southampton, United Kingdom and MESA-Institute, University of Twente, The Netherlands). They give a review of the emerging field of **"Organic solid-state integrated amplifiers and lasers"** with special consideration of fabrication technology, gain materials, and device performance. *Advances in the gain medium design and synthesis, in combination with new resonator architectures, lead to tremendous improvements in temporal and spectral properties, lifetime stability, gains produced and operating threshold powers. These devices are especially attractive for hybrid integration due to their compatibility with different material platforms, straightforward processing, and possibility to optimize easily their optical and electronic properties by molecular engineering.*

In addition to the articles on silicon-on-insulator (SOI) based integrated optics already published in the first special issue, Jonathan K. Doylend and Andrew P. Knights (McMaster University, Hamilton, Canada) address **"The evolution of silicon photonics as an enabling technology for optical interconnection".** The authors emphasize that silicon photonics defines a significant advance in the development of highly integrated devices on a single semiconductor substrate. Due to the high refractive index contrast between waveguide core and its surrounding, SOI waveguides can have an extremely small cross-section with strong mode confinement allowing bending radii even below 5 µm. This enables the development of very compact devices of unprecedentedly small size. Moreover, CMOS fabrication technology can be used, enabling integrated optical circuits of high integration density. Today, there are already many applications of silicon photonics in a range of areas such as telecommunications, sensing and optical interconnects. It is this last application which is addressed primarily in the review. *The potential for silicon photonics as a solution to high data rate transmission through the description of the devices and processes that have emerged in the last decade is discussed. An attempt is thus made to demonstrate that the integration of photonic and electronic functionality on a silicon substrate has the potential to propel communica-*

tion beyond the Terabit per second threshold, in a widely deployable paradigm.

The exciting field of photonic crystal (PhC) devices in integrated optics is reviewed by Richard M. De La Rue and Christian Seassal (University of Glasgow, Glasgow, Scotland, UK and CNRS Institute of Nanotechnologies, Ecole Centrale de Lyon, France) in their article **"Photonic Crystal Devices: Some Basics and Selected Topics"**. *The review starts with a discussion of basic principles for photonic crystals relevant to device applications – and continues by describing integrated devices such as PhC beam-splitters, slow-light structures, micro-/nano-resonators, coupled resonator optical waveguides (CROWs) and photonic crystal based semiconductor lasers. The review also addresses some of the problems encountered in the fabrication of photonic crystal devices using the planar technologies of integrated photonics, which are the ones that are most likely to be used in future commercial production.*

Integrated phased-array optical switches are advanced devices with a great potential to be used as building blocks of large-scale optical routers. Ibrahim M. Soganci, Takuo Tanemura, and Yoshiaki Nakano (University of Tokyo, Japan) review, in their article on **"Integrated phased-array switches for large-scale photonic routing on chip"**, *recent work on monolithically integrated InP phased-array switches and their applications to optical packet switching (OPS). A series of OPS experiments, employing high-bit-rate optical packets with different modulation formats, and a tunable optical buffering experiment are presented as potential applications of these switches. They can provide as many as 100 ports on a single photonic integrated circuit – by cascading many phased-array switches.*

Integrated optics-based biosensors are most suitable for lab-on-a-chip integration due to their capability for miniaturization, their extreme sensitivity, robustness, reliability – and their potential for multiplexing and mass-production at low cost. This application of integrated optical devices in the fast growing field of optical biosensing is reviewed by M.-Carmen Estevez, Mar Alvarez and Laura M. Lechuga (Research Center on Nanoscience and Nanotechnology (CSIC), Barcelona, Spain). In their article **"Integrated optical devices for lab-on-a-chip biosensing applications"**, *an overview of the state-of-the-art in integrated photonic biosensors is given – including interferometers, grating couplers, microring resonators, photonic crystals and other novel nanophotonic transducers. Particular emphasis has been placed on describing real biosensing applications and integration in lab-on-a-chip platforms.*

We hope that you enjoy the article collection in this issue and wish you pleasant reading.

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