The 11$^{\text{th}}$ International Workshop on

Optical Waveguide Theory and Numerical Modelling

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Preface

As a good tradition started two years ago in Paderborn, this year is again the traditional (11th in the series) Optical waveguide theory and numerical modelling workshop (April 4 - 5) organized jointly with the European conference on integrated optics (April 2 - 5), with two joint sessions, organized on Friday morning (April 4).

The OWTNM workshop is thus held in Prague, the beautiful capital of the Czech Republic. Therefore, together with OWTNM, you are also cordially invited to participate in the ECIO conference, both held under the auspices of the Czech Technical University in Prague, Faculty of Nuclear Sciences and Physical Engineering and Faculty of Electrical Engineering, and the Czech Academy of Sciences, Institute of Radio Engineering and Electronics, in cooperation with the Congress Department of the Czech Technical University. The OWTNM event is kindly supported by the European Office of Aerospace Research and Development. Due to the close connection to ECIO, the OWTNM meeting takes place in Masarykova kolej, Dejvice, Prague 6, Czech Republic, again after three years.

The aim is to promote personal contacts, to exchange ideas and to discuss current problems between scientists and experts for numerical modelling and theoretical description of optical waveguide structures. As mentioned, the event is organized as a Workshop with several structured interactive sessions and forums to allow for a wide interaction between participants. The emphasis is on invited and oral presentations although a good number of posters is also presented. Scientific topics for the workshop include both traditional and new topics within the field as (1) waveguide theory, (2) photonic bandgap structures, (3) photonic nanostructures, (4) waveguide gratings, (5) BPM improvements, (6) eigenmode solvers, (7) time domain methods, (8) laser modelling, (9) nonlinear media, (10) device-oriented modelling, and (11) others.

This year's workshop in Prague is already the 11th in the series of international workshops on Optical Waveguide Theory and Numerical Modelling held in the past in different places around Europe. Namely, the previous workshops took place in the following destinations: 2002 in Nottingham, UK, 2001 in Paderborn, Germany, 2000 in Prague, Czech Republic, 1999 in St. Etienne, France, 1998 in Hagen, Germany, 1997 in Enschede, The Netherlands, 1995 in Roosendaal, The Netherlands, 1994 in Siena, Italy, 1993 in Vevey, Switzerland, 1992 in Teupitz, Germany.

Hence, this year's meeting is continuation of a series of annual international workshops estabilished back in 1992. Continuation of this process is supervised by members of the OWTNM Technical Committee, consisting of Trevor Benson (University of Nottingham, UK), Jiří Čtyroký (IREE AS CR, Czech Republic), Anand Gopinath (University of Minnesota, USA), Hans - Peter Nolting, (HHI Berlin, Germany), Hugo J. W. M. Hoekstra (University of Twente, Netherlands), Olivier Parriaux (University of Saint Etienne, France), Reinhold Pregla (FernUniversität Hagen, Germany), and Christoph Wächter (Fraunhofer Inst. AOT Jena, Germany).

Based on oral contributions and selection of invited talks, it was possible to identify 8 scientific sessions, named

(1) Wave propagation
(2) Photonic bandgap structures I (both jointly with ECIO)
(3) Photonic bandgap structures II
(4) Gratings & subwavelength structures
(5) Laser & nonlinear & meta-material modelling
(6) Modelling methods and tools
(7) Device oriented modelling
(8) Waveguide theory & modelling

In response to the call for papers, total 68 papers have been received. Altogether, OWTNM 2003 includes 9 invited talks, 38 oral contributions (including 10 joint with ECIO program), and 21 posters, making it 68 contributions in total. Authors from 20 countries worldwide contribute, including United Kingdom (number of contributions 10), France (8), The Netherlands (7), Czech Republic (6), Germany (5), Italy (5), Russia (4), Australia (3), Belgium (3), Ukraine (3), Canada (2), Hong Kong (2), Indonesia (2), Spain (2), USA (2), Armenia (1), Japan (1), Sweden (1), Switzerland (1), and Taiwan (1).

Nine invited talks cover almost all topics of interest, and include (in alphabetical order): Henri Benisty from Laboratoire Charles Fabry de l'Institut d'Optique, Orsay cedex, FRANCE (*Planar Photonic Crystals: What are these teenagers capable of ?)*, Peter Bienstman from Ghent University, Dep. of Information Technology, Gent, BELGIUM (*Vectorial eigenmode modelling using perfectly matched layer boundary conditions)*, Gérard Granet, LASMEA, Unité Mixte de Recherche, Université Blaise Pascal, Aubiere Cedex, FRANCE (*Modal analysis of light transmission by subwavelength aperture arrays in metallic films)*, V. Kuzmiak, Institute of Radio Engineering and Electronics, Academy of Sciences of the Czech republic, CZECH REPUBLIC (*Amplification in 1D periodic and random active media near lasing threshold)*, Philippe Lalanne, Institut d'Optique/CNRS, Orsay Cedex, FRANCE (*Bloch wave engineering for applications of subwavelength optical structures,* jointly with ECIO), John Love, Research School of Physical Sciences & Engineering, Australian National University, Canberra, AUSTRALIA (*Passive Planar Devices for Light Processing in Telecommunications)*, Min Qiu, Laboratory of Optics, Photonics and Quantum Electronics, Department of Microelectronics and Information Technology, Royal Institute of Technology, Kista, SWEDEN (*Modelling photonic crystal devices using the finite-difference time-domain method)*, Phillip Russell, Department of Physics, University of Bath, Bath, UNITED KINGDOM (*Photonic crystals as waveguides: beyond total internal reflection*, jointly with ECIO), and C. M. Soukolis, Ames-Laboratory-USDOE and Department of Physics and Astronomy, Iowa State University, USA and Research Center of Crete, FORTH, Heraklion, Crete, GREECE (*Negative Refraction and Left-Handed Behavior in Photonic Crystals*). Most importantly, there are 38 oral contributions and 21 poster presentations to the OWTNM program, covering different areas and aspects of all 8 sessions, mentioned above.

Papers from the Workshop will appear in a Special Issue of Optical and Quantum Electronics Journal on the topic "Optical Waveguide Theory and Numerical Modelling". The papers presented both in oral and poster form at the OWTNM 2003 workshop in Prague will be included. Details about full paper submission will be available on the OWTNM 2003 web site.

This booklet includes abstracts of all contributions presented and consists of three parts. The first part contains the invited talks, the second part contains all accepted regular oral papers and joint oral papers with ECIO, the third part contains the written versions of the posters accepted for presentation during the workshop.

Information about the OWTNM 2003, including contribution abstracts, downloadable programme, and local travel information can be found at the Workshop's web site **owtnm.fjfi.cvut.cz**.

We would like to thank all individuals and institutions that have contributed to the success of the workshop, the invited speakers, authors of papers, sponsors, and the CTU Congress Department, especially.

Prague, April 2003

local organizers

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Transfer matrix and full Maxwell time-domain analysis of nonlinear gratings

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The transfer matrix approach and the direct integration of full time-dependent Maxwell equations are shown to improve nonlinear distributed feedback structure description and capture new features.

Keywords: nonlinear guided-wave optics, periodic structures, characterization methods

One-dimensional nonlinear periodic structures give rise to a number of intriguing phenomena such as bistability, limiting, self-transparency mediated by gap and forward-resonance soliton propagation. All these phenomena have been demonstrated in optical fibers or planar waveguides [1]. So far nonlinear gratings have been studied using consolidated methods based on the coupled-mode theory (CMT) and its extension using Bloch functions. Here we demonstrate the effectiveness of two different methods such as the transfer matrix method (TMM) [2] or the direct integration of Maxwell equations in time-domain via the finite-difference (FD-TD) technique [3] emphasizing that they have much wider range of applicability than CMT.

The TMM uses proper transfer matrices guaranteing field continuity between homogeneous sections of a stratified medium [2]. TMM is well suited to study the CW grating response and is exact for arbitrary large index changes. Its extension to the nonlinear regime simply requires to change the wavevectors to account for the intensity-dependent refractive index change $n_{2I}I$, being I the field intensity. Though it is often taken for granted that $I \propto |E^+|^2 + |E^-|^2$ (see, e.g., [4]), the correct expression for the total intensity $I \propto |E|^2$ contains a beating term which, being resonant with the period Λ, cannot be dropped. This is also at the origin of discrepancies between CMTs derived from first principles and by continuation of TMM techniques [4, 5]. A correct implementation of the nonlinear TMM technique requires then the calculation of the matrices on a scale much shorter than the grating period Λ. Comparing CMT and TMM results in the stationary limit for the in-out characteristics of a nonlinear grating we found that differences increase abruptly beyond a threshold value for the relative linear index change $\Delta n/n \sim 0.02$, above which the TMM must be taken as the only accurate method.

The FD-TD technique solves numerically the Maxwell equations directly in the time domain with no simplifying hypothesis. FD-TD is intrinsecally suited to investigate the transient behavior and the stability of the field configuration inside the excited structures. We used it to study the following aspects of the grating behavior: (i) bistability; (ii) spontaneous self-pulsing under continuous wave excitation; (iii) impact of third-harmonic generation (or second-harmonic in media with quadratic response); (iv) importantly, trapping of non-propagating (zero velocity in the lab frame) light inside the grating from external pulsed illumination.

In conclusion we have assessed that nonlinear gratings can be effectively studied beyond the simplifying assumptions implicit in the CMT approach, by means of TMM or FD-TD.

[1] M. de Sterke et al. *Spatial Solitons*, S. Trillo and W.E. Torruellas eds., Springer, Berlin, 2001.

[2] A. Yariv and P. Yeh, *Optical waves in Crystals* J. Wiley & Sons, 1984.

[3] A. Taflove, *Computational Electrodynamics: the FD-TD method for Electromagnetics*, Artech House, 1985.

[4] D.E. Pelinovsky, L. Brzozowski, and E. H. Sargent, Phys. Rev. E **62**, R4536-R4539 (2000).

[5] D.E. Pelinovsky, J. Sears, L. Brzozowski, and E. H. Sargent, J. Opt. Soc. Am. B **19**, 43-52 (2002).