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Analisys of the international Master's degree program "Mathematical modeling and information technologies in photonics"

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Abstract

This paper presents information on the content and resources of the internationally certified Master's program "Mathematical Modeling and Information Technologies in Photonics" in the field of Applied Mathematics and Physics. The paper investigates scientific achievements of the academic staff, peculiarities of courses currently held, opportunities of available facilities and resources, and prospects for the Master's worldwide research activities.

Keywords: Master's program; curriculum; core courses descriptions; modeling and synthesis of optical systems; computer optics; diffractive nanophotonics

1. Introduction

According to estimates of the Ministry of Education and Science of the Russian Federation presented by the Deputy Minister, Corresponding Member of the Russian Academy of Sciences (RAS) L.M. Ogorodova at the first BRICS Conference on Photonics (Skoltech, May 2016), the market of photonics industry is now estimated at 400 billion euro. In this regard, according to the report of the SPIE Industry Development Director Stephan G. Anderson presented at the first International SPIE Photonics West Conference (13 February – 18 February 2016, San Francisco, California, USA) [1], the possible market of photonics industry is estimated at 1450 billion US dollars.

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This significant market growth requires development of new educational programs in photonics to train highly qualified personnel.

The Master's degree program “Mathematical Modeling and Information Technologies in Photonics” (hereinafter referred to as the Master’s program) was developed by Samara National Research University (Samara University, until 2016 - Samara State Aerospace University) together with the Image Processing Systems Institute of the RAS (IPSI RAS) – the Branch of the “Crystallography and Photonics” Federal Research and Development Center of the RAS [2]. The content of the Master’s program is based on scientific advances of the leading Russian scientific school “Diffractive Nanophotonics and Computer Optics” within the field of Information Telecommunication Systems and Technologies under the leadership of the Academician of the RAS V.A. Soifer [3-7].

Fig. 1. Academician of the RAS, Doctor of Engineering, Professor V.A. Soifer.

The Master’s program has been implemented since 2012 at the Faculty of Information Technology of Samara University in the field Applied Mathematics and Physics. In 2015 the Master’s program “Mathematical Modeling and Information Technologies in Photonics” was internationally accredited by the Central Evaluation and Accreditation Agency Hannover (Zentrale Evaluations und Akkreditierungsagentur Hannover (ZEvA)) – Member of European Association for Quality Assurance in Higher Education (ENQA), registered in European Quality Assurance Register for Higher Education (EQAR) (www.zeva.org, www.enqa.eu, www.eqar.eu).

Zentrale Evaluations- und Akkreditierungsagentur Hannover ZEvA

Certificate of Accreditation

Upon application by

Samara State Aerospace University n. a. Academician S. P. Korolev

the Commission for International Affairs of the **Central Evaluation and Accreditation Agency Hannover (ZEvA)** has accredited the following Master’s programme:

Applied Mathematics and Physics: Mathematical Modelling and Information Technologies in Photonics

The accreditation is valid until 30 September 2020.

Hannover, 31 July 2015

Prof. Dr. Wolfgang Lücke
Academic Director ZEvA

Hermann Reuke
Managing Director ZEvA

Member of: ENQA European Association for Quality Assurance in Higher Education

Registered in: eqar

Fig. 2. Certificate of Accreditation.

The Master’s program director is a well-known scientist, Doctor of Physics and Mathematics, Professor, Chief of Laser Measurement Laboratory at the IPSI RAS V.V. Kotlyar.

Fig. 3. Doctor of Physics and Mathematics, Professor Victor V. Kotlyar.

The areas of scientific interests of Professor V. V. Kotlyar are as follows: Diffractive Optics, Nanophotonics, Vortex Beams, Line Focusing, Microoptics. Professor V.V. Kotlyar has got over 450 scientific publications (the Hirsch index in SCOPUS and Web of Science international citation databases are 24 and 21, respectively).

The following leading scientists from the Specialized Department "Optical Information Technologies" of the IPSI RAS are widely involved into education activities: Head of the Department, Doctor of Physics and Mathematics, Professor S.N. Khonina [8]; Doctor of Physics and Mathematics, Professor S.V. Karpeev [9]; Doctor of Physics and Mathematics, Professor L.L. Doskolovich [10]; Doctor of Physics and Mathematics, Associate Professor P.G. Serafimovich [11]; Doctor of Physics and Mathematics, Professor R.V. Skidanov; Doctor of Physics and Mathematics, Associate Professor A.A. Kovalev.

2. General Description

Type of education: full-time study.
Program duration: 2 academic years to complete.
Program workload: 120 ECTS credits.
Degree awarded: Master of Science.

Program objective. The Master's program objective is to train highly qualified specialists in Photonics, Diffractive Nanophotonics, Nanooptics and Diffractive Optics.

Educational process. The Master's program students are provided with the following opportunities:

- to work in laboratories equipped with the most-up-to-date training, process and research equipment;
- to use high-performance computer facilities to perform experimental research;
- to use professional software in training and research activities;
- to undertake internships in leading Russian and foreign research and development centers;
- to study on similar Master's degree programs in leading universities in Russian and Europe.

Interactive training methods and distant learning technologies are widely used in education process. Training is provided in accordance with both the master academic curriculum and individual training programs in English. There are also accelerated training courses.

Professional skills. Learning on the Master's program enables the graduates to broadly develop their professional skills such as:

- knowledge of methods for solving inverse diffraction theory problems;
- knowledge of methods for designing diffractive optical elements;
- knowledge of numerical methods for solving differential equations in optics: Maxwell and Helmholtz equations;
- knowledge of methods of photo- and e-beam lithography to develop photonics components;
- skills in performing near-field electronic microscopes, scanning optical microscopes, scanning probe microscopes;
- skills in performing tools and devices for fabrication and synthesis of 3D photonics components using two-photon polarization;
- ability to use dedicated software for professional purposes: OSLO-TracePro, FRED Software, FullWAVE FDTD Software, Mode Solvers–Waveguide CAD Software–FIMMWAVE;

- knowledge of multiple programming methods for solving problems in photonics;
- knowledge of IT solutions for computer-aided design;
- foreign-language skills as a tool for professional communication.

Areas of professional activities. Professional activities of the Master's program graduates are as follows:

- Optics and light-emitting devices (light-emitting diodes (LEDs)).
- Optics and diffractive nanophotonics.
- Microoptics and nanooptics.
- Photonic crystals.

Admission procedure. To enroll at the Master's program it is necessary to have a document confirming your previous basic education in Physics and Mathematics and to meet face-to-face for an interview to show your individual advances. Thus the following conditions should be taken into consideration: experience in research and development (publications, project involvement), practical experience, documents confirming your individual advances (diplomas, professional certificates, diplomas of winners and prize-winners of Olympiads and scientific competitions, grants). CVs should be applied beforehand.

3. Curriculum

The Master's program curriculum structure is shown in Table 1 where 1 ECTS credit equals to 36 academic hours, and the basic training courses focusing on the program specialization are marked with an *asterisk.

Table 1. Curriculum Structure of the Master's Degree Program "Mathematical Modeling and Information Technologies in Photonics".

Educational Units and Courses	Semester	Form of Examination	ECTS credits
Obligatory Courses			
Foreign language	1 2	Pass/Fail Exam	5
History, Methodology and Modern Philosophy of Science	1 2	Pass/Fail Exam	5
Modern Problems of Science, Technology and Sustained Development	1	Pass/Fail	2
Mathematical Modelling of Optical Signals and Systems *	1	Exam	4
Light Diffraction and Image Formation *	1 2	Pass/Fail Exam	7
Synthesis of Optical Systems Elements *	2 3 3	Pass/Fail Exam Diff (course work)	6
Modern Methods and Algorithms for Solving Complicated Problems on Supercomputers	3	Exam	4
Neuroinformatics	3	Pass/Fail	3
Elective Courses			
Tools and Technologies of Parallel Programming Continuum Mechanics	1	Exam	5
Software Development Management Applied Problems of Nonlinear Dynamics	1	Pass/Fail	3
Distributed Data Processing in Modern DBMS	2	Pass/Fail	3

Fractals and Chaos			
Grid Technologies and Cloud Computing			
Selected Topics of Theoretical and Applied Physics	3	Exam	4
Master’s Scientific Research	1 2 3	Diff Diff Diff	14 8 14
Internship	4	Diff	24
State Exam and Thesis	4	Exam Defense	9
Total			120

4. Core Courses Descriptions

4.1. Mathematical Modeling of Optical Signals and Systems

Course objective: Study of basic methods that enable to efficiently run numerical modeling of complex signals and fields in optical systems.

Syllabus:

Modeling procedures for light transmitting through optical systems within the framework of geometric optics.

Matrix methods for calculating optical systems.

Computing techniques for electromagnetic field by using integral methods.

Modeling procedures for electromagnetic field propagation in layered media.

Modeling procedures for electromagnetic field propagation through spiral optical elements.

Methods for reduction of the diffraction integrals to the form of simple analytic formulae in some selected apertures.

Methods for reduction of the integral Hankel and Radon transforms to the form of the Fourier transform.

Methods for fast computation of the Hankel transforms by means of the Dini’s sampling theorem, Laguerre polynomials and the Abelian transform.

The finite element method to calculate the Kirchhoff transform.

Methods for calculating the Fraunhoffer diffraction from a quantized-phase field.

Methods for fast computation of the Fresnel diffraction under light reflection from a relief surface.

Special integral transformations in optics: Gabor decomposition, wave package transform, partial Fourier transform, Zach transform, Wigner function.

4.2. Light Diffraction and Image Formation

Course objective: Study of basic methods for calculating amplitude and phase characteristics of coherent and incoherent light fields traveling in space, and images formed by spherical lenses.

Syllabus:

Method of integral transforms connecting complex amplitudes on different planes in space: expansions of coherent light fields in plane, spherical (Kirchhoff transform) and parabolic waves (Fresnel transform).

Analysis of mode solutions of the paraxial propagation equation: Gauss-Hermite and Gauss-Laguerre modes.

Description of coherent images being formed with one lens and a Fourier-correlator.

Development of a spatial spectrum by a Fourier-analyzer: the Fourier transform.

Incoherent image definition methods: van Siettert and Shell’s theorems.

Random light fields and their correlation curves.

Tomography and the Radon transform, holography and amplitude-and-phase coding methods for light fields.

Solution of Maxwell’s equations and solution of cylinder-and-dihedral-angle diffraction problems.

Geometric optics.

Parabolic equation of light propagation in inhomogeneous medium.

4.3. Synthesis of Optical Systems Elements

Course objective: Study of basic methods for calculating optical components aimed at forming the direction diagrams and focusing of optical radiation to defined areas, as well as using methods of computer-based simulation for these optical components.

Syllabus:

Basic definitions of Geometric Optics, eikonal and transport equations, solution of the eikonal equation within the ray coordinates, and Fermat's principle.

Computation of mirrors and refracting surfaces for focusing to defined areas and for forming specified direction diagrams (one-dimensional and radially-symmetrical cases).

Computation of refracting surfaces with regard to Fresnel reflection losses, plane wave equation, derivation of the Fresnel formulae (one-dimensional and radially-symmetrical cases).

Method for computing mirrors to form a direction diagram (DD) in the form of a line.

Computation of mirrors to form the direction diagram in the form of a segment using a curvilinear coordinate system.

Computation of mirrors to form two-dimensional DDs and to focus to two-dimensional areas.

Computation of diffractive optical elements (DOEs) to form DDs in the form of a line.

Computation of DOEs to focus in space line.

Computation of DOEs to focus in space line using special curvilinear coordinates.

Gradient method for calculating the eikonal equation to focus to defined areas, application of the method to calculate refraction optical elements.

Gradient method for calculating refraction optical elements to focus to defined areas.

5. Resourcing

Training on the Master's program is supplied with a wide variety of research, training and technological equipment [12]. For many years, Professor A.V. Volkov was engaged in maintaining the equipment and developing new experimental methods and techniques [13]. This work is now carried out under the supervision of Professor R.V. Skidanov.

5.1. Measurement Equipment

- 3D imaging surface structure analyzer NewView 7000.
- High-speed camera VS-FAST/C/G6.
- White-light computer-aided interferometer WLI-DMR.
- Scanning probe microscope SOLVER-Pro.
- Attachment to the laser beam analyzer Beam Profiler.
- Infra-red radiation analysis and reporting system XPORT.
- Integrated equipment for studies of the surface structure Nanopics 2100.
- Optical unit for integrated studies of thin-film properties Ellipsometer M2000DI.
- Hardware-software complex for remote monitoring of dynamic processes and objects.
- Device for analyses of mechanical properties of materials on the nanoscale NANOTEST 600.
- Argon lasers, helium-cadmium lasers, CO_2 and other lasers, optical tables and optical equipment.
- Dynamic transmission-type indicator (microdisplay) SXGA-R2-H1.
- High performance optical spectrum analyzer SR303i.
- Scanning electron microscope SUPRA 25.
- Analyzer system for studies of the surface structure ASIQ.
- Scanning electron microscope with a thermionic cathode and the electron-beam lithography system Quanta 200.

- Scanning probe nanolaboratory Ntegra Spectra.
- Spectrally tunable femto-picosecond fiber laser, "Itterbius-1100" model.
- Spectrograph, model MS7501.
- Selector OG8/1-F with electrooptic Pockels cells.
- Tunable laser system NT242 series.
- Optical spectrum analyzer MS9740A.
- System of small-angle X-ray scattering S3-micro.
- Spatial light modulator of high resolution PLUTO VIS.
- Educational and scientific laboratory Nanoeducator.

a) b)

c)

Fig. 4. Measurement equipment: a) 3D imaging surface structure analyzer NewView 5000; b) high-speed camera VS-FAST/C/G6; c) scanning probe nanolaboratory Ntegra Spectra.

5.2. Technological Equipment

- Laser recording station CLWS-200S.
- Precision grinding system NM 500.1.
- Lithographic attachment XENOS XeDraw 2 to a scanning electron microscope SUPRA 25.
- Plasma etching machine Carolina 15.
- Automated thermal and magnetron deposition system Caroline D12A.
- Three-dimensional nanostructuring plant 3D2S.
- Ultrahigh vacuum modular technology platform NanoFab 100.
- Clean zone laminar box, class II.
- Laboratory milling machine with coordinated movement Premium4030.

Fig. 5. Technological equipment: a) the laser recording station CLWS-200S; b) the plasma etching machine Carolina 15; c) the three-dimensional nanostructuring plant 3D2S.

5.3. Auxiliary Equipment

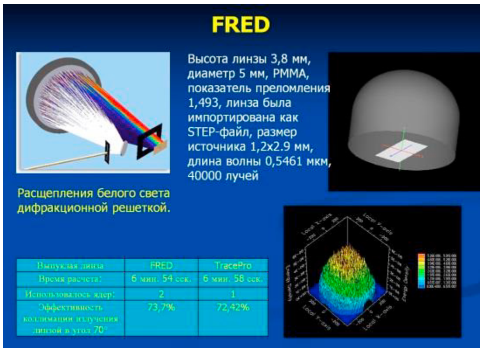
- Manual photoresist coating centrifuge Polos.
- Precise diamond scriber RV- 129.
- Centrifuge for separating of nanopowders (0.1 – 10 µm) in fractions Optima MAX.
- Pumping vacuum system MiniTask.
- Chemical reactor L2.ST.
- Cleaning system for substrate preparation SOLARUS 950.

5.4. Software

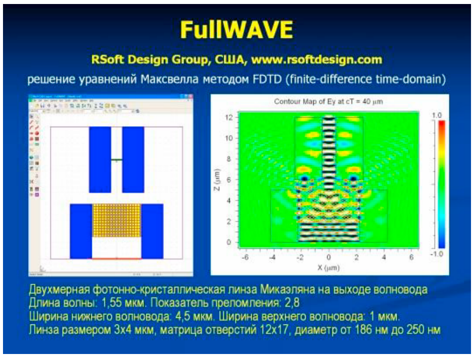
- OlympIOs Software for computing waveguides.
- Grating 2D and Grating 3D Software for modeling and optimization of multiordinal diffraction gratings.
- Trace Pro Expert Software from Lambda Research Corporation (USA) for modeling of optical systems.
- FRED Optical Engineering Software for lighting designs.
- FullWAVE Software.
- BeamPROP+GratingMOD+DiffractMOD Software.
- FIMMWAVE Software.

6. Master's Scientific Research

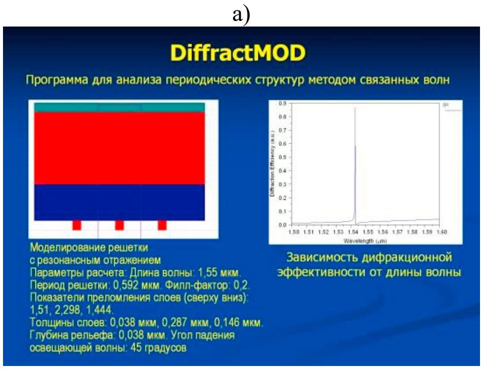
Worldwide scientific research of the Master's program students is ensured not only by good facilities and resources, but first of all by great scientific expertise of leading lecturers [3-13] and by 40 years' experience of high-impact research results in optics and nanophotonics. During these years some new types of optical elements such as focusators of laser radiation [4-6, 14-20] and surface electromagnetic waves [21-24], laser beam formers with unique properties [25-32], optical antennas [33-34], nanophotonic structures for optical information processing [35-39] and many other things have been developed. These works have been confirmed by analytical studies [40-43]; by development of mathematical modeling tools [44-49], methods for forming optical micro- and nanostructures [50-58] and optical experiments [59-62]. The obtained scientific reserve allowed to proceed to developing of optical devices with record characteristics: hyperspectral equipment for Earth remote sensing [63-67], computer vision systems [68-72], lighting devices [73-77], sensors [78-79], modulators [80], etc.



a)



b



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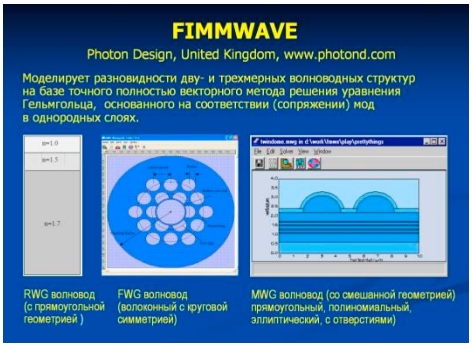

d)

Fig. 6. Dedicated software: a) FRED; b) FullWAVE +; c) BeamPROP+GratingMOD+ DiffractMOD; d) FIMMWAVE.

Fig. 7. V.A. Soifer, Academician of the RAS, and R.V. Skidanov, Doctor of Physics and Mathematics, are demonstrating their results to Zh.I. Alferov, Nobel Prize Winner, Academician, Vice-President of the RAS.

The Master's program students are provided with an opportunity to quickly and efficiently publish their results in the scientific journal "Computer Optics" [81] being issued by the scientific team headed by the Academician of the RAS V. A. Soifer [82]. According to SCOPUS, the journal "Computer Optics" is included [83] into the best dozen of journals, being classified in this international bibliometric database in three main areas of journal's activities: 1) Physics, Optics (Atomic and Molecular Physics, and Optics); 2) Information Technology (Computer Science Applications); 3) Electronics (Electrical and Electronic Engineering). Besides, the Master's program students and graduates have an opportunity to submit their research results at the annual International Conference "Information Technologies and Nanotechnologies" (ITNT) whose proceedings are indexed in SCOPUS database. The Youth School is organized within a framework of this conference where the participants have the opportunity to attend lectures of leading Russian and foreign scientists.

Students for a Master's degree may participate in joint investigations conducted by the scientific school headed by the Academician V.A. Soifer in cooperation with some leading Russian and international scientific schools in optics. Scientists from Samara University conduct their joint research together with scientists from M.V. Lomonosov Moscow State University [84-85], P.N. Lebedev Physical Institute of the RAS [84-85], A.M. Prokhorov General Physics Institute of the RAS [84-86], Institute of Physics of Microstructures of the RAS [87], G.I. Budker Institute of Nuclear Physics of the RAS, and Novosibirsk State University [86, 88], Ufa State Aviation Technical University [89], etc. The international cooperation is carried out together with scientists from Great Britain [90-91], USA [92-93], Canada [94-95], Germany [84, 96], Italy [97-98], Finland [99], India [100], Austria [101] and many other countries. Student for a Master's degree being successfully engaged in scientific research are financed from grants allocated by the Russian Science Foundation, the Russian Foundation for Basic Research, within the framework of various projects of Federal Target Programs and economic agreements made with manufacturing enterprises, including those ones of aerospace sector.

The Master's degree graduates may continue their studies in Samara University on postgraduate programs in the fields: 03.06.01 Physics and Astronomy (profiles: 01.04.05 Optics; 01.04.01 Instruments and Methods of Experimental Physics; 01.04.03 Radiophysics; 01.04.10 Physics of Semiconductors; 01.04.21 Laser Physics); 09.06.01 Informatics and Computing Engineering (profiles: 05.13.18 Mathematical Modeling, Numerical Methods and Software Systems; 05.13.17 Theoretical Foundations of Informatics; 05.13.01 System Analysis, Management and Information Processing; 05.13.05 Elements and Devices of Computer and Control Systems; 05.13.12 Design Automation Systems).

The Doctoral and Candidate's Dissertation Councils successfully operate in Samara University on the following specialties: 01.04.05 Optics (Physics and Mathematics); 01.04.01 Instruments and Methods of Experimental Physics (Engineering Sciences, Physics and Mathematics); 05.13.18 Mathematical Modeling, Numerical Methods and Software Systems (Engineering Sciences, Physics and Mathematics); 05.13.17 Theoretical Foundations of Informatics (Engineering Sciences, Physics and Mathematics); 05.13.01 System Analysis, Management and Information Processing (Engineering Sciences, Physics and Mathematics); 05.13.05 Elements and Devices of Computer and Control Systems (Engineering Sciences); 05.13.12 Design Automation Systems (Engineering Sciences).

Beginning from 2015, the special Regulations on PhD Training have been in force in Samara University thus giving an opportunity to defend a PhD thesis of Samara National Research University.

7. Conclusion

We look forward to welcoming you at the meeting at the Faculty of Information Technology of Samara University to get world-class education at the Master's program "Mathematical Modeling and Information Technology in Photonics". Photonics is the thing of the future!

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