dr inż. Maciej Dems

Summary of Professional Accomplishments

Lodz University of Technology
Faculty of Technical Physics, Information Technology and Applied Mathematics
Institute of Physics

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Contents

1. Personal Data

First and Last Name

Maciej Dems

Scientific Degrees

- **Philosophy Doctor** — “Plane-Wave Admittance Method and its Applications to Modeling Semiconductor Lasers and Planar Photonic-Crystal Structures” defended with honors at the Faculty of Technical Physics, Information Technology and Applied Mathematics in 2007.
- **Master of Science** — “Strain Generation in Multi-Layer Nitride Lasers During the Cooling Process” defended with honors at the Faculty of Technical Physics, Information Technology and Applied Mathematics in 2002.

Current Employment

- Lodz University of Technology,Faculty of Technical Physics, Information Technology and Applied Mathematics, Institute of Physics, ul. Wólczańska 219, 90-924 Łódź

Employment History

- **since 1 February 2008** — assistant professor in the Institute of Physics, Lodz University of Technology.
- **18 February – 11 March 2007** — COST MP0702 short term scientific mission in Department of Applied Physics and Photonics, Vrije Universiteit Brussel, Brussels, Belgium.
- **19 March – 2 April 2006** — COST P11 short term scientific mission in Department of Applied Physics and Photonics, Vrije Universiteit Brussel, Brussels, Belgium.
- **11 September – 1 October 2005** — COST P11 short term scientific mission in Department of Applied Physics and Photonics, Vrije Universiteit Brussel, Brussels, Belgium.
- **1 – 30 November 2004** — COST P11 short term scientific mission in Department of Applied Physics and Photonics, Vrije Universiteit Brussel, Brussels, Belgium.
- **20 February 2006 – 31 January 2008** — assistant in the Institute of Physics, Lodz University of Technology.
- **23 February 2004 – 19 February 2006** — assistant in the Centre of Mathematics and Physics, Lodz University of Technology.
- **1 March 2003 – 22 February 2008** — assistant in the Institute of Physics, Lodz University of Technology.
- **16 August 2002 – 28 February 2003** — scientific assistant in the Institute of Physics, Lodz University of Technology.

Bibliometric Data

Bibliometric data is retrieved from the Web of Science.

ResearcherID:	E-6065-2016
ORCID:	0000-0002-5576-1021
Total number of publications:	78
Citation count (without self-citations):	221
Hirsh Index:	11

2. Scientific Achievement

Title of the Scientific Achievement

Numerical Analysis of Optical Properties of Subwavelength Photonic Structures

List of publications constituting the Scientific Achievement

- [**A1**] M. Dems, „Semi-vectorial method based on effective index for VCSEL analysis", *J. Opt. Soc. Am. B* **26**, 792–796 (2009). [5-year Impact Factor in the year of publication 1,899]
- [**A2**] K. Panajotov and M. Dems, „Photonic crystal vertical-cavity surface-emitting lasers with true photonic band gap", *Opt. Lett.* **35**, 829–831 (2010). [IF 3,548]
- [**A3**] M. Dems, I.-S. Chung, P. Nyakas, S. Bischoff, and K. Panajotov, „Numerical methods for modeling photonic-crystal VCSELs", *Opt. Express* **18**, 16042–16054 (2010). [IF 3,939]
- [**A4**] M. Dems, „Modelling of high-contrast grating mirrors. The impact of imperfections on their performance in VCSELs", *Opto-Electr. Rev.* **19**, 340–345 (2011). [IF 1,054]
- [**A5**] T. Czyszanowski, M. Dems, R. P. Sarzala, K. Panajotov, and K. D. Choquette, „Photonic crystal vcsels: Detailed comparison of experimental and theoretical spectral characteristics", *IEEE J. Select. Topics Quantum Electron.* **19**, 1–8 (2013). [IF 3,566]
- [**A6**] M. Gębski, M. Dems, A. Szerling, M. Motyka, L. Marona, R. Kruszka, D. Urbańczyk, M. Walczakowski, N. Pałka, A. Wójcik-Jedlińska, Q. J. Wang, D. H. Zhang, M. Bugajski, M. Wasiak, and T. Czyszanowski, „Monolithic high-index contrast grating: a material independent high-reflectance VCSEL mirror", *Optics Express* **23**, 11674–11686 (2015). [IF 3,250]
- [**A7**] M. Dems, P. Wnuk, P. Wasylczyk, Ł. Zinkiewicz, A. Wójcik-Jedlińska, K. Regiński, K. Hejduk, A. Jasik, „Optimization of Broadband Semiconductor Chirped Mirrors with Genetic Algorithm", *Appl. Phys. B.* **122**, 266 (2016). [IF 1,686]
- [**A8**] M. Dems, „Monolithic High-Contrast Gratings: why they do not scatter the light?", *IEEE J. Lightwave Technol.* **35**, 159–165 (2017). [IF 2,543]

Summary of the above works and main results

2.1. Introduction

Subwavelength photonic structures have dimensions comparable to or smaller than the wavelength of electromagnetic wave, with which they interact. Physical phenomena in such structures qualitatively differ from those that can be observed in macroscopic systems. Hence, their proper use allows achieving the effects unattainable with other methods. The examples of such systems are: quarter-wave Bragg mirrors, subwavelength diffraction gratings, or photonic crystals. These structures have become the subject of my research, the results of which were published in the works constituting the Scientific Achievement.

The publications—listed above and discussed below—can be classified into two groups. The first group includes work [**A1**] and partly [**A4**] and [**A7**]. They show an innovative approach to numerical analysis of photonic structures and present custom advanced computational methods. Along with the older Plane-Wave

Admittance Method, these methods are a powerful tool to study the detailed physical phenomena in subwavelength structures. The results of such studies are shown in works [**A2**]–[**A6**] and [**A8**], which constitute the second subgroup of the Scientific Achievement.

Below I summarize the main theses of each of these works. First, I discuss the first group of publications, focusing on the new calculation methods, since they present important tools used in other works.

2.2. Novel numerical methods

2.2.1. Semi-vectorial method for VCSELs analysis

In the first work of the cycle [**A1**] I have presented a semi-vector method for analysis of VCSEL (Vertical-Cavity Surface-Emitting Lasers). This method solves time-independent Maxwell's equations in a planar planar structure i. e. a structure consisting of layers uniform in the z-direction (direction perpendicular to the layers). These equations can be reduced to the form:

$$
\begin{aligned}
\partial_z \mathbf{E}(z) &= -i\, \bar{\mathbf{R}}_{\mathbf{H}}\, \mathbf{H}(z), &(1)\\
\partial_z \mathbf{H}(z) &= -i\, \bar{\mathbf{R}}_{\mathbf{E}}\, \mathbf{E}(z), &(2)
\end{aligned}
$$

where $\mathbf{E}(z)$ and $\mathbf{H}(z)$ are electric and magnetic fields, ∂_z means partial derivative in z direction and $\bar{\mathbf{R}}_{\mathbf{H}}$ with $\bar{\mathbf{R}}_{\mathbf{E}}$ are some matrix operators in the xy-plane (parallel to the epitaxial layers). Equations (1) and (2) are expanded in the orthogonal plane-wave (Fourier) basis. Idential equations were also considered in my older—fully vectorial—method PWAM. However, in the work [**A1**] I have used a semi-vectorial approach, where Eqs. (1) and (2) are transformed to the form:

$$\left[\bar{\mathbf{R}}_{\mathbf{H}}\bar{\mathbf{R}}_{\mathbf{E}} f_E + \mathbf{I}\,\partial_z^2 f_E\right]\mathbf{E} = 0 \tag{3}$$

and a three-dimensional distribution of the electric field is approximated as a product of two factors:

$$\mathbf{E}(x,y,z) = f_E(z)\mathbf{E}(x,y). \tag{4}$$

where the scalar $f_E(z)$ depends solely on z and $\mathbf{E}$ is a vectorial lateral (in xy-plane) distribution of the electric field. This allows to replace the three-dimensional Eq. (3) with two others (1D and 2D):

$$
\begin{aligned}
\left(\partial_z^2 + \kappa^2 n(z)^2\right) f_E &= 0, &(5)\\
\left[\left\langle \bar{\mathbf{R}}_{\mathbf{H}}\bar{\mathbf{R}}_{\mathbf{E}} \right\rangle - \kappa^2 \left\langle n^2 \right\rangle \mathbf{I}\right]\mathbf{E} &= 0. &(6)
\end{aligned}
$$

In the above equations $\langle \ldots \rangle$ means the integral over z weighted by the vertical field intensity distribution $|f_E|^2$.

Such separation as shown in Eq. (4) is typical for the effective index method [1] and its variants. However, my approach does not ignore vector properties of the electromagnetic field and thus allows to analyze much wider spectrum of photonic structures. Examples of such structures are presented in works[**A1**] (oxide-aperture VCSEL and polarization-controlled VCSEL) and [**A3**] (photonic-crystal VCSEL).

For both structures presented in work [**A1**] I have achieved a very good agreement between the fully--vectorial and semi-vectorial models, which proves the applicability of the latter. Although classical oxide--confined VCSELs can also be modeled with scalar methods [2], the polarization-controlled ones or photonic--crystal VCSELs can be analyzed only with fully-vectorial method or with the presented semi-vectorial one. However, it is important to remember that the latter method has some limitations (due to the used approximations), which are discussed in the section 2.3.1 of this document.

In every considered case, the strong advantage of the semi-vectorial method over the fully-vectorial ones is numerical effort. The computation times can differ a few hundreds times. The typical computation time with the semi-vectorial method is few seconds, while the fully-vectorial ones can take up to an hour. This difference is the main reason, why I have developed the semi-vectorial method, as it allows to analyze certain class of photonic structures much more efficiently than before.

2.2.2. Plane-Wave Reflection Transformation

a very important class of photonic structures I have analyzed, are subwavelength gratings that—if properly designed—can be very effective mirrors. Their rigorous numerical analysis requires a novel approach, which differs from the ones I was using before. Hence, it became necessary to develop a new numerical method, which allowed to precisely investigate optical properties of VCSELs using such gratings as mirrors. I named this method the Plane-Wave Reflection Transfer (PWRT) and for the first time I have presented it in the work [**A4**]. Similarly to the approaches I had used before, the main idea of this method was an expansion of the electromagnetic field in two-dimensional Fourier basis. In multi-layered structures, the Maxwell equations (1) oraz (2) are diagonalized in each layer. The original concept of the new method lies in the separation of the field ($\tilde{\mathbf{E}}$) in each layer into a forward ($\tilde{\mathbf{F}}$) and backward ($\tilde{\mathbf{B}}$) propagating parts:

$$\tilde{\mathbf{E}}(z) = \exp(-i\boldsymbol{\Gamma} z)\tilde{\mathbf{F}} + \exp(i\boldsymbol{\Gamma} z)\tilde{\mathbf{B}},$$

where $\boldsymbol{\Gamma}$ is a diagonal matrix of propagation constants. The second step of the new method is an iterative determination of a reflection matrix $\mathbf{R}$ such that

$$\tilde{\mathbf{F}} = \mathbf{R}\tilde{\mathbf{B}}.$$

The exact form of this matrix and its derivation is presented in the article [**A4**]. Once its exact form is known, it is possible to determine the reflectivity of any subwavelength mirror. Contrary to common methods like e. g. RCWA [3] [4], PWRT allows to compute reflectivity for each diffractive order separately, whether it is a propagating or evanescent one. Hence, it has proven to be an efficient tool for analysis of grating-based VCSELs. Details of such analysis are presented further down.

2.2.3. Genetic algorithm for Bragg mirror optimization

An important aspect of photonic design is an optimization of structures. In order to create an efficient device, it is necessary to choose its construction parameters in such a way that its physical properties are as close to desired ones as possible. To achieve this, it is sufficient in many cases to use well known numerical optimization algorithms. However, for complex structures, these algorithms often prove insufficient. For example, optimization of a non-uniform Bragg mirror with negative dispersion requires independent tuning of a large number of layers in order to achieve strong negative dispersion over a broad band. Hence, in order to efficiently optimize such structure, it is necessary to use a new approach.

In the work [**A7**] I presented use of a genetic algorithm to do the optimization of non-uniform Bragg mirrors. Although genetic algorithms had been used for some time [5], their adaptation to analysis the optical properties of Bragg reflectors required additional research. First, I had to develop an innovative method of specifying design parameters of these mirrors. These parameters—on the one hand—had to precisely describe the structure and—on the other hand—had to be suitable for an effective optimization. In my method, the mirror is represented in the computer memory not as a set of low/high refractive index layer thicknesses, but as a set of Bragg lengths of each pair. This allowed to make mirror modifications during each iteration of the genetic algorithm without losing information about the fundamental optical properties of each pair. In consequence, broader range of mirror variations could be tested without introducing chaos deteriorating quality of already partially optimized structures.

In addition, my original contribution was a development of an effective scoring function. In the case of the high-dispersion Bragg mirrors, three factors had to be taken into account: the maximum absolute value of the negative GDD, the bandwidth in which this large negative GDD does not oscillate strongly, and the average value of the mirror reflectivity over the low GDD band. The fulfillment of these criteria strongly depended on both the formula of the scoring function and used coefficients. In the article [**A7**] I have presented a mirror optimization using the scoring function that provided the best results. The outcome of this optimization is presented later on.

2.3. Investigated subwavelength photonic structures

Numerical methods presented above are feasible tools for analysis of photonic structures. The results of such analysis are published in works ([**A2**] – [**A8**]). In particular, I have investigated novel VCSELs with subwavelength elements and their parts: non-uniform Distributed Bragg Reflector (DBR) with strong negative dispersion, or subwavelength high-contrast gratings. The common factor of all the analyzed structures was the way they interact with light: due to their subwavelength dimensions, the light-matter interaction significantly differs from the one observed in macroscopic structures.

2.3.1. Photonic-crystal VCSELs

The first structure I have analyzed is a DBR incorporating an etched photonic crystal. It has been presented in the article [**A2**]. The main motivation behind this work was a desire to design a Photonic-Crystal VCSEL (PhC-VCSEL), in which the photonic band gap played an important role for light propagation.

All PhC-VCSELs presented by various research groups so far [6][7][8][9][10][**J7**][**J8**][**B1**] have a similar structure: the photonic crystal is created by etching a regular lattice of holes in a classical VCSEL, comprising of the resonant cavity and two pairs of DBRs. Due to the technological constrains, only the top DBRs are usually etched. Such structures have several advantages, among which the most prominent one is the possibility to achieve a high-power single-lateral mode emission. However, in such VCSEL, the role of photonic crystal is reduced to non-linear modification of the effective refractive index, and photonic band gap effects are not utilized. This is confirmed by the fact that simplified numerical models that use only the concept of regional effective index yield a good agreement with the experiments. Furthermore, the photonic crystal period used in such PhC-VCSELs is too large for an effective generation of the photonic band gap near their emissions wavelengths (usually 800 nm to 1500 nm).

Because of this, I focused my research on search for such photonic crystal parameters, that would allow to observe photonic band gap for these wavelengths. I have limited myself to such form of photonic crystal that could be easily manufactured within VCSEL DBRs. Its structure—presented in the article [**A2**]—was a triangular lattice of vertical holes etched in a quarter-wavelength GaAs/AlO$_x$ or Si/SiO$_2$ stack. This design was very similar to PhC-VCSELs mentioned above, however, the distance between the holes was much smaller (0.5 µm as compared to 1 µm – 2 µm in the designs proposed by other researchers). Only for such small photonic crystal pitch, it was possible to observe the photonic band gap overlapping with the emission wavelength assumed to be 1.55 µm. Because the etched holes were vertically uniform, the photonic band gap was not complete. It could be observed only for modes with electric field polarization parallel to epitaxial layers. From the practical point of view, this was sufficient, as this is exactly the polarization of light generated in VCSELs.

Because photonic band gap prohibits light propagation, it can be used to confine modes into some limited area, where the periodicity is broken. Such resonant cavity can have effective refractive index either larger or smaller than the effective refractive index of the bulk photonic crystal. In the former case, the mechanism of light confinement is twofold: on the one hand, the cavity mode is confined by the photonic band gap and, on the other hand, by the effect of total internal reflection. In typical PhC-VCSELs, the second effect dominates. If, however, the cavity effective index is smaller than on of its surroundings, the only mechanism of light confinement is the band gap.

In order to demonstrate the role of the band gap, we have analyzed such a cavity in our article [**A2**]. We were able to find a confined mode regardless of the material present inside the cavity. In particular, we were able to find a mode inside a hollow cavity with an extremely high Q-factor of 43 000, which is three times more than observed usually in classical VCSELs.

In my research I have also considered traditional PhC-VCSELs. In these VCSELs—contrary to the structure described above—photonic crystal is used only for modification of effective refractive index in the etched region. Because the diameter of the etched holes is comparable with the emitted wavelength, the effective index cannot be straightforwardly computed as weighted average of the material indexes. Hence, the proper determination of modes in PhC-VCSELs is much more difficult than in classical, ax-symmetric VCSELs with oxide aperture.

Within the international program COST MP 0702 I have initiated a comparison of the performance of various numerical methods—developed and used by several research groups—for analysis of a PhC-VCSEL. The particulars and results of this comparison have been published in the article [**A3**]. It presents the main aspects of four different numerical methods and compares the calculation results for the same structure obtained with these methods. Such benchmark allows to compare precision of each method and estimate area of its applicability.

The methods compared in [**A3**] were: Coupled Mode Model (CMM) [11], Finite Element Method (FEM) [12][13], and two algorithms developed by me: Plane-Wave Admittance Transfer (PWAM) [**J2**] and semi-vectorial method [**A1**] presented above. The benchmark structure was a gallium-arsenide PhC-VCSEL, in which the light was confined only by photonic crystal. This photonic crystal comprised of triangular lattice of air holes etched in (a) the whole laser, (b) the cavity only, (c) the top DBR, and (d) half of the top DBR. In each case, the photonic crystal had one hole in the center removed, which created a resonant cavity. Both the diameter of the etched holes and their distance were varied, which allowed to determine the impact of the photonic crystal parameters on the optical laser properties: resonant wavelength and modal gain.

All compared methods have shown good agreement for deep etching cases. In case of the photonic crystal etched only in the part of the top DBR, the semi-vectorial method has shown strong disagreement with other methods: it was caused by the fact that this method does not consider scattering losses properly. In all other cases, the differences between the methods were much less pronounced. However, some methods have shown moderate differences for particular cases: very large holes (CMM), very small holes (FEM) and holes etched in the cavity only (PWAM and semi-vectorial method).

In summary, the research presented in [**A3**] have proved that numerical analysis of such complex system as PhC-VCSEL is not a trivial task and no numerical method yields exact results for each configuration. However, it was possible to to estimate ranges of parameters for each method, for which the simulation results can be considered reliable. This is the major outcome of the work and a valuable clue for all further research.

To be judge the quality of computer modeling, we must not only compare different methods with each other, but also with experimental results. Such a comparison is presented in [**A5**], which shows computed resonant wavelengths and modal losses of selected transverse modes in a PhC-VCSEL and relates them to experimentally measured emission spectra. The test structure was a 980 nm gallium arsenide VCSEL. The injected current was limited by the 12 µm oxide aperture, located in the first DBR layer. Active region consisted of three 8 nm-thick $In_{0.2}Ga_{0.8}As$ quantum wells. The resonant cavity was surrounded by a 35 pairs of bottom DBR and 19 pairs of the top one. a two-dimensional triangular photonic crystal lattice was etched in the top DBR. It had a single defect in the middle, which formed the optical resonant cavity.

Numerical analysis of this laser included thermal and electrical calculations—carried out by finite element method—and optical calculations done with PWAM [**J2**]. These calculations allowed to determine thresholds for each laser mode. Threshold gain values reflected very well experimentally measured emitted power (the higher the threshold, the lower the radiated power), however, a close correlation was observed only for currents close to the threshold. For higher currents, other effects—spatial hole burning and modes competition—became dominant. Despite this limitation, the performed numerical simulation—in particular optical analysis, for which I was responsible—allowed to draw several important conclusions: For structures with relatively small holes ($b/a = 40\%$ Where b was the diameter of the etched holes, and a the distance between their centers) and with the shallow etching, the confining effect of the photonic crystal was moderate and the light leaked from the structure through the etched holes. In this case, the light confinement was provided by the oxide aperture and, hence, the laser emitted multiple modes. However, with larger and deeper holes, lower-order modes were strongly confined to the photonic crystal defect, which reduced losses of these modes, and improved discrimination against higher order modes. In particular it was possible to obtain single-mode operation with Side Mode Suppression Ratio (SMSR) of 10 dB. Maximum value of SMSR were reached for situations where the fundamental mode was confined by the photonic crystal and the first-order mode by the oxide aperture.

Regardless of the parameters of photonic crystal, a good agreement between the calculation and experimental results was observed. It was particularly evident in the structures with high SMSR. These results confirm the correctness of the numerical methods described in the publications of the Scientific Achievment and prove that the conclusions drawn on the basis of theoretical analysis have direct experimental confirmation.

2.3.2. Highly-reflective subwavelength gratings

Around 2011, I expanded the scope of my research into subwavelength one-dimensional diffraction gratings with high contrast refractive index (High-Contrast Gratings, HCG). This was related to the discovery [14][15][16][17] that such gratings may be effective mirrors in surface-emitting lasers, effectively replacing the multilayer DBR mirror. The first stage of my work on these structures was a development of the above-described PWRT method, which has become an effective tool for the analysis of these gratings. This method is described in detail in [**A4**]. In the same article I also present an analysis of the impact of manufacture inaccuracy of subwavelength diffraction grating on its reflectivity. In particular, I have analyzed the dependence of the reflectivity of a grating optimized for TM polarization (i.e. the one in which the electric field vector of the incident wave is perpendicular to the grating bars) on the scale of random errors introduced into the geometry of the grating. Detailed calculations were carried out for four periods of the diffraction grating in which widths of the slit and of the silicon bar were randomly changed with a chosen standard deviation (varied between 0 nm and 50 nm). This way, the random disturbance of the grating periodicity was simulated. My calculations allowed to determine the dependence of the grating reflectivity on the precision of photolithographic process. In the results, I found that for the inaccuracy of the order of 10 nm, the average grating reflectivity decreases by 0.5% (wherein the grating is designed in such a way that, in the absence of inaccuracies, its reflectivity is exactly 100%). It remains above 99.9% for the standard deviation of 6 nm and above 99.0% for 15 nm. Modern technologies allow to manufacture diffraction gratings with such precision, however, the presented drop in the reflectivity must be taken into account in the devices designs.

The reflectivity of HCGs is affected by not only the lateral inaccuracies of photolithographic process, but also by the depth of etching. In my analysis I have also examined the dependence of reflectivity on etching-depth errors. The results clearly indicate that too short lithography process—resulting in incomplete gaps between the bars of the grating—causes a very rapid decline in its reflectivity. On the other hand, too strong etching does not affect the quality of the mirror. Hence, it is particularly important to always perform full grating etching and even over-etch to ensure its high reflectivity.

Apart of the mirrors analysis, in [**A4**] I studied the optical properties of a VCSEL, in which the top DBR mirror was replaced with a subwavelength diffraction grating made of silicon located on a SiO_2 cladding. That cladding layer plays a very important role for both the emitted wavelength and the cavity Q-factor. Its optimal thickness is ¾ wavelength.

I have also examined—like before—the impact of the grating inaccuracy on the laser parameters. In particular, I was most interested in the cavity Q-factor, because it directly affects the threshold current and the emitted power. The Q-factor of the unperturbed structure was 1600 (which is the value seen typically in VCSELs). The introduction of random grating disturbances with the standard deviation of 5 nm resulted in a decrease of the Q-factor to 1200, and the inaccuracy of the order of 10 nm resulted in the Q-factor of 800. Hence, it can be seen that the inaccuracies of the diffraction grating strongly deteriorate the laser parameters. This must be taken into account in the design of devices: for example, by improving the quality of the reference design, so that even when the Q-factor is reduced twice, the laser will still work.

A separate category of diffraction gratings I examined are Monolithic High-Contrast gratings (MHCGs): high reflectivity subwavelength gratings that do not need a low refractive index layer below. Hence, they may be etched directly in the material of high refractive index (e.g., gallium arsenide) forming a resonant cavity of a vertical-emission laser. This is a very innovative solution, first demonstrated by our research group [**A6**], [**B21**]. It enables the creation of extremely small thickness VCSEL [**B20**] using only one type of material. This allows to avoid combining mismatched lattice materials with different atomic compositions used in multi-layer DBRs. Consequently, it becomes possible to create a VCSEL in any material and, consequently, to obtain any wavelength of the emitted light.

Contrary to the standard high-reflectance subwavelength gratings, in MHCGs the refractive index of the material adjacent to the grating at the input side has an effective refractive index higher than the one of the grating layer. As a result, there is no effect of total internal reflection of higher than zero diffractive orders. In general, this may result in diffraction scattering of the reflected wave, which would make such grating useless in surface-emitting lasers. However, in [**A6**] I showed that in the structures described in these work, such scattering does not occur. I determined the reflectance spectrum of grating for each diffractive order separately, which was an important result presented in the article. In the case of the examined grating, the zero-order reflection coefficient was 100% at a wavelength of 980 nm (it was the wavelength for which the gratings were optimized), and the coefficients for the other orders—only for this particular wavelength—were zero. I have explained this surprising phenomenon by the specific characteristics of resonance responsible for the grating high reflectivity. This resonance has proved to be totally independent of the refractive index of the underlying layer. Therefore, the nature of the reflected wave is the same for a diffraction grating disposed on a material with a high refractive index (eg. gallium arsenide), and suspended in the air. In the latter case, only the zero diffractive order can propagate and hence it transfers all the energy. Since the profile of the reflected wave does not change with an increase of the refractive index of the layer below the grid, all the energy remains being reflected into the zero order, even if higher orders could possible appear.

I have extended this rough explanation in [**A8**]. This work contains a detailed analysis of the phenomenon of the lack of light scattering in MHCG. It shows that in classical HCGs, the wavelength of the resonances responsible for grating high reflectivity shifts with the change of refractive index layer immediately below the diffraction grating. If this refractive index rises sufficiently to allow propagation of the first diffractive order, the maximum grating reflectance drops drastically. However, by careful selection of the geometrical parameters, it is possible to re-achieve a reflectance of 100%, although the light is reflected into multiple diffractive orders, resulting in a strong scattering. On the other hand, in MHCGs the resonance responsible for the high grating reflectivity occurs for a constant wavelength and is independent of the refractive index of the layer beneath the grating. This is the result of a very special form of the grating's impedance/admittance matrix. This form of matrix can be obtained for any wavelength by tuning the geometrical parameters of the grating: its pitch, fill-factor, and height. Although choosing the appropriate parameters is not straightforward and may require numerical optimization, it is possible to find the high reflectivity peaks of MHCGs regardless of the material from which it has been fabricated, provided the material provides sufficient contrast.

The article [**A8**] can therefore be considered as a summary of my Scientific Achievement. In this work, I present the mathematical explanation of a new phenomenon taking place in a modern subwavelength structure and explain its cause.

2.3.3. DBR with strong negative dispersion

The last type of the structures I was interested in, are non-uniform Bragg reflectors with strong negative dispersion, for use in femtosecond lasers. I was working on them in cooperation with Institute of Electron Technology and Warsaw University. The aim of the mutual project was to design and manufacture a chirped Bragg mirrors that provided strong negative dispersion of the reflected wave, which was constant over a broad wavelength range. Such a mirror was to be used in 1035 nm Yb:KYW laser emitting femtosecond pulses. The main results of this project have been published in [**B16**]–[**B18**] and [**A7**]. In particular, the later article contains a large amount of my personal contribution, as it presents an optimization of the analyzed Bragg mirror with a genetic algorithm. For this reason I consider this work as a part of my Scientific Achievement. I have summarized the most important aspects of the genetic optimization process in section 2.2.3 above. Below, I present the main results of this optimization.

Genetic algorithm run for non-uniform Bragg mirror yielded two structures that could be considered optimal. The first of them (I) provided the Group Delay Dispersion (GDD) close to $-3000\,\mathrm{fs}^2$ within the 1030 nm – 1047 nm band. The second structure (II) provided the GDD around $-3500\,\mathrm{fs}^2$ with the same bandwidth, however it was oscillating more. Both designs were potentially good mirrors that should provide femtosecond operation of a Yb:KYW laser. Hence, both structures were manufactured with Molecular Beam Epitaxy (MBE) and their optical properties were measured. In case of the structure I, the measured parameters were inconsistent with the simulated ones, however, the structure II matched them very well, with only a slight shift of the reflectivity and GDD spectra resulting from the proportional change of the layer thicknesses. Despite this shift, the sample provided a 600 fs pulse operation of a Yb:KYW laser.

The main purpose of the work presented in [**A7**] was to create a variant of a genetic algorithm that allowed to effectively optimize Bragg mirrors providing strong negative dispersion and to experimentally verify it. The results obtained for the structure II confirm the applicability of the performed optimization process. It is worth to note that the optimized structure is strongly non-uniform, as its layer thicknesses do not vary smoothly and, thus, it would be infeasible to find such structure using classical optimization approaches.

2.4. Summary

Above, I have presented the main points of the publications constituting my Scientific Achievement "Numerical Analysis of Optical Properties of Subwavelength Photonic Structures". These works are partially the result of my collaboration with Polish and international researchers (5 articles) and partially of my own research (3 articles). All of them consider numerical modeling of subwavelength photonic structures: two publications [**A1**][**A4**] present new or improved numerical methods that create a basic toolset for further works. Three articles were created in close international collaboration and contain rigorous verification of these methods: either through comparison with other models [**A3**] or with the experiment [**A5**][**A7**]. Furthermore, [**A7**] presents a novel use of the modern optimization algorithm for designing a non-uniform Bragg mirror with strong negative dispersion.

The other works focus on analysis of physical properties of modern subwavelength structures. In [**A2**] a novel photonic crystal design is proposed for use in VCSELs: it fully uses the photonic band gap effect for light confinement. Works [**A4**], [**A6**],and [**A8**] show analysis of subwavelength gratings, which are interesting modern alternative to multi-layer DBRs in VCSELs. In [**A4**] the impact of manufacturing imprecisions on optical parameters of grating is discussed. In [**A6**] and [**A8**] a novel monolithic high contrast subwavelength grating is presented. I consider the explanation of the scatter-less properties of MHCGs—presented in [**A8**]—the most important element of the Scientific Achievement and my most significant contribution to the field of optics.

2.5. References

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Individual contribution in the publications constituting the Scientific Achievement

[A1] *M. Dems, „Semi-vectorial method based on effective index for VCSEL analysis", J. Opt. Soc. Am. B 26, 792–796 (2009).*
I am the only author of this article. My contribution is 100%.

[A2] *K. Panajotov and M. Dems, „Photonic crystal vertical-cavity surface-emitting lasers with true photonic band gap", Opt. Lett. 35, 829–831 (2010).*
I estimate my contribution to this article for 80%. I have performed numerical analysis of a novel photonic-band-gap structures originally proposed by Prof. Krassimir Panajotov. I have conducted all the numerical calculation and structure optimization, resulting in extremely high cavity Q-factor. I have edited the manuscript together with Prof. Panajotov.

[A3] *M. Dems, I.-S. Chung, P. Nyakas, S. Bischoff, and K. Panajotov, „Numerical methods for modeling photonic-crystal VCSELs", Opt. Express 18, 16042–16054 (2010).*
My contribution to this work (estimated for 60%) was primary. I have proposed the idea of comparison of numerical methods for a PhC-VCSEL and designed the benchmark structure. I have performed computation with two out of four compared methods.

[A4] *M. Dems, „Modelling of high-contrast grating mirrors. The impact of imperfections on their performance in VCSELs", Opto-Electr. Rev. 19, 340–345 (2011).*
I am the only author of this article. My contribution is 100%.

[A5] *T. Czyszanowski, M. Dems, R. P. Sarzala, K. Panajotov, and K. D. Choquette, „Photonic crystal vcsels: Detailed comparison of experimental and theoretical spectral characteristics", IEEE J. Select. Topics Quantum Electron. 19, 1–8 (2013).*
I estimate my contribution for 30%. I have developed a numerical optical model and I used it for analysis of side modes of the subject laser. The results of this analysis were used for comparison with the experiment.

[A6] *M. Gębski, M. Dems, A. Szerling, M. Motyka, L. Marona, R. Kruszka, D. Urbańczyk, M. Walczakowski, N. Pałka, A. Wójcik-Jedlińska, Q. J. Wang, D. H. Zhang, M. Bugajski, M. Wasiak, and T. Czyszanowski, „Monolithic high-index contrast grating: a material independent high-reflectance VCSEL mirror", Optics Express 23, 11674 (2015).*
I estimate my contribution for 15%. For this article I have developed a method for computation of grating reflectivity for each diffraction order separately and I have performed the computations. I have shown that the reflected wave shows no scattering and I have indicated what may be the reason for this. I took part in the manuscript editing.

[A7] *M. Dems, P. Wnuk, P. Wasylczyk, Ł. Zinkiewicz, A. Wójcik-Jedlińska, K. Regiński, K. Hejduk, A. Jasik, „Optimization of Broadband Semiconductor Chirped Mirrors with Genetic Algorithm", Appl. Phys. B. 122, 266 (2016).*
My contribution to this work (estimated for 70%) was primary. I have developed a method for numerical analysis of chirped mirrors and implemented a genetic algorithm for their optimization: I have proposed criteria of structure selection and designed a method for specifying its physical parameters, essential for genetic algorithm. The main contribution of other authors was for the experimental part: manufacture and measurement of the structures that I designed and optimized.

[A8] *M. Dems, „Monolithic High-Contrast Gratings: why they do not scatter the light?", IEEE J. Lightwave Technol. 35, 159–165 (2017).*
I am the only author of this article. My contribution is 100%.

3. Other achievements

The following list contains only the achievement, which I consider the most relevant for my academic career.

3.1. Prizes, scholarships and recognitions awarded after receiving the Ph.D. degree

- **2015** — Best Spin-off Idea Award,
- **2013** — Scholarship from the Ministry of Science and Higher Education for Outstanding Young Scientists,
- **2012** — Medal of the National Education Commission,
- **2011** — Scholarship for Young Scientists at the Faculty of Technical Physics, Computer Science and Applied Mathematics, Lodz Universtity of Technology,
- **2010** — Scholarship for the Young Doctor in Lodz University of Technology in the project „Innovative Education. . . ” funded by the Operational Programme Human Capital,
- **2008** — Scholarship for the Young Doctor in Lodz University of Technology in the project „Innovative Education. . . ” funded by the Operational Programme Human Capital,
- **2008** — START Stipend funded by the Foundation for Polish Science.

3.2. Participation in the most important research projects

- **od 2016** — project leader NCN Opus (2015/19/B/ST7/00562) *Modeling novel VCSEL structures manufactured using intra-cavity selective planar oxidation for high-power single-mode emission*, project value 499 200 PLN,
- **2015** — project leader FNP Impuls (37/UD/SKILLS/2015) *Software for modeling mutual interaction between physical phenomen*a *in semiconductor lasers*, project value 90 000 PLN,
- **2013–2016** — major contributor in the project NCN (2012/06/M/ST7/00442) *Coupled-Cavity Vertical-Cavity Surface-Emitting Lasers*, project value 663 436 PLN,
- **2012–2015** — major contributor in the international project NCBiR and A*STAR (1/3/POL-SIN/2012) a *Novel Photonic Crystal Surface Emitting Laser Incorporating a High-Index-Contrast Grating*, project value 948 353 PLN,
- **2011–2014** — project leader NCBiR (LIDER/17/5/L-2/10/NCBiR/2011) *Numerical model of* a *single-mode high-power photonic-crystal VCSEL with stable polarization of the emitted light*, project value 971 062 PLN,
- **2011–2013** — major contributor in the project NCBiR (NR02-0009-10/2011) *Design and manufacture of Yb:KYW pulse laser with semicondictor SDCM* mirror, project value 1 980 000 PLN,
- **2009–2013** — task leader w projekcie *InTechFun: Innovative technologies of multifunctional materials and structures for nanoelectronics, photonics, spintronics and sensor techniques* in the Operational Programme Innovative Economy (UDA-POIG.01.03.01-00-159/08-00), project value 2 320 880 PLN,
- **2009–2012** — task leaser *P 2.1 Photonic crystal and microcavity structures for lasing, sensing and telecom applications* in the international program *COST Action MP0702 „Towards functional sub-wavelength photonic structures”*,
- **2009–2012** — contributor in the international project Swiss National Science Foundation (IZ73Z0 128019/1) *Coupled VCSELS arrays for gas sensing and environment monitoring*, project value 75 000 CHF,
- **2009–2011** — major contributor in the project MNiSW (N N515 004 32/0297) *Analysis of applicability of photonic-crystal structures in junction lasers with transverse optical resonato*r, project value 249 668 PLN.

3.3. Presentation of selected research projects

Above I have listed the most important research projects I took part. In three of them I was the project leader. Below I present brief descriptions of these three projects and—for the finished projects—their major results.

Modeling novel VCSEL structures manufactured using intra-cavity selective planar oxidation for high-power single-mode emission

The project started in 2016. Its purpose is to investigate the influence of oxide anti-resonant structures located inside the Vertical-Cavity Surface-Emitting Lasers (VCSEL) on their physical properties. One of the methods to provide a single transverse mode operation of VCSEL is an application of anti-resonant waveguides (ARROW) etched on the surface of the laser. However, their effectiveness is limited because of the low light intensity on the mirror surface. Therefore, the inclusion of an anti-resonant layers inside the resonant cavity should provide a much more efficient elimination of higher order modes.

In the project we perform computer simulations to investigate the influence of buried ARROW structures on the optical, electrical, and thermal properties of lasers. These studies will help to understand the physics of these new structures, which in the future will enable the development and optimization of new generation single-mode high-power lasers. The project is realized by performing theoretical analysis that are conducted using advanced self-consistent computer model developed by the Photonics Group in the Institute of Physics at Lodz University of Technology. This model consists of several basic modules for the calculation of the heat propagation, the band structure of the active region, material gain, current distribution and transport phenomena and optical wave propagation. The modules are mutually compatible and they can be freely combined, thus forming a package for performing simulations of various types of semiconductor devices. Application of numerical analysis to the study of semiconductor lasers has the advantage that it allows consideration of the of individual phenomena in the laser in separation from other effects that hinder proper interpretation of test results. Inclusion of selected relations within individual modules and links between them, allows to pinpoint the physical phenomena responsible for the observed effects.

Obtained numerical results will be compared with the experimental data that will be provided by the research group from the Laboratory for Analysis and Architecture of Systems (LAAS-CNRS), which has a novel technology that allows to perform selective oxidation of any shape inside of the laser structures including buried ARROW structures. This project will result in a thorough understanding of the physics of the phenomena occurring in such structures. It will enable the successful design of new generation of single-mode VCSELs. This will be an excellent starting point for further applied research, aimed at creating a single-mode high power laser with excellent quality, for use e. g. in the field of optical communications.

By now, we have completed the introductory project stage: we designed a starting VCSEL structure and we have tested efficiency and accuracy of numerical analysis of its optical properties. These works have been done under my supervision by a Ph.D. student hired for the project. Currently, the second stage is being performed, which is an analysis of various possibilities of placing the anti-resonant structure in the laser cavity.

Numerical model of **a** *single-mode high-power photonic-crystal VCSEL with stable polarization of the emitted light*

The aim of the project was to develop a complex numerical model of a single-mode polarization-stable surface-emitting PhC-VCSEL. Such model allows to efficiently analyze different properties of the laser and, thus, to reduce the costs of its designing and production. Because of the multitude of physical phenomena affecting the operation of lasers, and mutual interactions of these phenomena, a precise numerical simulation required innovative software, whose creation was the main objective of the project. This objective was fully realized and its immediate effect is the advanced simulation software, described later in this document. a secondary goal of the project was to design a PhC-VCSEL structure, which could provide a large power of the emitted radiation, working on a single lateral mode. This was considered as a demonstration of the capabilities of the developed software, showing that it is suitable for efficient modeling of innovative and complex structures. The proposed structure was presented at one of the world's most important congresses in the field of photonics and published in [**D14**].

In the project, I leaded an interdisciplinary team, comprising six people besides me. They were both physicists and programmers. Thanks to the synergy resulting from such broad choice of the team members, the project end result—the software described below—can be considered a high quality one and can successfully compete with existing commercial solutions. In the aspect of modeling of subwavelength devices it significantly exceeds them.

The project ended with 6 publications in journals listed in JCR and with 6 conference papers.

*Software for modeling mutual interaction between physical phenomen***a** *in semiconductor lasers*

The aim of the project was further development of the software initialized in the previous project. Here, we have created a modern graphical interface and we have added the electrical drift-diffusion model to the simulation platform. This model allows for precise determination of the current distribution in analyzed structures.

We also performed optimizations of the used numerical methods. Some of the models were altered to allow conducting critical calculations in parallel on multiple processor cores. This accelerated some calculations by at least several percent. At the same time one of our solvers—the one used to determine the gain in the quantum wells—has been completely rewritten, which resulted in ten or twenty times shorter computation times.

3.4. Developed simulation software

As stated above, the main effect of the research projects “Modeling novel VCSEL structures manufactured using intra-cavity selective planar oxidation for high-power single-mode emission” and “Software for modeling mutual interaction between physical phenomena in semiconductor lasers” was advanced software allowing for modeling of broad spectrum of photonic devices. It has been developed using the experience of all the researchers of my team and since its first prototype (in 2012) it proved to be a versatile tool. The name of the software is PLaSK (**P**hotonic **La**ser **S**imulation **K**it).

Since the design stage, I have considered high quality of the software my priority and I have defined a set of strict requirements:

- numerical efficiency,
- ability to perform numerical analysis of different devices with multiple methods,
- flexibility of the architecture, which allows to add new solvers in the future,
- user friendly and flexible interface,
- multi-platform code that can be launched both on a personal laptop and on an HPC (High Performance Computing) cluster.

The above requirements implied software architecture design. We have decided that the whole program framework will comprise:

- common software core,
- material database,
- numerical solvers: each for a particular physical phenomenon and for a particular algorithm,
- scriptable textual user interface,
- graphical user interface.

The software core is the code allowing for: efficient data exchange between solvers, reading and parsing geometry definition, and providing data from the material database. Particular solvers are implemented in external modules and loaded on a request. The graphical user interface allows to design the analyzed structure efficiently with a visual feedback and to launch preliminary calculations on a personal computer. The textual interface allows to dispatch computations to HPC clusters, where they can be carried without further user interaction.

Such advanced goals requires application of modern technologies: the software core and solvers, which require high numerical efficiency, are written in C++11. On the other hand, the user interface is implemented in the Python programming language, which provides great flexibility for the end user. The analyzed structure geometry is described using one-directional graphs, based on the solutions used in computer graphics. This allows to represent virtually any photonic device with easy parsing by solvers.

Our novel contribution is the mechanism of data exchange between numerical solvers, which uses an approach of providers and receivers. It allowed for flexible choice of numerical solvers according to the specific problem in the working program.

a typical work-flow for analysis of photonic devices with the software is as follows:

1. Definition of the structure;
2. choice of used materials (either from the provided database or with custom parameters);
3. decision on required type of calculations: selection of proper solvers (thermal, electrical, optical, etc.);
4. configuration of the solvers and their connection;
5. specification of the sequence of calculations and of the requested output (graph, data saved to a file, etc.);
6. launch of computations, their monitoring, results analysis.

The quality of the software makes it suitable for commercialization. By now I have received buying interest from Technische Universität Berlin (Germany), Hewlett-Packard Labs (USA), Alight Technologies (Denmark), Finisar (USA).

3.5. Works published after receiving the Ph.D. degree

3.5.1. Publication in journals listed in the JCR

[**B1**] T. Czyszanowski, R. Sarzala, M. Dems, H. Thienpont, and K. Panajotov, „Threshold characteristics of bottom-emitting long wavelength VCSELs with photonic-crystal within the top mirror", *Opt. Quantum. Electron.* **40**, 149–154 (2008).

[**B2**] T. Czyszanowski, M. Dems, H. Thienpont, and K. Panajotov, „Modal gain and confinement factors in top- and bottom-emitting photonic-crystal VCSEL", *J. Phys. D: Appl. Phys.* **41**, 085102 (2008).

[**B3**] M. Dems, T. Czyszanowski, H. Thienpont, and K. Panajotov, „Highly birefringent and dichroic photonic crystal VCSEL design", *Opt. Commun.* **281**, 3149–3152 (2008).

[**B4**] T. Czyszanowski, R. P. Sarzala, M. Dems, W. Nakwaski, H. Thienpont, and K. Panajotov, „Optimal photonic-crystal parameters assuring single-mode operation of 1300 nm AlInGaAs vertical-cavity surface--emitting laser", *J. Appl. Phys.* **105**, 093102 (2009).

[**B5**] T. Czyszanowski, R. P. Sarzala, M. Dems, H. Thienpont, W. Nakwaski, and K. Panajotov, „Strong modes discrimination and low threshold in cw regime of 1300 nm AlInGaAs/InP VCSEL induced by photonic crystal", *Physic*a *Status Solidi A: Aplications and Materials Science* **206**, 1396–1403 (2009).

[**B6**] T. Czyszanowski, M. Dems, R. P. Sarzala, W. Nakwaski, and K. Panajotov, „Precise lateral mode control in photonic crystal vertical-cavity surface-emitting lasers", *IEEE J. Quantum. Electron.* **47**, 1291–1296 (2011).

[**B7**] T. Czyszanowski, R. P. Sarzala, M. Dems, J. Walczak, M. Wasiak, W. Nakwaski, V. Iakovlev, N. Volet, and E. Kapon, „Spatial-mode discrimination in guided and antiguided arrays of long-wavelength VCSELs", *IEEE J. Sel. Topics in Quantum Electron.* **19**, 1702010 (2013).

[**B8**] L. Frasunkiewicz, T. Czyszanowski, M. Wasiak, M. Dems, R. P. Sarzala, W. Nakwaski, and K. Panajotov, „Optimization of single-mode photonic-crystal results in limited improvement of emitted power and unexpected broad range of tuning", *IEEE J. Lightwave Technol.* **31**, 1360–1366 (2013).

[**B9**] M. Gebski, M. Dems, J. Chen, Q. J. Wang, D. H. Zhang, and T. Czyszanowski, „The influence of imperfections and absorption on the performance of a GaAs/AlOx high-contrast grating for monolithic integration with 980 nm GaAs-based VCSELs", *IEEE J. Lightwave Technol.* **31**, 3853–3858 (2013).

[**B10**] A. Jasik, P. Wasylczyk, M. Dems, P. Wnuk, A. Wojcik-Jedlinska, K. Reginski, L. Zinkiewicz, and K. Hejduk, „a passively mode-locked, self-starting femtosecond Yb:KYW laser with a single highly dispersive semiconductor double-chirped mirror for dispersion compensation", *Laser Physics Lett.* **10**, 085302 (2013).

[**B11**] K. Panajotov, Y. Xie, M. Dems, C. Belmonte, H. Thienpont, J. Beeckman, and K. Neyts, „Vertical-cavity surface-emitting laser emitting circularly polarized light", *Laser Physics Lett.* **10**, 105003 (2013).

[**B12**] T. Czyszanowski, N. Volet, J. Walczak, M. Dems, R. P. Sarzala, V. Iakovlev, A. Sirbu, A. Mereuta, A. Caliman, and E. Kapon, „Numerical analysis of mode discrimination by intracavity patterning in long-wavelength wafer-fused Vertical-Cavity Surface-Emitting Lasers", *IEEE J. Quantum. Electron.* **50**, 732–740 (2014).

[**B13**] M. Gebski, M. Dems, J. Chen, Q. Wang, D. H. Zhang, and T. Czyszanowski, „Optical Properties of GaAs/AlOx and Si/SiOx High Contrast Gratings Designed for 980-nm VCSELs", *IEEE T. Nanotechnol.* **13**, 418–424 (2014).

[**B14**] M. Gebski, O. Kuzior, M. Dems, M. Wasiak, Y. Y. Xie, Z. J. Xu, Q. J. Wang, D. H. Zhang, and T. Czyszanowski, „Transverse mode control in high-contrast grating VCSELs", *Opt. Express* **22**, 20954–20963 (2014).

[**B15**] V. Iakovlev, J. Walczak, M. Gebski, A. K. Sokol, M. Wasiak, P. Gallo, A. Sirbu, R. P. Sarzala, M. Dems, T. Czyszanowski, and E. Kapon, „Double-diamond high-contrast-gratings vertical external cavity surface emitting laser", *J. Phys. D: Appl. Phys.* **47**, 065104 (2014).

[**B16**] A. Jasik, M. Dems, P. Wnuk, P. Wasylczyk, A. Wojcik-Jedlinska, K. Reginski, L. Zinkiewicz, and K. Hejduk, „Design and fabrication of highly dispersive semiconductor double-chirped mirrors", *Appl. Phys. B: Lasers and Optics* **116**, 141–146 (2014).

[**B17**] A. Jasik, P. Wasylczyk, P. Wnuk, M. Dems, A. Wojcik-Jedlinska, K. Reginski, L. Zinkiewicz, and K. Hejduk, „Tunable semiconductor double-chirped mirror with high negative dispersion", *IEEE Photon. Technol. Lett.* **26**, 14–17 (2014).

[**B18**] P. Wnuk, P. Wasylczyk, L. Zinkiewicz, M. Dems, K. Hejduk, K. Reginski, A. Wojcik-Jedlinska, and A. Jasik, „Continuously tunable Yb:KYW femtosecond oscillator based on a tunable highly dispersive semiconductor mirror", *Opt. Express* **22**, 18284–18289 (2014).

[**B19**] K. Panajotov, M. Dems, C. Belmonte, H. Thienpont, Y. Xie, J. Beeckman, and K. Neyts, „Vertical-Cavity Surface-Emitting Laser with cholesteric liquid crystal overlay", *IEEE J. Lightwave Technol.* **32**, 20–26 (2014).

[**B20**] M. Gebski, M. Dems, M. Wasiak, J. A. Lott, and T. Czyszanowski, „Monolithic subwavelength high-index--contrast grating VCSEL", *IEEE Photon. Technol. Lett.* **27**, 1953–1956 (2015).

[**B21**] M. Marciniak, M. Gebski, M. Dems, E. Haglund, A. Larsson, M. Riaziat, J. A. Lott, and T. Czyszanowski, „Optimal parameters of monolithic high-contrast grating mirrors", *Opt. Lett.* **41**, 3495–3498 (2016).

[**B22**] T. Czyszanowski, M. Gebski, M. Dems, M. Wasiak, R. Sarzała, K. Panajotov, „Subwavelength grating as both emission mirror and electrical contact for VCSELs in any material system", *Scientific Reports* **7**, 40348 (2017).

3.5.2. Book chapters

[**C1**] M. Dems, T. Czyszanowski, R. Kotyński, K. Panajotov, „Plane-Wave Admittance Method and its Applications to Modeling Photonic Crystal Structures" in *Photonic Crystals: Physics and Technology*, pod redakcją C. Sibilia, T. M. Benson, M. Marciniak, T. Szoplik, Springer (2008), ISBN 978-88-470-0843-4, strony 253–278.

[**C2**] K. Panajotov, M. Dems, and T. Czyszanowski, „Photonic-Crystal VCSELs" in *Compact Semiconductor Lasers*, pod redakcją R. De La Rue, S. Yu, J.-M. Lourtioz, Wiley (2014), ISBN 978-3-527-41093-4, strony 149–193.

3.5.3. Publications in the SPIE proceedings

[**D1**] T. Czyszanowski, R. P. Sarzala, M. Dems, M. Wasiak, W. Nakwaski, and K. Panajotov, „Pulse-regime single-mode operation of antiwaveguide Photonic-Crystal 1300 nm VCSEL", *Proc. SPIE* **7720**, 77200a (2010).

[**D2**] M. Dems and K. Panajotov, „True photonic band-gap in vertical-cavity surface-emitting lasers", *Proc. SPIE* **8432**, 84321G (2012).

[**D3**] J. Walczak, T. Czyszanowski, M. Dems, R. P. Sarzala, A. Sokol, M. Wasiak, and V. Iakovlev, „Simulation of 1550 nm diamond VECSEL with high contrast grating", *Proc. SPIE* **8432**, 84321H (2012).

[**D4**] T. Czyszanowski, M. Dems, M. Wasiak, and R. P. Sarzala, „Three dimensional simulation of 1300 nm AlGaInAs VCSEL arrays", *Proc. SPIE* **8432**, 84320a (2012).

[**D5**] K. Panajotov, M. Dems, C. Belmonte, H. Thienpont, Y. Xie, J. Beeckman, and K. Neyts, „VCSELs with nematic and cholesteric liquid crystal overlays", *Proc. SPIE* **8639**, 86390a (2013).

[**D6**] T. Czyszanowski, M. Dems, R. P. Sarzala, and K. Panajotov, „Numerical analysis of photonic-crystal VCSELs", *Proc. SPIE* **8639**, 86390Q (2013).

[**D7**] M. Gebski, M. Dems, J. Chen, W. Qijie, Z. D. Hua, and T. Czyszanowski, „GaAs/AlOx high contrast gratings for 980 nm VCSELs", *Proc. SPIE* **8995**, 89950C (2014).

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3.5.4. Other conference publications

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3.5.5. Other publications

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3.5.6. Awarded patents

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3.6. Works published before receiving the Ph.D. degree

3.6.1. Publication in journals listed in the JCR

[**J1**] M. Dems and W. Nakwaski, „Thermal and molecular stresses in multi-layered structures of nitride devices", *Semicond. Sci. Technol.* **18**, 733–737 (2003).

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3.6.2. Publications in the SPIE proceedings

[**K1**] M. Dems, T. Czyszanowski, and K. Panajotov, „Plane-wave and cylindrical-wave admittance method for simulation of classical and photonic-crystal-based VCSELs", *Proc. SPIE* **6182**, 618219 (2006).

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3.6.3. Other conference publications

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[**L6**] T. Czyszanowski, R. P. Sarzala, M. Dems, H. Thienpont, and K. Panajotov, „Optimal designs of telecommunications oriented photonic-crystal VCSELs", in *ICTON 2007: Proceedings of the 9th International Conference on Transparent Optical Networks* **2**, 44–47 (2007).

3.7. Invited lectures in international scientific conferences

1. M. Dems, K. Panajotov, T. Czyszanowski, R. Kotynski, and W. Nakwaski, „Simulation of photonic crystal diode lasers with plane-wave admittance method", *7th International Conference on Transparent Optical Networks*, Barcelona, Spain, 3–7 July 2005.
2. M. Dems, T. Czyszanowski, K. Panajotov, „Strongly Birefringent and Dichroic VCSEL", *International Workshop on Advances in Physics and Technology of Photonic Crystals*, Prague, Czech Republic, 19 April 2007.

3. M. Dems, K. Panajotov, W. Nakwaski, „Polarization Control in VCSELs with Photonic Crystals”, *7th Belarusian-Russian Workshop “Semiconductor Lasers and Systems”*, Minsk, Belarus, 1–5 June 2009.
4. M. Dems, „Modelling of Photonic-Crystal VCSELs with Semi-Vectorial and Vectorial Models”, *11th International Conference on Transparent Optical Networks* (*ICTON 2009*), San Miguel, Portugal, 28 June – 2 July 2009.
5. M. Dems, I.-S. Chung, P. Nyakas, S. Bischoff, and K. Panajotov, „Modelling of photonic-crystal VCSELs with semi-vectorial and vectorial models”, *13th International Conference on Transparent Optical Networks* (*ICTON 2011*), Stockholm, Sweden, 26–30 June 2011.
6. M. Dems, P. Beling, M. Gebski, L. Piskorski, M. Kuc, M. Wasiak, and R. P. Sarzala, „Automated self-consistent approach to modeling of photonic devices”, *15th International Conference on Transparent Optical Networks (ICTON 2013)*, Cartagena, Spain, 23-27 June 2013.
7. M. Dems, M. Gębski, Jian Chen, Wang Qijie, Zhang Dao Hua, T. Czyszanowski, „Subwavelength high contrast grating mirrors for applications in vertical-cavity surface-emitting lasers”, *V Workshop on Physics and Technology of Semiconductor Lasers*, Kraków, Poland, 17-20 November 2013.

3.8. Teaching achievements

I have created course programs and lectures for the following courses: *Electrodynamic* (intermediate lecture in Polish for the 5th semester undergraduate track Technical Physics), *Foundations of Electrodynamics* (intermediate lecture in English for the 5th semester undergraduate track Science and Technology), *Programming in Engineering* (basic lecture and project in English for the 1st semester undergraduate track Science and Technology), and *Photonic Crystals and Optical Modeling* (advanced lecture and project in Polish for the 3rd semester postgraduate track Optoelectronics). Furthermore, in 2010 I have developed a series of model exercises and tutorials on photonic modeling within the project “Innovative Education. . . ” funded by the Operational Programme Human Capital. In 2016 I have prepared and conducted a series of tutorials on scientific programming and numerical data analysis in the course of the project “Skills Development Programme at the Lodz University of Technology on ICT” funded by the Operational Programme Knowledge Education Development.

3.9. Other achievements

3.9.1. Popularization of science

In the years 2002 – 2015 I was a supervisor of Student Association of Physics „Schrödinger’s Cat”. The most prominent role of the association was popularization of science. It was awarded in 2009 r. a prestigious prize Popularyzator Nauki by Polish Press Agency ans Ministry of Science and Higher Education. In addition, I cooperate with Lodz Children’s University, where in 2009 I presented a lecture “Let there be light. . . ” on the light and lasers for children 7–12 years old.

3.9.2. Scientific infrastructure development

Since 2005 I am responsible for construction, expansion and administration of High Performance Computing cluster `kraken`. The cluster consists of 20 servers HP ProLiant, each of which containing 2 Intel Xeon processors. Totally, the cluster providers 160 computing cores and 480 GiB RAM. It is used for advanced computing in photonics and molecular physics.

M. Dems