REVIEW

of the dissertation by Fedir O. Yevtushenko

"Resonant scattering and absorption of electromagnetic waves by infinite gratings of grapheme strips on dielectric substrates"

submitted for the degree of Doctor of Philosophy in the field of knowledge 10 "Natural Sciences" and the specialization 104 "Physics and Astronomy"

Urgency of the research topic

The mere fact that the dissertation explores electrodynamic structures with graphene elements is sufficient to consider its topic as urgent. A more detailed examination of the work will only strengthen this impression: algorithms with guaranteed convergence and controlled error have been developed for computer modeling of one-dimensional periodic gratings formed by graphene strips on a substrate. Using these algorithms, new scientific results have been obtained, and the studied periodic structures have been investigated not only as diffraction gratings but also as nanolasers in the THz and infrared ranges. All these aspects make the work relevant within the global scientific process.

Although the accessibility of technologies for working with micro- and nanostructures is increasing, laboratory experiments with them remain extremely costly. Therefore, the developed algorithms for computer simulation are highly valuable, especially for Ukraine, where conditions for experimental research on such structures are practically nonexistent.

Structure, content, and formatting of the dissertation

The dissertation is a logically structured study that sequentially describes the scientific process, starting with a literature review and the definition of approaches. It then proceeds with the formulation of mathematical problems and their solution using numerical methods. Subsequently, the developed algorithms are employed for modeling and analyzing the investigated electrodynamic structures. The dissertation is written in good English and is pleasant and interesting to read.

The dissertation comprises an abstract (in Ukrainian and English), an introduction (where the relevance, purpose, and objectives of the research are defined, methods used are described, and the novelty and value of the obtained results are outlined), four chapters with conclusions for each, general conclusions, a bibliography, and an appendix listing scientific publications and conference presentations based on the dissertation's material.

The work is formatted in accordance to the current requirements.

Connection to scientific programs, plans, and topics

The dissertation work was carried out at O. Ya. Usikov Institute of Radiophysics and Electronics of the National Academy of Sciences of Ukraine (Department of quasi-optics, Laboratory of micro- and nanooptics). The dissertation aligns with the scientific work of the Institute. The research was conducted within the framework of six state-funded and competitive research projects, including collaborations with University of Rennes 1 in France and T. Shevchenko National University of Kyiv. Additionally, the research was partially supported by an award from IEEE Antennas and Propagation Society in 2021.

Scientific results and their novelty

The dissertation contains the following novel scientific results. (i) The effect of electromagnetic induced transparency is discovered for H-polarization. It is realized by means of the tunability of plasmon modes via the chemical potential of graphene. This electrostatically controlled effect exists in the THz range on surfaces with a micro-sized periodicity. (ii) The existence of high-Q resonances on lattice modes, associated with Rayleigh anomalies, is demonstrated. They do not exist for gratings made of ideally conductive or graphene strips placed in free space. (iii) The threshold conditions for the modes of graphene strip gratings on the gain-material substrate acting as nanolasers were accurately studied. (iv) Analytical expressions for the complex frequencies of lattice modes are derived in the E-polarization case. These expressions, for the first time, demonstrate how the lattice mode poles hide to the non-physical sheet of the Riemann surface and migrate to the physical sheet due to the finite-thickness of substrate. (v) The rate of convergence of the developed numerical algorithms is studied, along with its dependence on various substrate and lattice parameters, including that of graphene.

Rationale grounds of the obtained results

The reliability of the obtained results stems from the mathematically rigorous formulation of the problems, the use of a reliable method of analytical regularization for preparation to the numerical solutions, and the numerical solutions themselves using methods with guaranteed convergence and controlled accuracy. Before being employed for research purposes, the developed algorithms underwent thorough testing.

The dissertation materials are published as five articles in peer-reviewed professional journals (all Q2 and Q3) and were presented as 11 talks at international conferences. This also serves as evidence of the high scientific level of the dissertation and publications.

Practical value of obtained results

The practical significance of the developed algorithms lies in their capacity to offer reliable simulations for sensors, absorbers, and filters based on graphene strip gratings in the THz and infrared frequency ranges. Unlike commercial software packages, the developed programs can deliver the precision necessary for accurately characterizing lattice-mode resonances. Additionally, these programs can serve as the foundation for multi-parametric optimization routines, thanks to their high speed and accuracy.

The analysis the electrostatic tunability of plasmon modes and their hybridization with lattice modes, along with the impact of electromagnetically induced transparency, assists in establishing secure frequency limits for designing frequency-tunable devices.

The details regarding threshold conditions for the modes of graphene-strip gratings on gain-material substrates can be applied in the design and assessment of low-threshold tunable nanolasers in the THz and infrared frequency ranges

Accomplishment of research tasks and mastery of the methodology of scientific work

The research methods employed in the study align with contemporary requirements for scientific studies. To fulfill the tasks, the author (i) has acquired proficiency in the method of analytical regularization, namely, using the Riemann-Hilbert problem method (in the case of H-polarization) or the inverse discrete Fourier transform (in the case of E-polarization), infinite matrix Fredholm equations of the second kind were obtained, whose numerical solution has guaranteed convergence. (ii) Based on these equations, full-wave meshless codes were developed, and their error behavior was studied. (iii) These programs were utilized to analyze the scattering and absorption characteristics of EM waves on graphene strip gratings. (iv) Approximate formulas for the frequencies and Q factors of plasmon, lattice, and dielectric substrate modes were derived. (v) An iterative search for the roots of determinantal equations and a full-wave analysis of threshold conditions for eigenmodes of a graphene strip grating on a gain-material substrate were conducted. The successful resolution of these tasks attests to the high level of accomplishment in the scientific research and the author's mastery of the methodology of scientific work.

Feedback on the dissertation

Like any work of this scope, this dissertation deserves several comments:

1. It might be beneficial to implement the algorithms not in MatLab but using the C programming language to make them even faster.
2. Formula (2.39) for E-polarization has the weight coefficient $|n|$ in the left, just like for H-polarization. However, in Chapter 1 (page 41, paragraph 1), it is stated that it should not be so.

3. It would be interesting to know the convergence speed and the rate of error decrease.
4. It would be nice to compare the developed algorithms with analytical results in scenarios where they exist.
5. It is unclear whether the results of the resonance investigation on pages 65–68 are new or if they are a continuation of algorithm validation.

These comments are purely cosmetic and do not affect the overall positive assessment of the dissertation.

Information on the academic integrity compliance

In the dissertation and scientific publications of Yevtushenko F. O., no instances of academic integrity violations have been identified.

Conclusions on the dissertation

The dissertation by F. O. Yevtushenko "Resonant scattering and absorption of electromagnetic waves by infinite gratings of grapheme strips on dielectric substrates" is a completed scientific work that fully complies with the requirements of the Ministry of Education and Science of Ukraine order No. 40 dated January 12, 2017 (with subsequent changes) and the Cabinet of Ministers of Ukraine resolution No. 44 dated January 12, 2022. The dissertation meets the standards in terms of execution level, relevance, volume and completeness of presentation, novelty and significance of the obtained results. The author, Fedir O. Yevtushenko, deserves to be awarded the degree of Doctor of Philosophy in the field of knowledge 10 "Natural Sciences" in the specialty 104 "Physics and Astronomy".

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The signature of PhD Kostyantyn Sirenko
is attested
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УКРАЇНА
ІНСТИТУТ РАДІОФІЗИКИ ТА ЕЛЕКТРОНІКИ ім. О.Я. УСИКОВА НАЦІОНАЛЬНОЇ АКАДЕМІЇ НАУК УКРАЇНИ
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