Introduction to photonics

Lecturers: Dr. Andrey Bogdanov
Assistants: Kirill Koshelev

October 22, 2019


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Kirill Koshelev

Master programs

1. Nanophotonics and metamaterials, 1^{st} semester.
2. Quantum materials, 1^{st} semester.

Course prerequisites: Electrodynamics

Course language: English

Important Dates:

Midterm #1 .... October 1, 2019
Final Exam .... January 15, 2020

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Contents

1 English

Abstract

Quantum optics studies the properties of light and light-matter interaction from the grounds of modern quantum mechanics. You will learn the basic quantum concepts of photon and polariton, how one can entangle photons, and find out whether one can violate Heisenberg principle.

The course aims at giving the students the basics of modern photonics and consider the basic practical tasks in this area. The course begins with a study of the theory of dielectric waveguides and optical resonators. The physical effects underlying the control of electromagnetic radiation are examined in detail. We will study methods that allow us to analyze the capture of light in resonators and it propagation in the simplest waveguide systems. The course presents the basics of the theory of photonic crystals and scattering theory.

1.1 Detailed content and structure with sectioning of lectures/seminars

№	Topic	Lecture	Seminar
	Part I Theory of waveguides		
1	Dielectric and Metal waveguides: part 1		
2	Dielectric and Metal waveguides: part 2		
3	Goos-Hanchen shift. Losses in waveguides. Propagation length		
	Part II Theory of optical resonators		
4	Fabry-Perot resonator. Eigenmodes. Quasi-normal modes		
5	Quality factor. Resonant transmission. Impedance matching and absorption		
6	Whispering gallery mode resonators		
	Part III Photonic Crystals		
7	Bragg reflector. T-matrix		
8	Band structure of 1D, 2D and 3D photonic crystals		
9	Plane wave expansion. Tight binding approximation		
10	Photonic crystal cavity		
	Part IV Coupled mode theory		
11	Reciprocity theorem. Orthogonality of waveguide modes		
12	Coupling between resonators and waveguides. CMT		
	Part V Scattering theory		
13	Lippmann-Schwinger equation. S-matrix		
14	S-matrix and coupled mode theory		
15	Scattering cross-section. Extinction cross-section. Absorption cross-section		

1.2 Recommended resources

1. L. D. Landau, et al. Electrodynamics of continuous media. Vol. 8. Elsevier (2013). [ENG]
2. L. D. Landau, and E.M. Lifshitz. The classical theory of fields. (1971). [RUS]
3. L. Novotny and B. Hecht. Principles of nano-optics. Cambridge university press (2012). [ENG]
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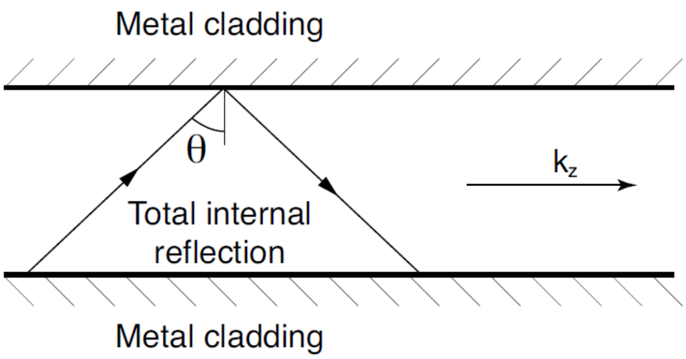
12. «Оптика» Online course [RUS]

1.3 Assignments

- There is a block of home problems, which are aim to help student in mastering the course (30- 40 problems of various level).
- During seminar classes the students are supposed to solve problems in class.

1.3.1 Tasks examples: Home Task 1

Submission deadline: 16.09
Correction submission deadline: 26.09
Threshold number of points allowing to make corrections is 2
The minimal number of points for successful passing the home task is 7



1. Find the dispersion equation of TM-polarized odd and even modes (**1 points**).
2. Plot the dispersion of TE and TM modes (**1 points**).
3. What are the differences between fundamental TE and TM modes (**2 points**)?
4. Plot distribution of different field components in xz-plane for TE and TM modes in the vicinity of cut-off frequency and far of it (**4 points**).
5. Plot electric and magnetic lines for TE and TM modes in xz-plane (**4 points**).
6. The geometrical theory of waveguides states that the waveguide mode represents the plane wave propagating inside the waveguide core reflecting from its claddings. According to the rigours electromagnetic theory the mode is determined by the mode number n, polarization, frequency ω , and wavenumber k_z. Find the relation between n, ω, k_z and angle θ (see Fig. 2). Analyze this dependence (**3 points**).

1.3.2 Colloquium questions on Mid-term attestation

1. The fundamental theorems of vector calculus. Vector differential operators in curvilinear orthogonal coordinates.
2. Complex amplitudes of electric and magnetic field.
3. Maxwell's equation in vacuum and in a media. Boundary conditions at plane interface.
4. Pointing vector and density of electromagnetic energy.
5. Electromagnetic waves. Wave equation. Dispersion equation in homogeneous dielectric media.
6. Polarization of electromagnetic waves. Stokes parameters. Polarization ellipse. Poincare sphere.
7. Fresnel equations. TE and TM polarizations. Brewster angle.
8. Dipole radiation.
9. Diffraction grating. Bloch theorem.
10. Waves in anisotropic media. Ordinary and extraordinary waves. Half- and quarter-wave plates. Birefringence.

1.3.3 Exam questions

1. Geometrical theory of waveguides.
2. Derivation of the dispersion equation (from Maxwell's equations) for eigenmodes of symmetric parallel plate hollow waveguide with metal claddings.
3. Mode structure of parallel plate hollow waveguide with metal claddings.
4. Derivation of the dispersion equation (from Maxwell's equations) for eigenmodes of parallel plate dielectric waveguide.
5. Dispersion of eigenmodes structure of parallel plate hollow waveguide with metal claddings. Graphical solution of the dispersion equation.
6. Phase and group velocity .
7. Field distribution in waveguide core and cladding layers of a dielectric slab waveguide.
8. Frequency cutoff and leaky modes.
9. Derivation of the dispersion equation (from Fresnel equation) for asymmetric parallel slab waveguide.
10. Goos-Hanchen shift.

11. Effective thickness of waveguide.
12. Losses in waveguides. Propagation length.
13. Classification of real waveguides.
14. Waveguide as a quantum well for photon.
15. Classification of optical resonators and their application.
16. Quality factor (definition, characteristic values for optical resonators).
17. Scattering matrix of two port network. Definition and main properties.
18. General form of S-matrix of symmetric time-reversal two port network without losses.
19. S-matrix of free space.
20. S-matrix of the interface separating two transparent media.
21. S-matrix of semi-transparent mirror.
22. S-matrix of Fabry-Perot resonator.
23. Transmission spectrum of Fabry-Perot resonator.
24. Main characteristics of Fabry-Perot resonator.
25. Resonant transmission and electron tunneling.
26. Fabry-Perot resonator with losses. The condition of perfect absorption.
27. Equation on resonant frequencies of whispering gallery modes in dielectric cylinder.
28. Field distribution of whispering gallery modes in dielectric cylinder.
29. Radiation losses of whispering gallery modes in dielectric cylinder.
30. Photonic crystals (definition, main properties, examples).
31. T-matrix for multilayer structure (TE and TM polarizations).
32. Derivation of the dispersion equation for 1D photonic crystal with unit cell consisting of two isotropic layers.
33. Band structure of 1D photonic crystal with unit cell consisting of two isotropic layers. Photonic band gap.
34. Reflection from 1D photonic crystal with unit cell consisting of two isotropic layers.
35. Effective medium approximation for multilayer structures. Spatial dispersion.

36. Width of photonic gap (weak contrast approximation).

37. Width of photonic gap (coupled mode theory).

38. Reciprocity theorem (conjugated form).

39. Reciprocity theorem (non-conjugated form).

40. Orthogonality of waveguide modes.

41. Integral identity for propagation constant.

42. Modal method for z-independent perturbation.

43. Coupling constant between two parallel waveguide.

44. Eigenmodes of coupled parallel waveguides.

45. Power exchange between two coupled parallel waveguides.

46. Temporal coupled mode theory. The main parameters, their physical meaning and properties.

47. Temporal coupled mode theory and scattering matrix.

48. Scattering of a plane wave on infinitely long cylinder with arbitrary cross-section. (S-matrix and R-matrix)

49. Scattering cross-section. Absorption cross-section. Extinction cross-section. Definition, geometrical meaning, physical meaning, connection with S-matrix.

50. Scattering problem in terms of temporal coupled mode theory. Expression for S-matrix.

51. Expressions scattering and absorption cross-sections predicted by temporal coupled mode theory.

1.4 Grading policy

1.4.1 Home tasks

- After each lecture you get a home task (see example 2.3.1).
- Each home task has a minimal number of point you need to get to pass the home task successfully.
- The solved home task should be sent to lecturer assistant by the deadline.
- Each home task has a deadline. If you didn't send your home tasks to the lecturer assistant by the deadline without reasonable excuse, the home task is accounted as failed.

- Each home task has a correction deadline. If you don't get enough points you can send the corrections to the lecturer assistant by the *correction deadline* set for each home tasks.

- Corrections can be sent to the lecturer assistant only if you get the minimal number of points mentioned in each home tasks.

1.4.2 Mid-term attestation

- Mid-term attestation consist of discussion with lecturer or lecturer assistant and answering the questions for the question list (see 2.3.2).

- Each students has two attempts to pass the mid-term attestation.

1.4.3 Admission to final exam

In order to admitted to the final exam you should have 70% of successfully passed home tasks.

1.4.4 Final exam

The final grade is completely determined by the final exam. The final exam consists of answering two questions for the question list (see 2.3.3) and discussion with lecturer or lecturer assistant.

1.5 Additional notes

Введение в фотонику

Лекторы: Андрей Богданов,
Ассистенты: Кирилл Кошелев

October 22, 2019

Программа магистратуры:

1. Нанофотоника и метаматериалы, 1$^{\text{ый}}$ семестр
2. Квантовые материалы, 1$^{\text{ый}}$ семестр

Предварительно пройденные курсы, необходимые для изучения предмета: Электродинамика

Язык курса: Английский

2 Русский

Аннотация

Quantum optics studies the properties of light and light-matter interaction from the grounds of modern quantum mechanics. You will learn the basic quantum concepts of photon and polariton, how one can entangle photons, and find out whether one can violate Heisenberg principle.

The course aims at giving the students the basics of modern photonics and consider the basic practical tasks in this area. The course begins with a study of the theory of dielectric waveguides and optical resonators. The physical effects underlying the control of electromagnetic radiation are examined in detail. We will study methods that allow us to analyze the capture of light in resonators and it propagation in the simplest waveguide systems. The course presents the basics of the theory of photonic crystals and scattering theory.

2.1 Детальное описание курса с разбиением по лекциям/ семинарам

№	Topic	Lecture	Seminar
	Part I Theory of waveguides		
1	Dielectric and Metal waveguides: part 1		
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2.2 Рекомендованная литература

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2.3 Задания

- There is a block of home problems, which are aim to help student in mastering the course (30- 40 problems of various level).
- During seminar classes the students are supposed to solve problems in class.

2.3.1 Пример: Домашнее задание 1

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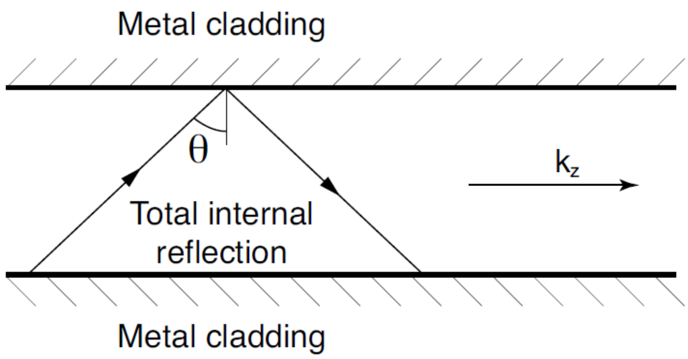

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2.3.2 Коллоквиум на промежуточной аттестации

1. The fundamental theorems of vector calculus. Vector differential operators in curvilinear orthogonal coordinates.
2. Complex amplitudes of electric and magnetic field.
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2.3.3 Экзамен

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2.4 Оценка успеваемости по курсу

2.4.1 Домашние задания?

- After each lecture you get a home task (see example 2.3.1).
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- Each home task has a correction deadline. If you don't get enough points you can send the corrections to the lecturer assistant by the *correction deadline* set for each home tasks.
- Corrections can be sent to the lecturer assistant only if you get the minimal number of points mentioned in each home tasks.

2.4.2 Промежуточная аттестация

- Промежуточная аттестация состоит из ответов на вопросы из списка (см. 2.3.2) и обсуждения лектором или ассистентом.
- У каждого студента есть две попытки пройти промежуточную аттестацию.

2.4.3 Допуск к экзамену

Для допуска на экзамен, у вас должно быть 70% успешно пройденных домашних заданий.

2.4.4 Экзамен

Итоговая оценка полностью определяется итоговым экзаменом. Финальный экзамен состоит из ответов на два вопроса из списка (см. 2.3.3) и обсуждения с лектором или ассистентом.

2.5 Дополнительные комментарии