Warsaw University
of Technology

COURSE OFFERED IN THE DOCTORAL SCHOOL

Code of the course	4606-ES-0000BCD-0103	Name of the course	Polish	**Kwantowa biofotonika**
			English	**Quantum biophotponics (QBF)**
Type of the course	Special courses			
Course coordinator	prof. dr hab. inż. Ryszard Romaniuk			
Implementing unit	WEiTI	Scientific discipline / disciplines*	information and communication technology, automation, electronic and electrical engineering, biomedical ingineering	

Level of education	Doctoral studies	Semester	Summer		
Language of the course	English				
Type of assessment:	Graded credit	Number of hours in a semester	30	ECTS credits	2
Minimum number of participants	12	Maximum number of participants	50	Available for students (BSc, MSc)	Yes/~~No~~

Type of classes		Lecture	Auditory classes	Project classes	Laboratory	Seminar
Number of hours	in a week	2	0	0	0	0
	in a semester	30	0	0	0	0

* does not apply to the Researcher's Workshop

1. Prerequisites

Recommended pre-courses: physics, photonics, electronic materials, computer architecture, bioelectronics, biomedical apparatus, metrology, image processing.

2. Course objectives

The aim of the course is to show the application of quantum techniques in biology, medicine, quantum metrology, research and protection of the natural environment, quantum imaging.

Quantum biophotonics (QBF), which is part of such disciplines as quantum information technologies, quantum metrology, imaging technologies, and biomedical apparatus, is not taught in a compact form as a whole. QBF is creating a new area of engineering and technical sciences on the border with life sciences and medicine. This area is interdisciplinary and includes the following specializations with the adjective quantum: principle of operation, technology of elements and devices as well as functional systems, photonics, computer science, architecture of quantum biomedical equipment, etc. Fast pace of development of this area allows for new measurement and imaging methods, more often well below the classical limits of resolution, noise, and even some of quantum limitations. Quantum apparatus will displace the classical one in many areas over the next decades.

3. Course content (separate for each type of classes)

Lecture

Quantum Biophotonics as a sub-area of quantum information techniques. Area of interest and branches QBF. Differences between classical interaction and imaging technologies and quantum ones. Quantum crossing of noise, diffraction and some quantum barriers. Biophotonics is a combination of biology and photonics, and in some more frequent and future-oriented areas, quantum information techniques, including metrology. Biophotonics concerns the development of the application of optical and quantum optical techniques, especially the detection of weak signals and imaging for the study of biological molecules, cells and tissues. The use of QBF techniques, e.g. in the form of quantum detectors, has a number of advantages that preserve the integrity of the biological objects under study. Biophotonics and QBF are general terms for all techniques dealing with the interaction between biological objects and photons, including single photons, photon-pairs, and non-classical waves like squeezed / anti-compressed, sub / super Poisson light. The phenomena studied include emission, detection, absorption, reflection, scattering, modification and generation of radiation from biomolecular objects, cells, tissues, organisms and biomaterials. The current application areas of BF and potential QBF include life sciences, medicine, agriculture, and environmental sciences. The main area of action / application of BF / QBF is diagnostics, although it also has therapeutic applications. The developed QBF techniques introduce completely new research possibilities in the above-mentioned areas and, consequently, the application. Areas such as microscopy, 2 / 3/4D imaging, sensor fusion, knowledge extraction, weak signal detection and processing, magnetometry, etc. have strong quantum perspectives.

A reminder of the classics, metrology, intelligent imaging - a key element of diagnostics, noise and distortions, noise confinement, diffraction and quantum limitations, the limits of classical techniques, Rayleigh's criterion, data formats, data processing. What is given additionally by quantum technologies in comparison to the classical methods. Technological availability of quantum techniques.
Quantum optics. Photon Statistics. Poisson light. Super and sub-Poisson light. A single photon. The Heisenberg principle. Photonics. Quantum lighting. Detection of non-classical light. Signals below noise.
Quantum information. Qubit. Non-locality. Entanglement. Informational causality. Processing quantum information. Theorems about quantum impossibilities. The relation of quantum to classical information. Quantum coherence and decoherence. Accuracy in quantum operations.
Biophotonics. Definition of the domain. Biophotonic phenomena. Applications. Review of biophotonic techniques. Raman and FTIR (Fourier-transform IR) spectroscopic techniques. Nanoscale optical trapping. Photoacoustic microscopy (PAM). Strong and weak laser interactions. Photodynamic, photoactivation and photothermal techniques. Resonant energy transfer.
Quantum biophysics. Quantum biology. Quantum Biophotonics. An unusual meeting of quantum physics and quantum optics with biology, medicine and life sciences. Quantum information biology (QIB).
Optical biosignals. Biofluorescence. Bioluminescence. Biophosphorescence. Biolaser. Photonic activation and deactivation. Quantum activation. Quantum decoherence in biological systems.
Quantum metrology. Classical metrology and quantum enhancement. How Accurate is Quantum Metrology. Quantum and classical estimation. Two-part and multi-part entanglement. Heisenberg limit. Where to look for an advantage over classical metrology. The noise and imperfections of the experiment. The quantum Zeno effect and the accumulation of errors. Quantum metrology in biomedicine.
Quantum materials in biophotonics. Photonic metamaterials. Elliptical materials, How does elliptical metamaterial give super resolution? The use of metamaterials in the construction of equipment, Increasing the resolution of imaging. detectors, sources, microscopy, Nano-markers, fluorescent nanodiamonds, Fluorescent nanoprobes - AgInS2 quantum dots.
Quantum sensors. Technical maturity of quantum sensors. Limitations of quantum sensors. Accuracy of quantum sensors. Quantum sensors for the measurement of biomedical quantities. SQID. Compressed light interferometer. Quantum NMR spectroscopy. Entangled photon detection. Quantum pixel detectors.
Quantum and classical imaging. Quantum lithography. Ghost imaging. Pixel dimension and sensor dimension - two approaches to increasing the resolution, Imaging quantum matrices, Types of quantum imaging methods.
Quantum microscopy. Modified microscopic techniques. Rules for increasing the resolution. LSM (light sheet microscopy) technique, kinds of quantum light microscopy, ultra-fast 3D imaging using the LSM method.
Photonic techniques. OB techniques (optical biopsies), endospectroscopic imaging.
MPI / MPE (multiphoton imaging / endosopy) techniques, multi-photon imaging, fiber optic probes, technical solutions of Raman probes, SRS techniques (spontaneous Raman spectroscopy), spontaneous Raman spectroscopy, fast in-vivo diagnostics without markers, non-elastic photon scattering on the molecule causing excitation characteristic for its vibration modes, single-cell and tissue analysis, distinguishing macromolecules of proteins, lipids, nucleic acids, carbohydrates and others, CRS microscopic techniques (coherent Raman scattering) microscopy with coherent Raman scattering, belongs to the SRS group, SERS techniques (surface-enhanced Raman spectroscopy), belongs to the SRS group, MES (microendospectroscopy) techniques, micro-endo-spectroscopic imaging, CSAR (coherent anti-stokes Raman scattering) techniques, coherent anti-Stokes Raman scattering,
TPEF Techniques (two-photon excited autofluorescence) excited two-photon autofluorescence, MUSE techniques (microscopy with UV surface excitation): non-destructive microscopy with UV surface excitation for molecular tests. SHG techniques (second harmonic generation) excitation of the second harmonic in a sample for identification and differentiation, THzI techniques (terahertz imaging), terahertz imaging equipment.
Special techniques. Mesoscopic and nanoscopic techniques. Plasmonics. Micro and nanofluidics, Nanoscopic trapping, Optical tweezers. Quantum labeling. Quantum fluorescent labels (quantum dots). Quantum emergencies. Quantum drug discovery techniques.
Subcritical and activation interactions. Photodynamic, photoactivation and photothermal techniques. Quantum nanoactivators. FRET (Forster resonance Energy transfer) techniques. Optogenetics. National experiments in the field of quantum optogenetics.
Quantum assisted computational techniques in biophysics and biophotonics. Machine learning and AI for data interpretation. Biology-inspired quantum computational techniques. Hardware and programming environments for the design and construction of quantum apparatus and software: QISKIT, ARTIQ, SINARA.

Project

4. Learning outcomes			
	Learning outcomes description	Reference to the learning outcomes of the WUT DS	Learning outcomes verification methods*
Knowledge			
K01	Has knowledge of: the basics of quantum physics, quantum phenomena, including photonic ones, in biomedical systems, and those used to build technical devices.	SD_W2, SD_W3,	exam, presentation evaluation; assessment of activity during classes;
K02	Has ordered, theoretically founded knowledge in the field of design and rules of using quantum technical devices such as sensors, measuring devices, complex systems, including biomedical quantum apparatus.	SD_W2, SD_W3,	exam, presentation evaluation; assessment of activity during classes;
K03	Can assess where the potential of IQT techniques can be used in biomedical research and medicine.	SD_W2, SD_W3,	exam, presentation evaluation; assessment of activity during classes; housework;
Skills			
S01	Is able to use the known methods and theoretical and technical models to analyze the basic issues in the area of quantum biophysics and biophotonics and some quantum information technologies and to basic methods of designing functional quantum metrological devices.	SD_U1, SD_U4, SD_U5, SD_U8,	exam, presentation evaluation; assessment of activity during classes;
S02	Can use the learned principles and methods of quantum biophotonics and some quantum information technologies as well as appropriate design tools to solve basic tasks in the field of quantum metrology and its integration with classical methods.	SD_U1, SD_U4, SD_U5, SD_U8,	exam, presentation evaluation; assessment of activity during classes;
S03	Can obtain information from literature, databases and other sources; Can integrate the obtained information, interpret it, as well as draw conclusions and formulate and justify opinions. Can work effectively in a virtual design environment.	SD_U1, SD_U4, SD_U5, SD_U8,	exam, presentation evaluation; assessment of activity during classes;
Social competences			
SC01	Understands the need for lifelong learning; can inspire and organize the learning process of other people.	SD_K2, SD_K4,	exam, presentation evaluation; assessment of activity during classes;
SC02	Can interact and work in a group, assuming various roles in it.	SD_K2, SD_K4,	exam, presentation evaluation; assessment of activity during classes; housework;

*Allowed learning outcomes verification methods: exam; oral exam; written test; oral test; project evaluation; report evaluation; presentation evaluation; active participation during classes; homework; tests

5. Assessment criteria
Activity during classes; Substantive quality of the preparation of an individual academic seminar; Participation in publication workshop/seminar and preparation of a team article;

6. Literature

Basic bibliography (exemplary):
[1] M.Arndt, et al., 2009, Quantum physics meets biology, HFSPJ 3(6) 386-400
[2] Di Zhou, R.Gilmore, 2010, What is quantum biophysics, physics.drexel.edu
[3] G.R.Fleming, et al., 2011, Quantum effects in biology, Proceedia Chem. 3(2011) 38-57
[4] Ken-Tye Yong, 2012, Quantum dots for biophotonics, Theranostics 2(7) 629-630
[5] L.Liu, et.ao., 2013, NIR Ag nanocrystals as optical probes for in Vivo applications, Theranostics 3(2) 109-115
[6] M.Asano, et al., 2015, Quantum information biology, arXiv:1503.02515
[7] A.Stekhin, et al., 2018, Quantum biophysics of water, CP 15(3) 663-670
[8] V.Giovannetti, 2011, Advances in quantum metrology, arXiv:1102.2318
[9] R.Demkowicz-Dobrzański, et al., 2012, The elusive Heisenberg limit in quantum enhanced metrology, arXiv:1201.3940
[10] Y.Israel, et al., 2014, Supersensitive polarization microscopy using NOON states of light, PRL 112(103604)
[11] G.Toth, I.Apellaniz, 2014, Quantum metrology from a quantum information science perspective, arXiv:1405.4878
[12] M.Tsang, et al., Quantum theory of superresolution for two incoherent optical point sources, arXiv:1511.00552
[13] S.Piradola, et al., 2018, Advances in photonic quantum sensing, arXiv:1811.01969
[14] L.Pezze, et al., 2018, Quantum metrology with nonclassical states of atomic ensembles, arXiv:1609.01609
[15] Journals, Photonics Spectra Magazine [photonics.com]; Biophotonics magazine [biophotonics-digital.com]; AIP Biophysics Reviews [aip.scitation.org/journal/bpr]
Supplementary bibliography:
A series of articles by the lecturer on IQT published in the IJET PAN quarterly and the Elektronika monthly in the years 2021-22

7. PhD student's workload necessary to achieve the learning outcomes**

No.	Description	Number of hours
1	Hours of scheduled instruction given by the academic teacher in the classroom	30
2	Hours of consultations with the academic teacher, exams, tests, etc.	10
3	Amount of time devoted to the preparation for classes, preparation of presentations, reports, projects, homework	20
4	Amount of time devoted to the preparation for exams, test, assessments	10
	Total number of hours	**70**
	ECTS credits	**2**

** 1 ECTS = 25-30 hours of the PhD students work (2 ECTS = 60 hours; 4 ECTS = 110 hours, etc.)