

Teaching methods of photonics and paradigm of present-day science

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Abstract: - The article deals with the teaching methods of photonics in relation to the paradigm of present-day science. The reasoning is referring the difference between old (Cartesian-Newtonian) paradigm of science and the new one. Special problems of teaching methods of photonics are analysed. These problems are connected with the interpretation of „non-classical“ phenomena concerning the principles of new paradigm of science. Basic system of photonics teaching methods at Department of Radio Electronics of FEEC BUT in Brno are presented.

Key-Words: - paradigm of science, teaching methods of photonics, optical communications

1 Introduction

The definition and the meaning of photonics are included in the following text (see [1]): „Photonics – the generation, transmission, manipulation, detection and utilization of light information and energy – is to be in the 21st century what electronics was in the 20th. It is often called “the next multi-trillion-dollar industry”. But I would say that – more than an industry – photonics is a key enabling technology that cuts through all industry sectors, from medicine to manufacturing, from research to consumer products, from art to telecommunications. So why are so few people educated and trained to work in photonics? And what are we going to do about it?”

These two questions became the basis for reflections in this article. Not only applications of photonics, but its physical bases and philosophical connections as well should be stressed in the photonics teaching. Some problems appear at the moment when the students meet „non-classical“ phenomena which they have to accept, interpret and apply somehow. It is necessary to overcome certain difficulties resulting from explaining of „non-classical“ phenomena and principles like e.g.: particle-wave duality, the Heisenberg uncertainty principle, probabilistic character of microcosm, information growth in informatively opened systems with positive feedback etc.

The students have got natural tendency to associate the „non-classical“ phenomena with their classical ideas. It is incorrect to associate visual macroscopic pictures with the microcosm on principle. Microcosm has its own „logic“ and we can only try to perceive the phenomena of microcosm somehow by means of what we have at disposal. In connection with photonics teaching it appears as needed to present certain phenomena in connections with paradigm of present-day science and to stress that we describe something what is not immediately accessible to our senses. In understanding of microcosm phenomena it is necessary to accept inner contradiction of researched field.

The application of photonics elements in optical communications has got a lot of advantages mainly lying in achieving high bit rate and in obtaining large number of communication channels joined by means of WDM technology. Optical communications development was stimulated mainly by managing the technologies of optical fibres, semiconductor lasers and photodiodes. It is necessary to include photonics in teaching, but extend of photonics teaching at the universities does not correspond with its importance. We are pleased by the fact, that an appropriate attention is given to photonics teaching at Department of Radio Electronics of FEEC BUT in Brno [2]. Department of Radio Electronics has got good experience in photonics teaching both in theory and practice. Photonics applications at Department of Radio Electronics are concentrated on optical communications and medicine.

2 Fundamentals of present-day science paradigm

Paradigm is the basic model of ideas by means of which it is possible to interpret certain field of reality as a whole. Substantial paradigm of classical science (Cartesian-Newtonian paradigm) was drawn up in the 17th century. Paradigm of modern science comes from the knowledge of the 20th century science. In this article the paradigm of science is not analysed in detail, controversial conclusions are not discussed. Chosen are only those points to which appropriate attention in teaching the fundamentals of photonics should be devoted [3].

It is possible to sum up the whole characteristics of modern science paradigm into following points [4]:

1. Universal world constant was accepted – the velocity of light in vacuum, which represents the limiting velocity of energetic effects spreading. The consequence is that there is not one universal time in cosmos. In various reference systems the time may pass differently in speed. The present is not a moment but it is variable interval and its magnitude is in general different for various reference systems.

2. The theory of irreversible time was accepted with that, that cosmos has its own history beginning with Big Bang. Elementary particles are certain memory state of original dynamic activity and within this meaning the time enters the objects.

3. Planck constant – constant associated with energy quanta was accepted. As a result, there are relations of uncertainty which show on impossibility of single-valued deterministic prediction of observable quantities. The light quantum of energy is called photon and it is possible to join it with material quantities such as mass, moment and spin. Particle character of light appears by generation or detection of light and e.g. in elucidation of quantum noise in optical communications it is impossible to avoid it.

4. There was a wave function postulated in the quantum theory [5]: „For any possible state of a system, there is a function, ψ , of the coordinates of the parts of the system and time that completely describes the system.“ (ψ is called a wave function and the state of system that is described is the quantum state.) For the wave function the meaning of probability was given: “The quantity $\psi\psi^*d\tau$ is proportional of finding the particles of the system in the volume element $d\tau$ “. The consequence is the principle meaning of probability and statistics in microcosm. The wave function may be linked both with field and material particles.

5. It was proved that positive feedback under certain conditions need not lead to collapse of the system and its degradation to lower, less organised level. Under certain conditions in the system a new (higher) stationary state may come into existence. These conditions are: information, energetic and material openness of the system, big fluctuations of the system and proof of „newness“ by new rules enabling its repeating. As a result there is a conception of informatively opened cosmos with emergent changes of order. (Stimulated emission – principle of laser – serve as an example for information exchange among objects).

6. Genetic memory as a memory of past evolution (time), which entered the new order was proved. The ability of nature systems to self-renewing its own order is the result of genetic memory. The condition of systems self-creation the is that existing order of nature activity includes in itself not only certain openness towards next evolution (information openness), but it is the memory of past evolution (past time) at the same time.

7. Human being had been included in nature activity as a whole. Impossibility of separation the experimenter from the experiment serve as a result. (See double-slotted experiment of interfering electrons: „While we see the electrons, they do not interfere; while we do not see the electrons, they interfere!“ [6].)

With the new paradigm of modern science Newton's substantial conception of reality and Descartes' partition of reality to two wholly separate and independent on themselves realities – substance and spirit – falls. This statement does not lower the greatness of Newton and Descartes, however, substantial Cartesian-Newtonian paradigm of classical science is for the present-day science unacceptable. There is no place for detailed reflections about old and new paradigm of science

in this article. Therefore only choice of some conclusions resulting from the new paradigm of science important for the photonics teaching follows.

Microcosm appears as if there is a move but there was no moving object and it is not possible to describe it by means of illustrative macroscopic pictures [4]. From the particle-wave duality results that the material particle sometimes expresses itself as „non-local“ wave and the field has sometimes expression of local particles. Mentioned feature has to be explained correctly: Particle of microcosm is not particle and wave at the same time and light is not wave and particles at the same time. The wave aspect of material elements indicates, that it is not possible to separate them exactly from the surroundings and the particle aspect of light indicates, that emission and reception of light are done in quanta. Using of macroscopic pictures “particle” and “wave” is for microcosm imperfect but there is nothing better available. Terms wave and particles are used only for better illustration, however, building up an idea of microcosm similar to that, we are get used from classic level of reality, is incorrect.

3 Pedagogical aspect of photonics and research aided education

Photonics teaching at Department of Radio Electronics goes on in three courses representing a whole system. However, each of them can be considered as an independent course. „Quantum and laser electronics“ is the first course of the comprehensive photonics teaching. In this course the basic characteristics of laser radiation, laser theory, laser drivers, laser family, characteristics of special lasers and laser applications in medicine and optical communications are presented. The subjects of interest are also physical and philosophical aspects of quantum theory and statistical thermodynamics.

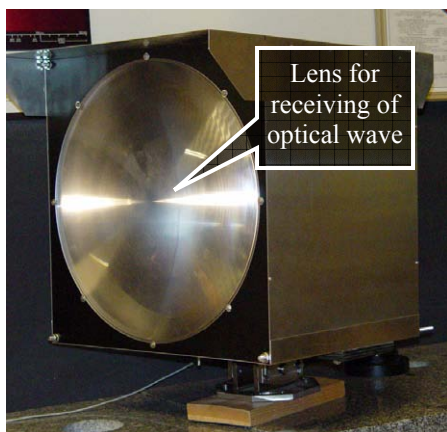
„Quantum and laser electronics“ is followed by „Optoelectronics“. This course begins with an approach to fibre-optic communication systems. Wave optics, Fourier optics, semiconductor optoelectronics, theory of mode distribution in optical fibre and matrix optics are presented. Then, designing of fibre-optic communication systems (link budget analysis, dispersion limitation) is clarified. Energy and information aspects are pointed out. The subjects of interest are also laser safety in optoelectronics laboratory and medical aspects of optoelectronics.

„Photonics and optical communications“ is the last course of comprehensive teaching of optical communications at Department of Radio Electronics. In this course photon optics, coherent and non-linear lightwave communications, soliton transmissions in optical fibres and design aspects of erbium-doped fibre amplifiers are presented. Other subjects of interest are atmospheric optical propagation and its effect on communication performance in space links. And finally, penetration of photonics transport technologies into networks, especially optical multiple accessing and services of optical networks are discussed.

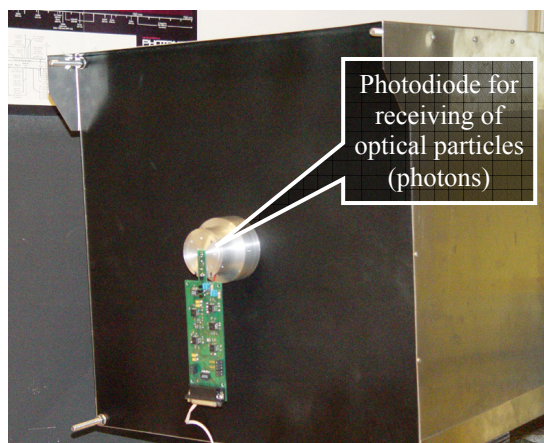
The ways of thinking our students - the knowledge of a new paradigm of science and the responsibility for application of their new skills - plays an important role in development and applications of communication technologies. With those in mind, the comprehensive teaching of photonics at Department of Radio Electronics includes philosophical aspects of mysterious quantum theory and social aspects of open optical networks as well.

Photonics teaching at Department of Radio Electronics is supported by its own research and by projects in the field of optical wireless links (OWL), microwave photonics, optical quantum key distribution etc. One of the projects in photonics, developed at Department of Radio Electronics and supported by the Ministry of Education was the development of single-photon receiver with avalanche photodiode (SP-APD receiver). It is possible to use the SP-APD receiver in optic wireless transmissions working on the technology of „quantum key distribution” (QKD) or reception of low optical signals from the satellite. Optical QKD transmissions via OWL are used in optical quantum cryptography. This application of photonics is hardly possible to manage without knowledge of new paradigm of science.

The students consider it interesting, that in application of optical part SP-APD receiver via OWL, not only the problem of receiving the only “local” photon, but “non-local” optical waves, have to be solved as well. The information of one bit is coded in certain quantum state of one photon and it is carried by light wave of certain polarization. For optical waves the receiving Fresnel’s lens was proposed and for single-photon detection the special SP-APD receiver with quenching circuit (see Fig. 1, 2) [7] was developed.



Pic. 1 SP-APD receiver (front view)



Pic. 2 SP-APD receiver (back view)

The importance of quantum cryptography lies in the fact, that aggressor intercepting the quantum transmission canal has not (thanks quantum theory rules, on principle) a possibility to measure exactly transmitted quantum state and to obtain an information from it, without being identified. Nowadays the OWLs are at high technology level and the experiment published in [8] shows that (SP-QKD via OWL) are able to operate at range of 10 km in terrestrial conditions with practical data rates.

4 Conclusion

The basic organisation of photonics teaching at Department of Radio Electronics of FEEC BUT in Brno is showed in the article. Brief characteristic of new paradigm of present-day science is elucidated as well. Social importance and perspectives of photonics are sufficient reason to include it in the system of teaching at technical universities. The present extend of photonics teaching at the universities, however, does not correspond to its importance. The purpose of the article is to support the interest to photonics teaching.

It is suggested that photonics teaching should be completed in higher degree with the study of paradigm of present-day science, because the principles, which the student within photonics teaching meets, are beyond the bounds of classical human imagination. The basic request for correct approach to paradoxes of photonics is not to apply classic conceptions of macrocosm there, where totally different (“non-classical”) level of reality is concerned.

The article is completed with the example of own photonics research, concerning the development of SP-APD receiver with quenching circuit. It turned out as necessary that the project researchers are acquainted closer with the new paradigm of science. This new paradigm aimed the discussions about the purpose of the work at the scope of tactful professionalism.

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References:

- [1] <http://www.opeta.ca/>
- [3] SALEH, B. E. A. - TEICH, M. C., Fundamentals of Photonics, New York, Wiley, 1991.
- [4] KRÁL, M., Změna paradigmatu vědy, FÚ AV ČR Filosofie, Praha 1994.
- [2] TOMANEK, P. Fotonika na Vysokém učení technickém v Brně. *Inf. bulletin ČSSP*, No 30, 2001
- [5] HOUSE, J. E., Fundamentals of Quantum Mechanics, London, Academic Press, 1998.
- [6] FEYNMAN, R. P. et al., Feynmanove přednášky z fyziky 2, Bratislava, ALFA, 1982.
- [7] ŠÍP, J., WILFERT, O., Active quenching circuit for single-photon avalanche diodes. *Proceedings of Elektrotechnika a informatika 2002, ZCU Plzeň 2002*, p.280-282.
- [8] HUGLES, R. J., NORDHOLD, J. E., DERKACS, D., PETERSON, C. G., Practical free-space quantum key distribution over 10 km in daylight and at night, *New Journal of Physics* 4, 2002.