

Ten-year experience in continuing biomedical optics education  
at Saratov State University

V.V.Tuchin, A.B.Pravdin

Saratov State University, Optics Department  
Astrakhanskaya 83, Saratov 410071, Russia  
E-mail <tuchin@scnit.saratov.su>

Key words: biomedical optics, continuing education, interdisciplinary approach

## 1. INTRODUCTION

Nowadays in Russia, as well as in Europe, problem of the lack of trained specialists in interdisciplinary fields of science and technology, and among them engineers-physicists and physicists-researchers able to collaborate with biologists and physicians at high today's scientific level, is sharply outlined.

As a result, problems are evident in efficiency of employment and development of modern medical diagnostic and therapeutic equipment. Skilled specialists trained in the field of physics and mathematics with substantial knowledge in biology and medicine are needed. Similar situation has been seen in Russia in the field of biophysics in early sixties. Today, in medicine, the growing emphasis is placed on less invasive methods of intervention [1]. The demand of less invasive intervention is best of all met by laser (optical) diagnostic methods and laser treatment. The use of these techniques and laser surgery methods and tools provides shorter hospitalization and rehabilitation time. But the medical personnel and technicians who work now in clinics often can't provide effective, reliable, and safe employment of such intricate equipment as laser units and tools.

However, if for the efficient and safe clinical use of lasers training specialists in the field of laser technology and optical units with very general understanding of medico-biological principles of laser radiation effect on bio-objects seems to be sufficient, in the case of basic medical and biological research the participation of specialist with basic education in biotissue optics, properties of coherent radiation, theory of lasers and fiber optics, laser measurements, and principles of spectroscopy, on the one hand, and physiology, biochemical and biophysical mechanisms of radiation action on living systems, principles of medical diagnosis and objective criteria of treatment, on the other hand, is essential.

In recent years, the need for specialists trained in physics and laser technology and at the same time with the knowledge of biology and medical disciplines is evident in industry. Many plants and research-productive amalgamations with modern high technologies lost the bulk of orders for the cutting of budget allocations to defense (in the US the reduction of defense spending takes place too [1]).

Conversion of industry, the use of high technology facilities for production of technically intricate medical equipment, including laser diagnostic and therapeutical units, is the way out. As a rule, large manufacturers have their own research and design departments, and that is the place where the specialists trained in biomedical optics are needed.

It is University with its traditional developed system of basic education in various fields of natural sciences that is able to train specialists who can on the base of basic knowledge and practical skills perform research and design project on their own. At the same time, basic training and additional training of instructors and lecturers for higher school remain the central task of educational process at University.

Highly qualified faculty, permanent research activity, close relations with research and development divisions of industrial enterprises and with research groups in clinics, all that forms the basis for realization of the principle of continuity in biomedical optics education: physicist/engineer-physicist - Candidate of Science (Ph.D.) - Doctor of Science.

## 2. FIELDS OF RESEARCH AND TRAINING

For ten years works on biomedical optics hold a firm place in research activity of Optics Department of Saratov University. There are many projects that are performed in collaboration with institutes of Russian Academy of Sciences and medical research centers. To our opinion, training students in such substantially interdisciplinary subspecialty as biomedical optics besides understanding by the students basic principles of physical and biomedical disciplines should include early and active participation in real research work. The fields of research work which is performed at Optics Department and collaborating laboratories are the following :

The study of optical properties of eye tissues is conducted as co-work with Laboratory of Laser Medicine of Saratov Branch of Radioengineering and Electronics Institute of Russian Academy of Sciences. For experiments on bio-objects, there were created and are intensively used laser polarizing nephelometer and other computer-aided optical measuring experimental setups. The investigations of biotissues by means of optical-acoustic spectroscopy are performed. Group of researches deals with the problems of mathematical modeling of optical properties of ordered biotissues. Personnel of the laboratory as half-time faculty provides practical training in automation of biomedical research and in computing.

On the base of Laboratory of Laser and Optoelectronic Measuring Systems of Saratov Branch of Mechanical Engineering Institute of Russian Academy of Sciences the Branch of Optics Department was organized [2]. The main field of research activity here is the development of fundamental problems connected with diffraction and interference methods of measurements [3]. As applied to bio-objects the methods of pulse-wave and cardiovibration monitoring, capillary blood and lymph flow analysis based on the dynamics of statistically inhomogeneous speckles, study of epidermis structure by means of laser scanning microscopy are developed.

At the Laboratory of Laser and Optical Methods of Diagnosis and Therapy of Saratov Institute of Rural Hygiene students take part in development of laser and fiber optic equipment for in vivo experiments. They have an opportunity to work with laboratory animals and volunteers. Here the alterations of optical properties of skin and skin physiological response to UV laser irradiation are studied, the techniques of phototesting, laser therapy, and PUVA therapy are developed.

At the Central Research Laboratory of Saratov State Medical University students specializing in biomedical optics can study microscopy techniques: microscopy with image analysis, microphotometry, and microfluorimetry. They can prepare here their annual student projects or diploma thesis (see below) in the field of the effect of low intensity laser radiation on biosystems. At this laboratory the laser speckle-anemometer for biological fluids diagnostics (see the list of special laboratories in biophysics below) is mounted.

Just at the Optics Department, in the Laboratory of Photobiology and Photomedicine, the research activity is concentrated on the study of optical properties of biotissues (absorption spectrophotometry, reflectance spectrophotometry, fluorescence spectroscopy, and resonance Raman spectroscopy), on the theoretical aspects of light propagation within scattering media with absorption, on reverse problem of biotissue optics, and improvement of computational technique. Group of researches is engaged in development of mathematical model of cell dynamics control by low intensity laser radiation.

The active participation of students in biomedical optics research is realized in the frame of curriculum through the work at annual student's project and diploma work and during long-term practical training (see curriculum below), in the case of post-graduate students through research on their own, under the supervision of leading researchers of laboratories. Students may begin their research work just at the first academic year preparing the annual student's project, as a rule, in a form of literature review on the topical problem of biomedical optics, the theme of review being assigned by instructor. Subsequent annual projects include elements of computations and/or experimental work. The results obtained are discussed at special seminar. All students may participate in discussions at the seminar "Topical problems of laser biomedicine". During tenth semester students work at their diploma works. It is a practice when the work is carried out in the laboratory where the student will get position. The best results usually serve as a basis for publications or presentations at conferences. Contributions with students as co-authors was presented at many conferences, such as Biomedical Optics in USA and Europe, in 1992-1995. Some ten students and instructors of Optics Department of Saratov University took part in International Conference on Education in Optics, Sept.-Oct. 1991, St. Petersburg, Russia.

Let us list some titles of diploma works of the students specializing in biomedical optics: "The investigation of statistical properties of partially developed speckle-fields in analysis of human epidermis structure", "The development of breadboard model of laser photoerythroelastometer", "Dynamics of epidermis fluorophores photobleaching", "Numerical simulation of light propagation in scattering media with macro inhomogeneities", "The use of resonance Raman spectroscopy for detection of carotene in human blood serum".

During last five years Optics Department established close contacts with world biomedical optics community. Some ten professors and researchers are the members of BiOS (Biomedical Optics Society), and representatives of the Department take part almost in all BiOS supported events. Optics Department performs active scientific and educational exchange with the research and educational centers from the USA, Germany, the Netherlands. Some joint research is conducted by our researchers at our partners' laboratories, and our professors deliver lectures abroad. In turn, leading foreign experts in biomedical optics deliver lectures to our undergraduates and postgraduate students. Two students study current academic year in USA:- undergraduate student studies and prepared her diploma thesis on optical properties of scattering phantoms of living tissue at Middlebury college, Vermont;- postgraduate student works at his Ph.D. thesis and participates in research on development of optical diagnostics methods at Pennsylvania University, Philadelphia.

This year five students of Optics Department were awarded the title "Soros Student" and got the ISF stipend.

### 3. CURRICULUM OF "BIOMEDICAL OPTICS" SUBSPECIALTY

Training in specialty "physics" (biomedical optics being one of the subspecialties of it) takes five academic years. During first three years students get fundamental knowledge in mathematics and physics. Common curriculum for the specialty is shown in Table 1. Just at the first year from the course "Introduction into specialty" students gain the impression about biomedical optics research that is performed at Optics Department. Specialized training begins according to current curriculum from the third year. Disciplines of the specialization "biomedical optics" are listed in Table 2.

Table 1. Common curriculum for specialty "Physics"

Disciplines	Exam	Pass-exam	Hours				
	The number of the corresponding semester		Total	Lectures	Laboratory	Practical trng	Seminars /trng
1. Political history of XX century	1	2	120	40			60/20
2. Philosophy	4	3	140	56			60/24
3. Political economy	6	5	140	54			62/24
4. Sociology	9	8	80	34			34/12
5. History of religion and atheism		9	24	24			
6. Fundamentals of law		9	32	28			/4
7. Labour protection and protection of environment		1	36	36			
8. Foreign language	6	3, 4, 5	260			180	/36
9. Introduction into the specialty			18	18			
10. Seminar on annual student project and diploma work *)		2,4,6,8, 10	86				/86
11. Higher mathematics:							
a) mathematical analysis	1, 2, 3	1, 2	406	212		106	/88
b) analytical geometry and higher algebra	2	1	140	70		35	/35
c) principles of vector and							

tensor analysis		3	54	36		18	
d) differential and integral equations	3		72	36		18	/18
e) probability theory and mathematical statistics		6	68	34		17	/17
12. General physics:							
a) mechanics	1	1	126	72		36	/18
b) molecular physics	2	2	119	68		34	/17
c) electricity and magnetism	3	3	126	72		36	/18
d) optics	4	4	119	68		34	/17
e) physics of atom	5		90	54		18	/18
f) nuclear physics and physics of elementary particles	6		34	34			
13. Practical training in physics		1 - 6	403		210		/193
14. Physical principles of radioengineering	4	4	119	51	68		
15. Theoretical physics:							
a) methods of mathematical physics	5	4	106	53	35		/18
b) analytical mechanics	4		68	34	17		/17
c) theory of continuous media		5	54	36			/18
d) quantum mechanics	7	6	140	70	35		/35
e) electrodynamics	5	4	140	70	35		/35
f) thermodynamics and statistical physics	7	6	140	70	35		/35
g) solid state physics	8		51	34			/17
16. Computing:							
a) computers and programming	2	1	105	53			
b) computational methods in physics		3	54	18	18	17	/35
c) data banks, knowledge bases, and data-base management systems		5	18	18			/18
d) system analysis		7	36	36			
e) numerical simulation in physics	8		68	17	34		/34
f) computer-aided research and development		9	36	18	18		
g) computer-aided design systems		9	36	18	18		
17. Foundations of research and engineering		8	34	34			
18. Management		9	36	18		18	
19. Disciplines of specialization	7, 7, 8, 8, 9, 9	6,7,7,7,8,8,8,9,9	722	378	212		/132
20. Civil defense		2	50	40		420	/10
21. Sports		1-8	560				/140
22. Military training	6, 8	5, 7	440	350			/90

\*) Diploma work  $\approx$  master's thesis. At the end of the first, second, third, and fourth year - defense of the annual student projects.

Optional disciplines

- 1 Ethics and aesthetics
- 2 History of the world and home culture
- 3 Second foreign language

Long-term practical training:

- Computing after 4 semester 2 weeks
- Engineering after 7 semester 2 weeks
- Prediploma at 9 semester 10 weeks

Defense of the diploma work.

Table 2. Curriculum for specialization "Biomedical Optics"

Disciplines	Hours	Semester	Exam/Pass-exam
1. Introduction into cell biology	34	6	pass-exam
2. Theory of radiation	36	7	exam
3. Introduction into physics of lasers	36	7	pass-exam
4. Theoretical optics	36	7	exam
5. Holography and optical information processing			
6. Foundations of biochemistry and biophysics of photobiological processes	36	7	pass-exam
7. Special practical physics - 1	72	7	pass-exam
8. Statistical optics	72	7	
9. Atomic and molecular spectroscopy	51	8	exam
10. Special practical physics - 2	51	8	exam
11. Molecular optics	68	8	pass-exam
12. Diffraction methods in biomedicine	34	8	pass-exam
13. Nonlinear optics	34	8	pass-exam
14. Special practical physics - 3	36	9	exam
15. Lasers and fiber optics in biomedicine	36	9	pass-exam
16. Luminescence	36	9	exam
17. High-resolution spectroscopy	36	9	pass-exam
18. Spectroscopy of bio-objects	18	9	
	36	9	pass-exam

Some courses are common for all students who have chosen one of the subspecialties of Optics Department. These disciplines prepare students to comprehensive understanding of the mechanisms of light interaction with bio-objects and principles of optical diagnostics and measurements. Lectures on introduction into cell biology and on physiology of man and animals are delivered by lecturers from Biology Department. Courses "Foundations of biochemistry and biophysics of photobiological processes", "Diffraction methods in biomedicine", "Lasers and fiber optics in biomedicine", and "Spectroscopy of bio-objects" have been developed by the lecturers of Optics Department using the literature that encompasses both traditional and modern approaches in biomedical optics and photobiology [4-10].

After five years of training and defense of diploma work students get the grade "physicist/engineer-physicist". Every year 8-12 students get their grades in biomedical optics. Best graduates usually enter post-graduate course and during three years, carry out research work and prepare Candidate Thesis, after defense of which they get the grade of Candidate of Science (corresponds to Ph.D.). At Optics Department the following theses have been prepared: "The features of light scattering by biological structures as applied to laser-aided diagnosis in ophthalmology", "Concentration effects in light scattering by systems of bioparticles", and "Numerical simulation of light propagation within scattering media with absorption". Now six Candidate Theses and two Doctoral Theses in the field of biomedical optics are under preparation.

In the course of realization of the curriculum we faced the problem that the knowledge of chemistry and biology students get at secondary school is insufficient for successful mastering of disciplines of subspecialty. As a consequence of this we decided to insert ten-hour auxiliary course "Fundamentals of general and bioorganic chemistry" into curriculum just before "Introduction into cell biology". This curriculum and approaches to interdisciplinary education developed at Optics Department were used as a basis in organizing Medical Physics Department of Free Russian-German University in Saratov.

#### 4. SPECIALTY "BIOPHYSICS"

Ten-year research and teaching experience in biomedical optics and laser biomedicine allowed to open new specialty at Physics Department of Saratov State University - "Biophysics". This specialty will be divided into two subspecialties: "Biomedical optics" and "Laser biomedicine". The admission procedure to this specialty is in progress now; it is anticipated that the group of students specializing in biophysics will number 15-20 students.

Here we present (see Table 3) a draft version of biophysics curriculum, list of special disciplines of two subspecialties, and the list special practical works on biomedical optics.

Table 3. Draft curriculum for specialty "Biophysics"

Disciplines	Exam	Pass-exam	Hours				
	The number of the corresponding semester		Total	Lectures	Laboratory	Practical trng	Seminars /trng
1. Humanitarian and social-economical							
a) history of Russia	1		54	36			17
b) world history and culture		7	54	36			17
c) history of natural science		9	36	36			
d) history of religion		9	36	36			
e) philosophy	4	3	116	56			60
f) economics	6	5	116	54			62
g) politology		5	54	36			18
h) fundamentals of law		8	34	34			
i) sociology	9		36	18			18
j) psychology (social)		6	51	36			17
k) foreign language	4	1, 2, 3	210			210	
2. Health protection and ecology							
a) sports		1,2,3,4	280			280	
b) fundamentals of healthy way of living		5	36	36			
c) labour protection		5	18	18			
d) radioprotection		6	34	17	17		
e) civil defense		5	40	40			
f) protection of environment		2	34	17		17	
3. Introduction into the specialty			18	18			
4. Physiology	8		34	34			
5. Seminar on annual student project and diploma work *)		2,4,6,8, 10					
6. Higher mathematics:							
a) mathematical analysis	1, 2, 3	1, 2	318	202		106	
b) analytical geometry and higher algebra	2	1	105	70		35	

c) principles of vector and tensor analysis		3	54	36		18	
d) differential and integral equations	3		54	36		18	
e) probability theory and stochastic processes		6	51	34		17	
7. General physics:							
a) mechanics	1	1	108	72		36	
b) molecular physics	2	2	102	68		34	
c) electricity and magnetism	3	3	108	72		36	
d) optics	4	4	102	68		34	
e) physics of atom	5		72	54		18	
f) nuclear physics and physics of elementary particles	6		34	34			
g) practical physics		1,2,3,4,5,6	220		210		
8. Fundamentals of the theory of oscillations	4		85	34	34	17	
9. Biochemistry	7		36	36			
10. Theoretical physics:							
a) methods of mathematical physics	5	4	88	53		35	
b) analytical mechanics	5		54	36		18	
c) theory of continuous media		6	34	34			
d) electrodynamics	6	5	71	36		35	
e) quantum mechanics	7	6	71	36		35	
f) solid state physics	8		34	34			
g) thermodynamics of living systems	7	6	70	35		35	
11. Biophysics	7		126	54	54	18	
12. Nonlinear oscillations and selforganization in biophysics		8	68	34		17	
13. Introduction into cell biology		4	34	34			
16. Informatics:							
a) computers and programming	2	1	70	53		17	
b) computational methods in biophysics		4	34	17	17		
c) information technologies and knowledge bases		5	36	18	18		
d) numerical simulation in biophysics			51	17	34		
e) system analysis		7	54	36		18	
f) computer-aided research and development	8	9	36	18	18		
15. Radioengineering in biophysics		9	36	36			
16. General and bioorganic chemistry	6		68	34	17	17	
17. Disciplines of specialization	6, 7, 8, 8, 9, 9	6,7,7,7,7,8,8,8,9,9,9					

\*) Diploma work  $\approx$  master's thesis. At the end of the first, second, third, and fourth year - defense of the annual student projects.

List of disciplines of specialization  
for subspecialties "Biomedical optics"  
and  
"Laser biomedicine" ("Biophysics specialty").

Theory of radiation  
Medical optoelectronics  
Biotissue optics  
Theoretical optics  
Foundations of biochemistry and biophysics of photobiological processes  
Statistical optics  
Atomic and molecular spectroscopy  
Molecular optics  
Diffraction methods in biomedicine  
Nonlinear optics  
Luminescence  
Spectroscopy of bio-objects  
General pathology and principles of application of lasers to medicine  
Lasers in ophthalmology  
Laser and optical methods in dermatology  
Holography and interferometry in biomedicine  
Optical microscopy and tomography  
Special practical physics - 1 "Spectral devices and optical spectroscopy techniques"  
Special practical physics - 2 "Lasers and holography"  
Special practical physics - 3 "Biomedical optics"

List of practical works of special practical physics 3  
"Biomedical optics" for specialty "Biophysics"

1. Computer-aided coherent scanning microscope
2. Laser speckle-anemometer for biological fluids diagnostics
3. Methods of speckle-optics for biovibration detection
4. Laser interferometric retinometer
5. Colorimetric erythemometer
6. In vivo frequency-domain study of photon migration in biotissue
7. Determination of optical parameters of human epidermal layers using spectrometer with integrating sphere
8. Photogoniometric measurements on biotissues
9. Spectrofluorimetric study of human epidermis

Besides, faculty and technicians of optical department updated some works of basic practical biophysics (7 semester) and offered some new works. Among them are:

Determination of electrophoretic mobility of red blood cells  
Study of photodynamic haemolysis of erythrocytes  
Nefelometric study of immunoreactions  
Study of optical activity of biomolecular solutions  
Determination of electroconductivity of bioobjects

The curriculum will be introduced during five years. We opened new specialty and developed the curriculum keeping in mind the idea of bringing fundamental biophysics (and biomedical optics as a part of it) closer to clinical and biomedical research practice, as we expect that research laboratories at clinics as well as research and development departments at medical equipment manufacturers can offer new working places to University graduates.

## 5. CAREER OPPORTUNITIES FOR GRADUATES

The graduates of Optics Department of Saratov University who specialized in biomedical optics may get positions at clinics of Saratov Medical University where laser equipment is more and more widely used and research projects in laser biomedicine are performed, or at research and design departments of large research-productive amalgamations. Great amount of graduates joins the staff of laboratories of institutes of Russian Academy of Sciences; for example, almost all researches of Laboratory of Laser Medicine of Radioengineering and Electronics Institute are the graduates of Optics Department. Rapid growth of small business in Russia offers new positions at joint ventures that works in medicine and with medical equipment; some graduates have already got there positions of experts on the staff. Graduates actively and with good results working as researchers in biomedical optics may enter post-graduate course (three-year term) to work at Candidate Thesis or join Optics Department for one-year term to prepare Doctor of Science Thesis (those who have Candidate degree).

Also, the idea of continuity of education is embodied in the project developed at the Optics Department; the aim of which is to organize at Saratov State University the International Education & Technology Center of Small Business (E&T Center), which could provide training and improving qualification of beginners in small science-based business. Within the E&T Center a specialized training center in laser medical technologies is suggested. It is supposed that this business & technology center will promote small science-based business in Russia and opening new positions for highly skilled personnel of defense industry enterprises undergone conversion and Saratov schools graduates.

## 6. ACKNOWLEDGMENTS

Many thanks to Associate Professors R.Mukhamedov and A.Velichko for their help in preparation of curricula and to Professor V.Anischenko for fruitful discussions.

## 7. REFERENCES

1. W.G.Janssen The Role of a Biomedical Laser Specialist, Proc.SPIE, Vol.1650, Medical lasers and Systems, 1992, pp. 150-155.
2. V.Ryabukho, V.Tuchin Fundamentals and curriculum of education on optical and laser metrology, Proc. SPIE, vol. 2 525, paper # 51, 1995.
3. S.Ul'ayanov, V.Tuchin, S.Kuzmin, A.Bednov Teaching of diffraction methods in biomedicine to undergraduates specializing in optics, Proc. SPIE, vol. 2525, paper # 90, 1995.
4. A.V.Priezzhev, V.V.Tuchin, L.P.Shubochkin Laser Diagnostics in Biology and Medicine, Nauka Publishers, Moscow, 1989. (in Russian)
5. P.R.Carey Biochemical Applications of Raman and Resonance Raman Spectroscopies, Academic Press, 1982.
6. A.B.Rubin Biophysics, Vol.2, Biophysics of cell processes, Vysshaya Shkola, Moscow, 1987.(in Russian)
7. V.V.Tuchin. Lasers and fiber optics in biomedicine. Laser Physics, vol.3,N4, pp 767-820; N5, pp. 925-950, 1993.
8. V.V.Tuchin. Laser light scattering in biomedical diagnostics and therapy. J.Laser Applications (Laser Inst. of America), vol.5, N2 & 3, pp. 43-60, 1993.
9. V.V.Tuchin. Lasers and fiber optics in biomedicine. Saratov Univ. Publ., (Saratov Univ. Publ.- M., Inotec-Progress, 1993, floppy- disk, in Russian).
10. Yu.A.Vladimirov, A.Ya.Potapenko Physico-chemical foundations of photobiological processes, Vysshaya Shkola, Moscow, 1989. (in Russian)