Ministry of Education and Science of the Russian Federation
Federal Independent Educational Institution
«NATIONAL RESEARCH TOMSK POLYTECHNIC UNIVERSITY»

Research School of Chemical and Biomedical Technologies
Program/specialty 12.04.04 «Biotechnical systems and technologies»

MASTER'S THESIS

Topic of the work
Оптимизация параметров лазерного излучения для воздействия на пигменты на основе диоксида титана (TiO_2) **Optimization of laser radiation parameters for an affect on pigments, based on titanium dioxide (TiO_2)**

UDC 621.373.826.08:667.6:661.88

Student

Group	**Full name**	**Signature**	**Date**
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Position	**Full name**	**Academic degree, rank**	**Signature**	**Date**
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Section «Social Responsibility»

Position	**Full name**	**Academic degree, rank**	**Signature**	**Date**
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Tomsk – 2019

Planned program learning outcomes

Код резуль-тата	Результат обучения (выпускник должен быть готов)	Требования ФГОС, критериев и/или заинтересованных сторон
	Профессиональные компетенции	
P1	Применять глубокие специальные естественнонаучные, математические, социально-экономические и профессиональные знания в инновационной инженерной деятельности при разработке, производстве, исследовании, эксплуатации, обслуживании и ремонте современной биомедицинской и экологической техники	Требования ФГОС (ОК-2, ОПК-2), Критерий 5 АИОР (п. 5.2.1), согласованный с требованиями международных стандартов *EUR-ACE* и *FEANI*
P2	Ставить и решать инновационные задачи инженерного анализа и синтеза с использованием специальных знаний, современных аналитических методов и моделей	Требования ФГОС (ОПК-1, 3; ПК- 1 – 4), Критерий 5 АИОР (п. 5.2.2), согласованный с требованиями международных стандартов EUR-ACE и FEANI
P3	Выбирать и использовать необходимое оборудование, инструменты и технологии для ведения инновационной практической инженерной деятельности с учетом экономических, экологических, социальных и иных ограничений	Требования ФГОС (ОК-9, ПК-10, 14, 18). Критерий 5 АИОР (пп. 5.2.3, 5.2.5), согласованный с требованиями международных стандартов EUR-ACE и FEANI
P4	Выполнять комплексные инженерные проекты по разработке высокоэффективной биомедицинской и экологической техники конкурентоспособной на мировом рынке	Требования ФГОС (ОК-2, 3; ПК-5 – 11, 14), Критерий 5 АИОР (пп. 5.2.3, 5.2.5), согласованный с требованиями международных стандартов *EUR-ACE* и *FEANI*
P5	Проводить комплексные инженерные исследования, включая поиск необходимой информации, эксперимент, анализ и интерпретацию данных с применением глубоких специальных знаний и современных методов для достижения требуемых результатов в сложных и неопределенных условиях	Требования ФГОС (ОК-2, 3; ОПК-5, ПК-1 – 4). Критерий 5 АИОР (пп. 5.2.2, 5.2.4), согласованный с требованиями международных стандартов *EUR-ACE* и *FEANI*
P6	Внедрять, эксплуатировать и обслуживать современное высокотехнологичное оборудование в предметной сфере биотехнических систем и технологий, обеспечивать его высокую эффективность, соблюдать правила охраны здоровья и безопасности труда, выполнять требования по защите окружающей среды	Требования ФГОС (ОПК-1, 2), Критерий 5 АИОР (пп. 5.2.5, 5.2.6), согласованный с требованиями международных стандартов *EUR-ACE* и *FEANI*
	Универсальные компетенции	
P7	Использовать глубокие знания в области проектного менеджмента для ведения инновационной инженерной деятельности с учетом юридических аспектов защиты интеллектуальной собственности	Требования ФГОС (ОПК-2; ПК-14, 15). Критерий 5 АИОР (п. 5.3.1), согласованный с требованиями международных стандартов *EUR-ACE* и *FEANI*
P8	Владеть иностранным языком на уровне, позволяющем активно осуществлять коммуникации в профессиональной среде и в обществе, разрабатывать документацию, презентовать и защищать результаты инновационной инженерной деятельности	Требования ФГОС (ОК-1), Критерий 5 АИОР (п. 5.3.2), согласованный с требованиями международных стандартов *EUR-ACE* и *FEANI*
P9	Эффективно работать индивидуально и в качестве члена и руководителя команды, состоящей из специалистов различных направлений и квалификаций, с делением ответственности и полномочий при решении инновационных инженерных задач	Требования ФГОС (ОК-3, ОПК-3; ПК-3, 12, 13), Критерий 5 АИОР (п. 5.3.3), согласованный с требованиями международных стандартов *EUR-ACE* и *FEANI*
P10	Демонстрировать личную ответственность, приверженность и готовность следовать профессиональной этике и нормам ведения инновационной инженерной деятельности	Критерий 5 АИОР (п. 5.3.4), согласованный с требованиями международных стандартов *EUR-ACE* и *FEANI*
P11	Демонстрировать глубокие знание правовых социальных, экологических и культурных аспектов инновационной инженерной деятельности, компетентность в вопросах охраны здоровья и безопасности жизнедеятельности	Критерий 5 АИОР (п. 5.3.5), согласованный с требованиями международных стандартов *EUR-ACE* и *FEANI*
P12	Самостоятельно учиться и непрерывно повышать квалификацию в течение всего периода профессиональной деятельности	Требования ФГОС (ОК-2, 4; ОПК-4), Критерий 5 АИОР (п.5.3.6), согласованный с требованиями международных стандартов *EUR-ACE* и *FEANI*

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Research School of Chemical and Biomedical Technologies
Program/specialty 12.04.04 «Biotechnical systems and technologies»

APPROVED BY
Head of the Program
_________ _________ F.A.Gubarev
(Signature) (Date)

ASSIGNMENT
for the Master's Thesis completion

In the form:

Master's Thesis

For a student:

Group	Full Name
1DM7I	Lichny Alexey Andreevich

Topic of the work:

Оптимизация параметров лазерного излучения для воздействия на пигменты на основе диоксида титана **Optimization of laser radiation parameters for an affect on pigments, based on titanium dioxide**	
Approved by the order of the Head (date, number)	

Deadline for completion of the Master's Thesis:	

TERMS OF REFERENCE:

Initial data for work: *(the name of the object of research or design; performance or load; mode of operation (continuous, periodic, cyclic, etc.); type of raw material or material of the product; requirements for the product, product or process; special requirements to the features of the operation of the object or product in terms of operational safety, environmental impact, energy costs; economic analysis, etc.).*	The object of the research: titanium dioxide dispersive solutions. Subject matter of the research: optimization of laser radiation parameters for an affect on titanium dioxide pigments. As a result of the research, an obtained data will serve as the foundation for the development of methods for removing white pigments for tattoos and will increase the effectiveness of permanent makeup removal. The results obtained during the study can be applied by cosmetologists to build an optimal plan for a painless procedure for removing permanent makeup (PMU) or tattoos, as well as manufacturers of medical cosmetology lasers to optimize their factory built-in modes. The work can be applied further in medical research centers and in cosmetology clinics
List of the issues to be investigated, designed and developed *(analytical review of literary sources in order to elucidate the achievements of world science*	To accomplish the task, it is necessary to investigate a number of questions: •Writing a literature review on the topic; •Research of existing solutions in this area;

and technology in the field under consideration, the formulation of the problem of research, design, construction, the content of the procedure of the research, design, construction, discussion of the performed work results, the name of additional sections to be developed; work conclusion).	•Planning of the experiment; •Completing in vitro research; •Evaluation of the feasibility of further in vivo research; • Feasibility study; • Industrial and environmental safety.
List of graphic material *(with an exact indication of mandatory drawings)*	
Advisors on the sections of the Master's Thesis	
Chapter	**Advisor**
Section «Financial Management, Resource Efficiency and Resource Saving»	Senior Lecturer, Department of Social and Human Sciences Potekhina Nina Vasilyevna
Section «Social Responsibility»	Associate Professor of General Technical Disciplines Mikhail Vladimirovich Gorbenko

Date of issuance of the assignment for Master's Thesis completion according to a line schedule	

The task was issued by the Scientific Supervisor and Technical Advisor:

Position	Full Name	Academic degree, rank	Signature	Date
Assistant professor	Razin Alexey Valerievich	Candidate of Physical and Mathematical Sciences		

The assignment was accepted for execution by the student:

Group	Full Name	Signature	Date
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ASSIGMENT FOR THE SECTION
«FINANCIAL MANAGEMENT, RESOURCE EFFICIENCY AND RESOURCE SAVING»

For the student:

Group	Full name
1DM7I	Lichny Alexey Andreevich

School	RSCABS	**Department (SEC)**	
Level of education	Master degree	**Program/Specialty**	12.04.04 Biotechnical systems and technologies

Background data to the section "Financial management, resource efficiency and resource saving":	
1. *The cost of scientific research (SR) resources: material, energy, financial, informational and human*	*Salary of the head - 33664 rub.* *Engineer's salary - 21,760 rub.*
2. *Norms and standards of resource use*	*Additional salary 12%;* *Overhead costs 16%;* *District coefficient of 30%;* *Depreciation rate 33%*
3. *Tax system, tax rates, deduction rates, discount and credit rates*	*The ratio of deductions for payment to extra-budgetary funds is 30%.*
The list of issues to be investigated, designed and developed:	
1. *The tax system used, the rates of taxes, deductions, discounting and lending*	*Description of the potential consumer of the research results,* *QuaD analysis* *SWOT analysis* *Assessment of project readiness for commercialization*
2. *Development of the charter of the scientific and technical project*	*Building a project goal tree* *Project stakeholders*
3. *STR management process planning: structure and schedule, budget, risks and procurement organization*	*Planning work stages, determining the schedule of the study* *Definition of project risks, assessment of risk and loss probability*
4. *Determination of resource, financial, economic efficiency*	*Calculation of the budget of the cost of the study.* *A description of the potential effect of the project.*
The list of graphic material *(with the exact indication of the mandatory drawings):*	
1. *Market segmentation map* 2. *QuaD analysis of the study* 3. *SWOT matrix* 4. *A form for assessing the degree of readiness of a scientific project for commercialization* 5. *Project Objective tree* 6. *The Calendar schedule of the study* 7. *Estimated research project budjet* 8. *Key risks reduction measures*	

Date of assignment for the section on a linear schedule	

Assignment was issued by an advisor:

Position	Full name	Degree	Signature	Date
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«SOCIAL RESPONSIBILITY»

For the student:

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1DM7I	Lichny Alexey Andreevich

School	RSCABS	**Department (SEC)**	
Level of education	Master's degree	**Program/Specialty**	12.04.04 Biotechnical systems and technologies

Initial data to the section «Social responsibility»:	
1. *Characteristics of the object of study (substance, material, device, algorithm, method, working area) and its areas of application*	*Optimization of laser radiation parameters for an affect on pigments based on titanium dioxide*
The list of issues to be investigated, designed and developed:	
1. Legal and organizational safety issues: *1.1. Special legal norms of labor legislation.* *1.2. Organizational arrangements for the layout of the working area.*	*Special legal norms of labor legislation (medical examination of employees, safety instructions, provision of personal protective equipment).* *Requirements for the organization of the workplace.*
2. Industrial safety: *2.1. Analysis of harmful and dangerous factors that can be created by object of study.* *2.2. Analysis of harmful and dangerous factors that may arise in the laboratory during research.* *2.3. Justification of measures to protect the researcher from the effects of hazardous and harmful factors.*	*Harmful industrial factors:* *1) deviations of illumination rates;* *2) adverse electromagnetic environment;* *3) exceeding noise levels;* *4) the variances of indicators of a microclimate* *Hazardous industrial factors:* *1) laser equipment emission* *2) an increased value of voltage in an electrical circuit* *3) fire hazard*
3. Environmental safety: *3.1. Analysis of the impact of the object of research on the environment.* *3.2. Analysis of the "life cycle" of the object of study.* *3.3. Justification of measures to protect the environment.*	When using devices necessary for the implementation of graduation thesis, the atmosphere, hydrosphere or lithosphere is not harmed, since no harmful substances are released into the air and water. In the event of a device malfunction, this technology is also recycled.
4. Safety in emergency situations: *4.1. Analysis of probable emergencies that may occur in the laboratory during research.* *4.2. Justification of measures to prevent emergencies and the development of procedures in case of an emergency.*	*When performing this graduation thesis, the most likely type of emergency is fire.* *The list of measures to reduce the threat of possible emergencies is given.*

Date of assignment for the section on a linear schedule	

Assignment was issued by an advisor:

Position	Full name	Degree	Signature	Date
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Assignment was accepted for execution by the student:

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Abstract

This Master's thesis contains 92 pages, 22 figures, 30 tables, 38 references, 1 appendix.

Key words: titanium dioxide, pigment, laser radiation, Nd: YAG laser, permanent makeup, tattoos.

The object of the research: titanium dioxide dispersive solutions.

Subject matter of the research: optimization of laser radiation parameters for an affect on titanium dioxide pigments.

The purpose of this work is to explore the effects of laser radiation on pigments based on titanium dioxide by changing its parameters.

A qualitative assessment of the results of the experiments showed that laser irradiation of the pigment in solutions with concentrations from 10% to 1×10^{-2}%, λ = 1024 nm, τ = 750 ps and an energy density of 8.7 J/cm^2 leads to an increase in the turbidity of the solution and its whiter shade. Analysis of images from a microscope showed that pigment destruction is observed. On the whole, the principle of destruction of the white pigment in the laboratory was proposed and the feasibility of further *in vivo* testing was evaluated.

As a result of the research, an obtained data will serve as the foundation for the development of methods for removing white pigments for tattoos and will increase the effectiveness of permanent makeup removal.

The main design, technological and technical and operational characteristics: laboratory conditions of operation.

Degree of implementation: data obtained in the thesis work are ready for *in vivo* testing.

Scope: medical centers, private clinics, aesthetic medicine clinics, beauty centers.

Definitions, designations, abbreviations, normative references

References to the following standards are used in this work:

1. SP 52.13330.2011. Natural and artificial lighting;

2. GOST 12.2.032-78 Occupational Safety Standards System (OSS). Workplace when working sitting. General ergonomic requirements;

3. GOST 12.1.003-83. Noise. General safety requirements;

4. GOST 12.1.029-80. Means and methods of noise protection;

5. GOST 12.1.005-88. General sanitary and hygienic requirements for working area air;

6. GOST R 12.1.019-2009 SSBT. Electrical safety. General requirements and nomenclature of types of protection;

7. GOST 12.1.004-91 SSBT. Fire safety. General requirements;

8. OST 42-21-16-86. The system of labor safety standards, offices, physiotherapy rooms. General safety requirements;

9. SanPiN № 5804-91 Sanitary norms and rules for the construction and operation of lasers;

10. GOST R-50723-94. Laser safety. General requirements safety in the development and operation of laser products;

11. GOST R 50723-94. Laser hazard sign and recommended dimensions;

12. SanPiN 2.1.7.728-99 "Rules for the collection, storage and disposal of waste treatment facilities";

13. OST 12.0.003-2015 Occupational Safety Standards System (OSS). Dangerous and harmful production factors. Classification.

The following abbreviations are used in this paper:

Nd:YAG – neodymium-doped yttrium aluminum garnet;

PMU – permanent makeup;

UV – ultraviolet;

IR – infrared.

Contents

Introduction

The prerequisites for the creation of laser systems began in 1917, when Albert Einstein published a publication on the topic “Quantum Theory of Radiation”, in which it was said that, along with spontaneous emission of energy and absorption, there can be induced and induced radiation. On the basis of this conclusion in the 1950s, Soviet scientists A.M. Prokhorov and N.G. Basov developed the theoretical aspects of quantum electronics. Later, Charles Towns, together with his students, published a brief article that talked about the microwave spectrum, where the forced emission of radiation was achieved. This development was the world called "Mazer". With the development of the maser in the 60s, the American scientist Theodore Meiman assembled the first active laser using synthetic ruby crystals. Despite the fact that the first laser pulse, received at a wavelength of 690 nm, lasted only hundreds of microseconds, it marked the beginning of the mass use of laser systems in various technical and scientific fields.

Today, lasers perform a huge number of technological operations, allowing you to simplify and speed up work, saving time. Laser systems have become indispensable in scientific and many other studies, and their unique properties prove their value, efficiency and versatility.

Over the past century, the trend of decorating your body with tattoos and permanent makeup has increased dramatically. According to studies, at this moment about 25% of the world population in the age group up to 35 years have tattoos. [10] In addition to improving the technology of tattooing and reducing the cost of such services, the range of various pigments introduced to customers under the skin has also increased.

For the first time, the laser tattoo removal method was carried out at the dawn of the development of laser technology in the 60s, where a ruby crystal was used as the active medium, which worked in the free-running mode. However, the first results were not crowned with success. This was due to the lack of knowledge about the processes occurring in biological tissues when exposed to laser radiation, as well as the uncertainty of the optimal parameters of the laser beam.

During this time titanic work was carried out to obtain clinical material, and laser irradiation methods became the most advanced and most effective in terms of aesthetic medicine.

Over time, tattoos change their social susceptibility, pattern geometry, or fade. In connection with the development of laser technology in aesthetic medicine, it is possible to remove the injected and natural pigment by acting on it with selective laser radiation. However, today there is no definite and exact method of destruction of light pigment in human biological tissue due to the fact that the white color reflects any visible radiation. It implicates aesthetic discomfort, and often entails social problems.

Object of the research: titanium dioxide dispersive solutions.

Subject matter of the research: optimization of laser radiation parameters for an affect on titanium dioxide pigments.

The purpose of this work: to explore the effects of laser radiation on pigments based on titanium dioxide by changing its parameters.

To achieve the purpose, it is necessary to solve a number of tasks:

- Writing a literature review on the topic;
- Research of existing solutions in this area;
- Planning of the experiment;
- Completing *in vitro* research;
- Evaluation of the feasibility of further *in vivo* research

1 Literature review

1.1 Physical fundamentals of laser exposure

For an effective and deliberate application of laser therapy, the processes occurring during the interaction of laser radiation with tissues should be understood.

Introductory definitions

Wave is a disturbance of a field in which a physical attribute oscillates repeatedly at each point or propagates from each point to neighboring points, or seems to move through space [1]. This excitation propagates in space with a finite speed:

$$I = I_0 \cdot \sin(\omega t + \varphi_0), \text{ where}$$

I – wave amplitude;

$\omega = 2\pi v$ – angular frequency;

t – time;

φ_0 – initial phase.

Frequency (v) is the number of times that a wave, especially a light, sound, or radio wave, is produced within a particular period, especially one second. [2]

Period (T) of the wave is the distance between two close points of a wave of one amplitude that oscillate in one phase.

Wavelength (λ) is the wave propagation distance in one oscillation period ($\lambda = c/v$).

Phase of oscillation (φ) is the argument of the function that describes the harmonic oscillations, namely the state of the process at a certain point in time: $\varphi = \omega t + \varphi_0$

1.1.1 The laws of electromagnetic radiation and the properties of laser radiation

Electromagnetic wave is an alternating electromagnetic field, where the intensity of the electromagnetic field varies periodically. Electromagnetic radiation in the optical range is from 0.1 to 30 microns. The optical spectrum as the matter of fact is the separation of the frequencies of optical radiation by intensity.

Table1 – Ranges of the optical spectrum

Title of the range	Wavelength
Ultraviolet (UV):	
Short wave (UV-C)	100 - 280 nm
Middle wave (UV-B)	280 - 320 nm
Long-wave (UV-A)	320 - 400 nm
Violet	400 - 450 nm
Blue	450 - 480 nm
Cyan	480 - 510 nm
Green	510 - 575 nm
Yellow	575 - 585 nm
Orange	585 - 620 nm
Red	620 - 760 nm
Infrared (IR):	
Near infrared (NIR)	760 nm - 3 μm
Middle wave infrared (MWIR)	3 μm - 30 μm
Far infrared (FIR)	30 μm - 1000 μm

Electromagnetic radiation can propagate in virtually all environments. In vacuum (space free from matter and bodies absorbing or emitting electromagnetic waves) electromagnetic radiation propagates without attenuation over arbitrarily large distances, but in some cases, it propagates quite well in space filled with matter (changing its behavior somewhat). The main characteristics of electromagnetic radiation is considered to be the frequency, wavelength and polarization.

The wavelength is directly related to the frequency through the (group) propagation velocity of the radiation. The group velocity of propagation of electromagnetic radiation in a vacuum is equal to the speed of light; in other media, this velocity is less. The phase velocity of electromagnetic radiation in a vacuum is also equal to the speed of light, in various environments it can be both less and more than the speed of light.

Laser radiation is electromagnetic radiation in the optical range. It has such properties as: coherence, monochromaticity, polarization, directivity.

Coherence is the consistency of several oscillatory processes over time, which is manifested in addition. When added, two or more than two waves can mutually strengthen or weaken. The addition of waves creates an interference pattern in space which always divided into spatial and temporal. Spatial coherence means a strong correlation (fixed phase relationship) between the electric fields at different locations across the beam profile. Temporal coherence means a strong correlation between the electric fields at one location but different times [3]. Most lasers used in laser technology have a small coherence length. The coherence length of pulsed semiconductor lasers is a fraction of a millimeter. That is, the radiated field manifests itself as an incoherent source at a short distance from the biological object. [23]

Monochromaticity is the property of light source to emit an electromagnetic wave of a certain and constant frequency (small width of the spectrum). Lasers are the primary sources of quasi-monochromatic light, and some of them exhibit extreme degrees of monochromaticity, i.e., an extremely small optical bandwidth. The highest degree of monochromaticity is achieved with carefully stabilized single-frequency lasers. Pulsed semiconductor lasers have a spectrum width of less than 5 nm, and for single-mode continuous lasers the width is not more than 0.3 nm. [4, 5]

Polarization is the distribution of the vector of magnetic and electric field strengths relative to the propagation and direction in an electromagnetic wave. If the two components of the electric field intensity vector **E** oscillate with a constant phase difference in time, then this wave is considered polarized.

Directivity can be considered as a result of radiation coherence, when photons propagate in one direction.

Laser power is the energy characteristic of electromagnetic radiation. In the SI base system - [W].

Radiation energy is the power of an electromagnetic wave per unit of time. In the SI base system - [J], [W·s].

Intensity of the laser radiation is the ratio of the power to the surface area perpendicular to the direction of the radiation. In the SI base system - [J/m^2].

Radiation dose density is the common energy over the surface area of an impact. In the SI base system - [J/m^2].

For the direct destruction of the target, the magnitude of the energy and power of the laser radiation are important. In practice, the radiation parameters are recalculated per unit area - the energy flux density (J/cm^2) and the energy flux rate (W/cm^2) [17, 22]. The density of the energy flow should be sufficient for the bleaching of the pigment to occur without side effects. Larger irradiation spots provide deeper penetration, which also reduces the possibility of skin damage. As review shows most clinicians and dermatologists recommend to use flux density (fluence) in the range 0.5 – 11 J/cm^2. [9, 12, 25]

1.1.2 Popular modes of operation of cosmetic lasers

The different time modes of operation of a laser are distinguished by the rate at which energy is delivered.

Continuous Wave (CW) lasers operate with a stable average beam power. In most higher power systems, one is able to adjust the power. In low power gas lasers, such as HeNe, the power level is fixed by design and performance usually degrades with long term use.

Single Pulsed (normal mode) lasers generally have pulse durations of a few hundred microseconds to a few milliseconds. This mode of operation is sometimes referred to as long pulse or normal mode.

Single Pulsed Q-Switched lasers are the result of an intracavity delay (Q-switch cell) which allows the laser media to store a maximum of potential energy. Then, under optimum gain conditions, emission occurs in single pulses; typically of 10^{-8} second time domain. These pulses will have high peak powers often in the range from 10^6 to 10^9 Watts peak. The nature of the phenomenon is similar to the one in electronics, when we change duty cycle of impulses to change its average voltage.

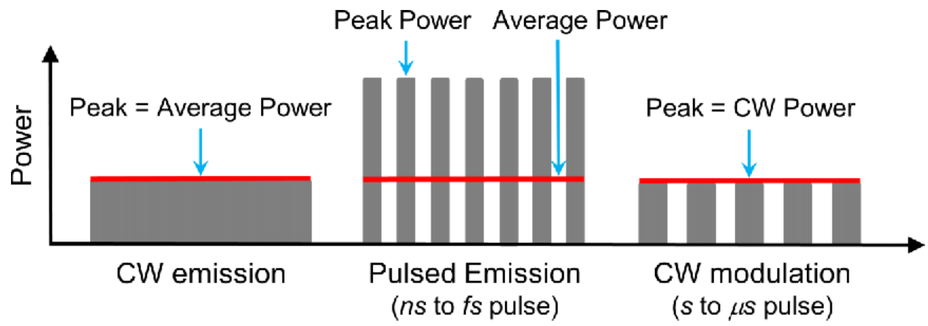

Figure 1 – Modulation of laser pulses [6]

Repetitively Pulsed or scanning lasers generally involve the operation of pulsed laser performance operating at a fixed (or variable) pulse rates which may range from a few pulses per second to as high as 20,000 pulses per second. The direction of a CW laser can be scanned rapidly using optical scanning systems to produce the equivalent of a repetitively pulsed output at a given location.

Mode Locked lasers operate as a result of the resonant modes of the optical cavity which can effect the characteristics of the output beam. When the phases of different frequency modes are synchronized, i.e., "locked together," the different modes will interfere with one another to generate a beat effect. The result is a laser output which is observed as regularly spaced pulsations. Lasers operating in this mode-locked fashion, usually produce a train of regularly spaced pulses, each having a duration of 10^{-15} to 10^{-12} sec. A mode-locked laser can deliver extremely high peak powers than the same laser operating in the Q-switched mode. These pulses will have enormous peak powers often in the range from 10^{12} Watts peak. [7]

1.2 Interaction of laser radiation with tissues

1.2.1. Tissue reaction to laser radiation

The physical mechanism of the effect of laser radiation on biological tissue entails certain processes: the effect of the temperature factor, the initiation of a shock wave in the tissues that have been irradiated, the transformation of the electric field in the tissue, etc. The conversion of the light and heat energy of laser radiation into electrical, chemical and other forms of radiation occurs. [20]

When laser radiation interacts with tissue, the following reactions may occur:

Photostimulation. When using low-intensity lasers. The energy parameters of the impact on the tissue does not damage the biosystem. Enough energy to activate the vital activity of the body.

Photodynamic reaction. When exposure occurs at a specific wavelength on a photosensitizer, providing a cytotoxic effect on abnormal tissue.

Photothermolysis and photomechanical reactions. When radiation is absorbed by the chromophore, energy is converted into heat. With sufficient power, this leads to thermal destruction of the target.

Consider the optical and thermal properties of living skin in more detail. At the time of exposure to the skin by laser radiation, there are three processes: reflection, absorption and (or) transmission [30].

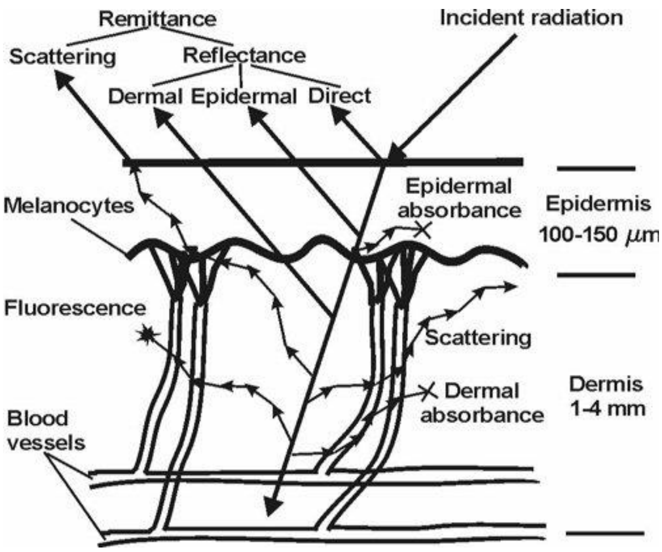

Figure 2 – Optical phenomena in human skin [8]

Depending on the wavelength of the radiation that falls on the skin, up to 60% of the laser radiation is reflected [30]. Inhomogeneous structures of the skin and different refractive indices of the cellular structure determine the degree of scattering. If the radiation wavelength is much larger than the cell diameter (≥ 10 μm), then the scattering occurs to an insignificant degree. However, due to the fact that the electromagnetic spectrum of the lasers used covers the wavelength range from IR to UV, in almost all cases we deal with scattering. Based on the Bouguer – Lambert – Beer law, the radiation penetration depth (δ) is calculated for a wavelength above 1 μm. The intensity of radiation (I) can be determined by the following relationship:

$$I = I_0 e^{-\alpha d}, \text{ where}$$

I_0 is the initial intensity, α is the absorption coefficient, d is the layer thickness.

If radiation is monochromatic of a certain wavelength λ, the value of the absorption coefficient α will take the form:

$$\alpha = 4\pi nk/\lambda$$

It is worth noting that the refractive indices (n) and absorption (k) in this medium are constant. The law of the Bouguer – Lambert – Behr is applicable when the absorption significantly exceeds the scattering value. The depth of radiation penetration (δ) determines the depth where radiation penetrating into a substance will decrease by e (= 2.71) times. The formula for calculating δ is [30, 31]:

$$\delta = 1/\alpha$$

Table 2 – Interaction of lasers with biological fluids

Wavelength λ, μm	Laser type	Absorption coefficient α, cm^{-1}		Depth of radiation penetration β, cm	
		Water	Blood	Water	Blood
10.6	CO_2	1000	1000	0.001	0.001
1.064	Nd:YAG	0.1	4	10	0.25
0.488/0.514	Ar	0.001	330	1000	0.003

The degree of scattering on living tissue directly depends on the wavelength of the laser radiation. The penetration depth of the excimer laser with the UV range and the YAG: Er laser with the IR range, as well as the CO2 laser with λ = 10.6 μm will be 1–20 μm. In this case, scattering plays a subordinate role. For radiation with a wavelength of λ = 0.45 - 0.59 μm, the penetration depth varies from 0.5 to 2.5 mm. And the absorption and scattering in this case plays a huge role. Despite of the fact that laser radiation in the center of the fabric is collated, it is surrounded by a region with high scattering. Of the total incident beam, 15–40% is dissipated. Dominance scattering occurs in the spectral region from 590 to 1500 nm. In this case, the depth of radiation penetration reaches 2 - 8 mm. In this case, a cone of diffuse scattering is formed. [28, 31]

Absorption of laser radiation in the ultraviolet range depends on the protein content. it is worth pointing out that the absorption of laser radiation by various pigments and macromolecules occurs with intensity and depends on the radiation wavelength.

Absorption is completely dependent on the interaction of laser radiation with skin chromophores, which are oxyhemoglobin and melanin [31]. Melanin is the most important epidermal chromophore. Selective effects on a bioobject directly depend on the spectral range. UV radiation is absorbed by proteins and lipids, as well as nucleic acids. The visible range is absorbed by the chromophore groups of protein molecules. Near IR is predominantly absorbed by oxygen and water.

1.2.2 Tissue chromophores and biophysics of tattoo

In aesthetic medicine, cosmetologists work with endogenous and exogenous chromophores of the skin. Endogenous include melanin, hemoglobin, collagen, water.

Melanin is found in the epidermis and hair follicles. The absorption spectrum lies in the ultraviolet (up to 400 nm) and visible (400-760 nm) spectral ranges. With increasing wavelength, the absorption of laser radiation by this chromophore decreases. The weakening of the absorption occurs in the infrared region of the spectrum (from 900 nm). Hemoglobin is located in red blood cells. The peaks of the absorption spectrum are in the ultraviolet (320-400 nm), violet (400 nm), green (541 nm) and yellow (577 nm) ranges. Collagen forms the basis of the dermis. The absorption spectra lie in the visible range (from 400 nm to 760 nm) and in the near-IR range (from 760 nm to 2500 nm). Water makes up to 70% of the dermis. The absorption spectrum lies in the middle (2500 nm-5000 nm) and far (5000 nm-10064 nm) infrared spectral region. [26]

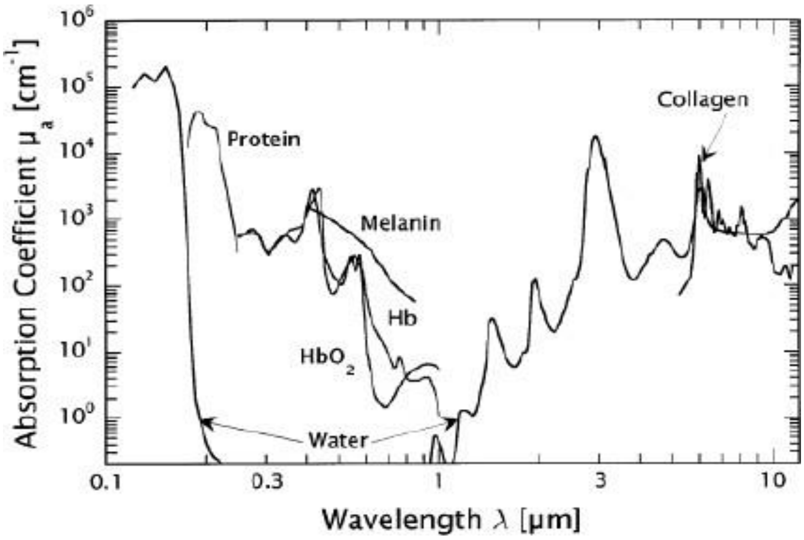

Figure 3 – Absorption spectra of living tissue chromophores [31].

Exogenous chromophores of the skin include tattoo ink and introduced elements (dirt, wood, cloth, etc.). The composition of the ink is very diverse from metal oxides to organic compounds.

A tattoo is a form of body modification where a design is made by inserting ink, dyes and pigments, either indelible or temporary, into the dermis layer of the skin to change the pigment. The paint particles are initially arranged as thin granules in the upper layer of the dermis, after two weeks they aggregate. A biopsy of old tattoos demonstrates pigment in the deeper layers of the dermis rather than fresh tattoos. Ultimately, the ink appears in the regional lymph nodes. [24] The accumulations of coloring pigment in tattoo are rather small: in professional tattoos they are approximately 190 microns, and in amateur 280 microns. It is worth noting that tattoos made by professionals are located closer to the surface layer of the skin, most often in the epidermis, which is not the case for amateur [9].

When a tattoo needle punctures the skin, it rips through the epidermis, the outer layer of skin, and spills ink in the dermis, the inner layer of skin which is flooded with blood vessels and nerves. With each penetration, the immune system is alerted there’s a wound going on and immune system cells are sent to the site. Some of these are macrophages which gobble up the ink in an attempt to clean the area. What’s left of the ink becomes absorbed by skin cells called fibroblasts. Most of the fibroblasts and macrophages alike become suspended in the dermis where they’re locked permanently.

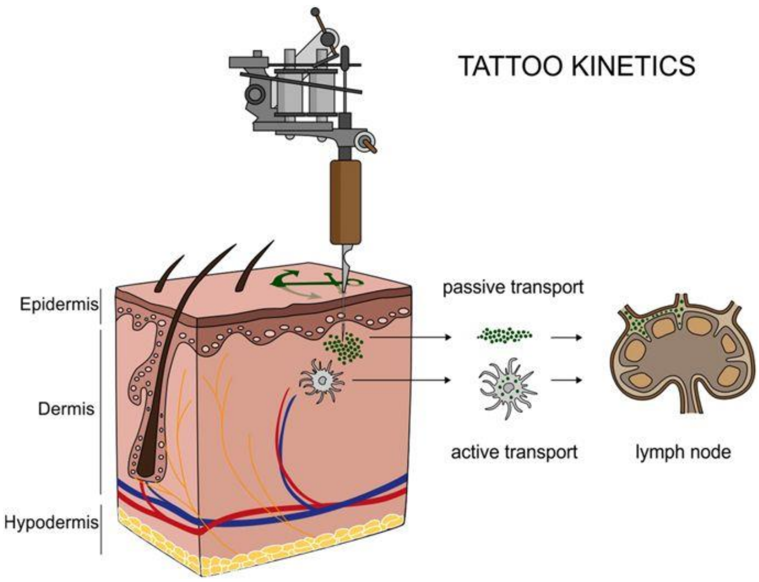

Figure 4 – Kinetics of tattoo ink in an organism [10]

Tattoo inks are commonly made up of a mixture of small organic pigments, water and isopropyl alcohol. Surprisingly, manufacturers of tattoo ink are not compelled to reveal the precise ingredients or chemical composition of their ink products despite their potential systemic absorption. Black inks are commonly made from soot (carbon black) particles. Tattoo inks can contain polycyclic aromatic hydrocarbons (PAHs) at a range of concentrations, which are reported to be carcinogenic, mutagenic and could pose other health risks to the skin. Further, it was recently reported that tattooed young individuals can exhibit adverse reactions, especially with black or red ink tattoos, including photosensitivity, skin elevation and itching [11, 29]

1.3 Review of cosmetic lasers and the fundamentals of tattoo-removing lasers

The first basic concept is that the lasers are absorbed by the tattoo pigments, and since these pigments come in a variety of colors, multiple wavelengths of laser lights may be needed to remove the tattoo. Often, a given laser removes most of the pigment that is “seen” by the laser and/or alters the remaining pigment, such that the initial laser is no longer effective in removing this pigment. This results in tattoos becoming refractory to treatment. b) Longer wavelengths penetrate deeper into the skin and are less scattered. Besides wavelength, spot size determines the depth of penetration of the laser light. Light scatters at the edge of the field, so a small spot size will result in a greater proportion of the light being scattered and not reaching significant depths in the skin. Therefore, the largest available spot size capable of delivering clinically relevant fluences should be used instead of increasing the fluence in refractory tattoos. The latter would result in more energy being placed in the superficial layer, and hence more damage and scarring. c) When a given laser no longer results in effective treatment of a tattoo, another device should be considered. d) Any of the lasers can be used for treating black tattoos because black absorbs virtually every wavelength of light. The laser that would emit light in the wavelength corresponding to the color of the tattoo cannot be used for the removal of the same colored tattoo. e) The exact mechanism of tattoo removal/lightening is unknown, but it appears that laser treatment leads to instant alteration of optic properties of the tattoo pigments, partly by destruction and partly by thermal, photochemical (cleavage of pigment molecules by laser irradiation and oxidation), or photoacoustic (fracturing molecules by virtue of acoustic or pressure waves) means. [12]

1.3.1 Lasers review

The Q-switched ruby laser (QSRL) for tattoo removal was first demonstrated by Goldman who demonstrated that the Q-switched ruby laser using nanosecond pulses interacted with and removed dark tattoo pigments without causing a scar, but millisecond pulses resulted in thermal damage to the treated area [25, 38].In another study by Schiebner et al. [37], QSRL was used for treating 163 tattoos (101 amateur and 62 professional), using 5- to 8-mm spot size and 2 to 4 J/cm^2 fluence range. Each tattoo underwent an average of three treatments. Amateur tattoos were once again seen to respond better to treatment than the professional tattoos and among the professional tattoos, the red, yellow, and green colors faded less than the black pigment. No scarring was seen in any of these patients.

The Q-switched 755-nm alexandrite laser has a pulse duration of 100 ns, a spot size of 3 mm, and a repetition rate of 1 Hz. Therefore it offers advantages over earlier ruby lasers in terms of reliability, speed, and repetition rates. It has been used for the removal of green, blue, and black tattoos, and is considered the treatment of choice for the removal of green-colored tattoos. In a study by Fitzpatrick and Goldman, 25 patients were treated for amateur and professional tattoos and demonstrated 95% removal of tattoo pigment using an average of 8.9 treatment sessions [12, 28]. This showed the efficacy and safety of alexandrite lasers for blue and black tattoo removal.

Q-switched 1,064-nm Nd:YAG laser: The Q-switched Nd:YAG laser can emit two wave lengths of light, 1,064 nm and 532 nm. This property can be used to treat dark tattoo pigments using 1,064-nm wavelength and removal of red and orange pigments can be brought about by using the 532-nm wavelength. Kilmer et al. treated 39 tattoos using a Q-switched Nd:YAG laser with fluences from 6 to 12 J/cm^2, demonstrating more than 75% of pigment removal in 77% of the black tattoos and more than 95% of the black ink cleared in 28% of the tattoos at 10 to 12 J/cm^2 after four treatment sessions. In a study on 15 tattoos treated with the Q-switched Nd:YAG laser in patients with Fitzpatrick skin type VI, more than half of the treated tattoos had 75–95% clearance after three or four treatments. This can be attributed to the fact that in darkly pigmented individuals, 1064 nm wavelength laser has low absorption in epidermal melanin. Lapidoth and Aharonowitz studied tattoo removal in 404 subjects of Ethiopian origin with skin types V and VI. All tattoos were blue/black and had been made by injecting charcoal into the skin and underwent three to six laser treatments with the Q-switched Nd:YAG (380 patients) or ruby (24 patients) laser at intervals of at least 8 weeks. At the last follow-up, a clearance of 75–100% was achieved in 92% of the patients. Transient (2–4 months) mild hyperpigmentation was noted in 44% of the patients, and mild textural changes in two. There were no cases of scarring or permanent pigmentary changes [12, 36]. The Nd:YAG Laser (1,064-nm) can be passed through an optical crystal (potassium titanyl phosphate-KTP) that doubles the frequency and halves the wavelengths to yield green light with a wavelength of 532 nm. Besides being useful in the removal of red, orange, and purple-colored tattoos, the Q-switched 532-nm Nd:YAG laser has been found to be a safe and effective method of treatment for red ink tattoo reactions in combination with topical Dermovate [28, 33].

Pigmented dye laser: The flashpump-pumped pulsed dye laser emits a wavelength of 510 nm and a long pulse time of 300 ns with a 3-mm spot size. It is used only for treating red dyes or certain orange and yellow pigments. Successful clearing without scarring usually occurs in 3–7 treatments performed at 1-month intervals using 3–3.75 J/cm^2. Purple, orange, and yellow pigments require an average of five treatments for complete ink removal [12, 32].

1.3.2 Photothermolysis and minimizing tissue damage technics

The theory of selective photothermolysis predicts that laser pulses in the nanosecond to picosecond domain appropriately target very small structures such as tattoo pigment particles, whereas pulses in the microsecond domain best target larger structures such as vessels. A large amount of clinical data exists in support of this theory. As such, QS lasers should be the only devices used when attempting tattoo removal. When tattoos are treated with pulse durations in the millisecond range or with continuous lasers, the heat is not confined to the target. This transfer of heat causes nonspecific destruction of surrounding tissue and may result in subsequent scarring. [13, 21]

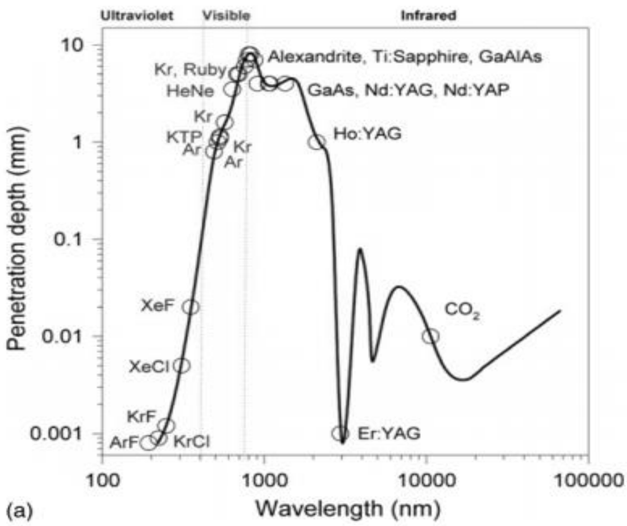

Figure 5 – Depth of penetration by various lasers [14]

In addition to use of the appropriate wavelength and pulse duration, fluence must be considered. Fluence is the energy density of the laser light delivered, measured in J/cm^2. The lowest fluence required to invoke the whitening response should be used. The use of excessive fluence causes the epidermis to absorb a greater amount of energy, which may result in blistering, skin sloughing, and a higher likelihood of scarring. Greater laser light absorption by the epidermis in darkly pigmented skin may result in similar phenomena. Attempting to avoid this in these individuals by decreasing fluence causes laser light to penetrate the skin less deeply, possibly delivering insufficient energy to the tattoo pigment. Therefore, it may be preferable to use a longer-wavelength device such as the Nd:YAG (1,064 nm) when treating darkly pigmented individuals. This allows for the use of adequate fluence and resultant dermal effect with less epidermal damage. [13, 26]

The proliferation of Q-switched lasers and the creation of extremely short, high-energy bursts of power for a particular tattoo pigment provides the basis for creating new, more advanced lasers, such as picosecond lasers. The point is that these bursts of energy are closer to the time of thermal relaxation of particles that become targets. [15, 16]

Picosecond Lasers with shorter pulse durations than the QS lasers are currently being developed. Pulses in the picosecond range may more effectively target pigment particles, with less surrounding tissue disruption. Evidence suggests that the primary mechanism of pigment elimination in laser tattoo removal is through damage of cells harboring pigment by photoacoustic rather photothermal effects. Shorter pulse durations produced by picoseconds lasers cause the target to heat and expand more rapidly than QS lasers, resulting in more substantial locally destructive forces.[27] Anderson's group found that 12 of 16 black tattoos treated using the 1,046-nm Nd:YAG laser showed greater lightening with a pulse duration of 35 picoseconds than one of 10 nanoseconds. Another recent study examined the effect of a novel 758-nm 500-ps laser on a black tattoo in an animal model. The 758-nm 500-ps laser produced greater tattoo clearance at all tested fluences than the QS alexandrite laser, a laser with a similar wavelength of 755 nm. [13, 16, 35]

Colored tattoos are becoming increasingly common and respond less predictably to treatment. In general, QS lasers will fade most colors, although certain colors may be highly resistant to treatment. Some lasers may treat particular colors more effectively, such the QS Nd:YAG (532/1024 nm) and QS alexandrite lasers for red and green pigments, respectively, but tattoo pigments are complex compounds with variable compositions, and successful treatment of colored tattoos may at times involve a “trial and error” approach.

1.4 Tattoos darkening and non-response for laser treatment

1.4.1 Tattoo and permanent makeup inks composition

Tattoo ink consists of pigments and a carrier. The carrier may be a single substance or a mixture. The purpose of the carrier is to keep the pigment evenly distributed in a fluid matrix, to inhibit the growth of pathogens, to prevent clumping of pigment, and to aid in application to the skin. [17]. For many years the main ingredients of tattoo inks were minerals, soot, plant extracts, ocher and carbon. Now the composition has changed, but some ingredients are still preserved. The composition of the pigments used for permanent makeup and tattoos includes both inorganic and organic compounds; however, the manufacturer does not always indicate the information on the composition of the ink. Black pigment is most commonly used in tattoos. It is based on the soot of animal bones and includes iron oxides, tar and wood tar. The red pigment includes cinnabar and cadmium selenide or mercury sulphide. For yellow pigment, cadmium sulfide is the basis. The composition of the blue pigment is cobalt. Lead carbonate, titanium dioxide and zinc oxide contain white pigment. The remaining colors are based on the coloring matter of sandalwood, brazilin and other substances. [24, 29] Pigment substances are solid and insoluble in water. In order for the pigment to be introduced into the skin through a needle, a liquid carrier is required with which the pigment is mixed. Distilled water, alcohol, glycerin, and witch hazel extract are used as such carriers. Composition of some most popular ink is presented in Figure 6.

Number	Name	Percentage of Elemental Composition[b]
8001	Black	85.95% iron, 13.51% oxygen, 0.29% sulfur, 0.25% aluminum
8007	White	98.55% titanium, 1.45% aluminum
8016	Fire red	30.06% oxygen, 26.21% aluminum, 23.29% carbon, 10.78% sulfur, 9.68% chlorine
8022	Flesh No. 1 (tan)	74.27% titanium, 23.98% iron, 1.75% aluminum
8031	Indian brown	57.26% iron, 41.98% titanium, 0.76% aluminum
9001	Crimson red	49.36% carbon, 22.25% oxygen, 17.2% silica, 11.19% magnesium
9002	Devil's red	51.67% carbon, 27.65% titanium, 17.55% oxygen, 2.6% aluminum, 0.53% silica
9008	Lotus (red)	40.17% titanium, 38.92% oxygen, 17.71% carbon, 3.2% aluminum
9009	Venetian brown	79.85% iron, 18.04% oxygen, 1.73% silica, 0.38% aluminum
9014	Florida orange	84.35% carbon, 15.65% oxygen
9017	Lemon yellow	53.06% titanium, 23.9% carbon, 21.18% oxygen, 1.86% aluminum
9022	White	96.41% titanium, 3.59% aluminum
9023	Black	87.98% iron, 12.02% oxygen
9024	Permanent green	51.55% chlorine, 34.24% carbon, 13.32% copper, 0.89% aluminum
9025	Emerald green	72.66% chromium, 17.25% oxygen, 5.45% titanium, 4.15% chlorine, 0.49% aluminum
9026	Pine green	44.34% titanium, 21.96% oxygen, 14.64% carbon, 8.27% copper, 6.71% chlorine, 4.08% aluminum
9029	Parrot green	58.57% titanium, 17.19% oxygen, 17.12% carbon, 4.61% chlorine, 2.51% aluminum
9061	Blue green	52.24% chlorine, 32.16% carbon, 14.46% copper, 1.14% aluminum
9090	Cerise (red)	51.51% titanium, 21.16% oxygen, 15.34% iron, 9.81% carbon, 2.18% aluminum
9091	Yukon white	94.98% titanium, 5.02% aluminum
9092	Misty green	51.5% titanium, 23.97% oxygen, 18.43% carbon, 3.59% chlorine, 2.51% aluminum
9093	Misty blue	94.82% titanium, 4.13% aluminum, 1.05% chlorine
9094	Tulip yellow	37.3% carbon, 30.31% oxygen, 27.29% titanium, 2.29% aluminum, 2.29% chlorine, 0.3% sulfur, 0.22% silica
9095	Peony (pink)	63.77% titanium, 20% oxygen, 13.85% carbon, 2.38% aluminum
9096	New blue	50.93% titanium, 18.57% oxygen, 18.21% carbon, 8.54% copper, 2.36% aluminum, 1.39% chlorine
9097	Blush (orange)	58.06% titanium, 22.43% oxygen, 14.39% carbon, 2.87% chlorine, 2.25% aluminum
9098	Wild violet (pink)	65.29% titanium, 22.27% oxygen, 9.56% carbon, 2.88% aluminum
9099	Tulip red	52.29% carbon, 25.12% oxygen, 13.4% silica, 9% magnesium, 0.19% aluminum
None	India ink	92.19% carbon, 7.81% oxygen

Figure 5 – Composition of popular inks [28]

1.4.2 Features and difficulties of titanium dioxide pigments treatment

Titanium – an element of the IV group of the periodic system D.I. Mendeleev, his atomic number is 22 and atomic weight is 47.90. The titanium - oxygen system is very complex; a large number of phases of variable composition are formed in it, some of them are stable only in a certain temperature range. In addition, solid solutions of oxygen in titanium are formed (up to 30% at.). There are three main titanium oxides:

TiO, Ti_2O_3, TiO_2. Under the action of alkalis on Ti_2^+ solutions $Ti(OH)_2$ is formed - a black substance, which is unstable and easily oxidized, forming violet color $Ti(OH)_3$ in moist air, then turning into white $Ti(OH)_4$. Chemically, TiO_2 is inert and resistant to organic and dilute mineral acids, H_2S, SO_2. In solutions of alkali soluble slightly. [18] Maximums of absorption for titanium dioxide are placed in ranges of UV 100-400 nm, NIR region 1850-2100 nm and MWIR region >8 μm

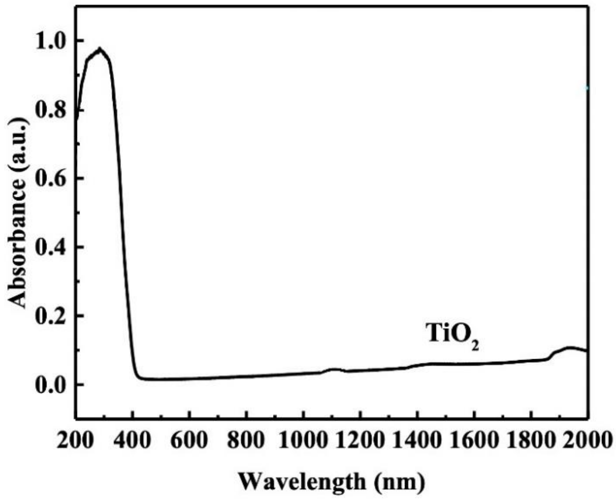

Figure 7 – UV and NIR peaks of absorption of TiO_2 [18]

In the form of titanium dioxide, it was discovered by the English amateur mineralogist W. Gregor in 1791 in the magnetic ferrous sands of the town of Menakan (England). In 1795, the German chemist MG Klaproth established that the mineral rutile is a natural oxide of the same metal, which he called "titanium". It was not possible to select an element in its pure form for a long time, only in 1910 the American scientist MA. Hunter received titanium metal by heating his sodium chloride in a sealed steel bomb; the metal obtained by him was plastic only at elevated temperatures and brittle at room because of the high content of impurities.

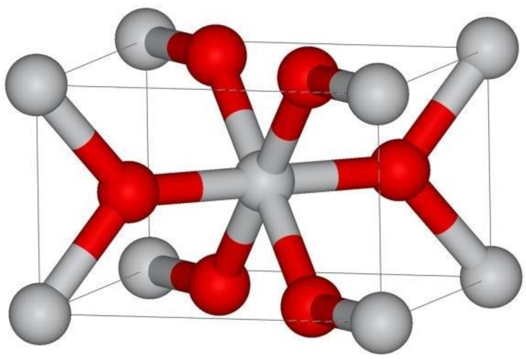

Figure 8 – Molecular structure of TiO_2 [19]

1.4.3 Tattoo darkening and colorshifts

When color shifts occur, there are a number of options, including continued treatment using a QS laser, treatment using nonselective ablative lasers, and surgical excision. One study found that continued QS laser treatment faded or cleared 21 of 29 tattoos followed for pigment darkening. [21, 35] There are numerous case reports documenting complete or near-complete clearing of blackened red to brown tattoos after treatment using a Nd:YAG (1,064 nm) laser. This approach appears to be more successful with red and brown pigments that darken, as opposed to white and yellow pigments, which tend to be more resistant. For some pigments, such as white, that can almost certainly be expected to darken with QS laser treatment, nonselective tissue ablation with lasers such as the pulsed carbon dioxide (10,600 nm) and erbium-doped Er:YAG (2,940 nm) laser may be considered. These lasers are more likely to cause scarring and produce less-predictable results than the QS lasers, but in the appropriate clinical setting, they may be of use. Finally, surgical excision remains an option for paradoxical darkening that is highly resistant to laser treatment and is cosmetically unacceptable. [13]

In most clinics removal of pigment based on TiO_2 using a laser is not possible. Titanium dioxide behaves unpredictably, and after the procedure shifts color from white to dirty green, dark gray, bluish and even pale purple, or does not react to radiation at all. Repeated visits usually cause scarring of the skin or a weakening of the tattoo. [20, 27]

Figure 9 – Darkening of medical cosmetic tattoo that contains TiO_2 after laser treatment [21]

Figure 10 – Colorshift of permanent makeup ink that contains TiO_2 after laser treatment [22]

Figure 11 – Colorshift of PMU TiO_2 ink used for conturing patient's lips after laser treatment [21]

As Fur-Jiang Leu et al assume the causes of white tattoo ink's poor response to Q-switched laser treatment are related to the ink's poor absorption even after laser-darkening and its large particle size. [20]

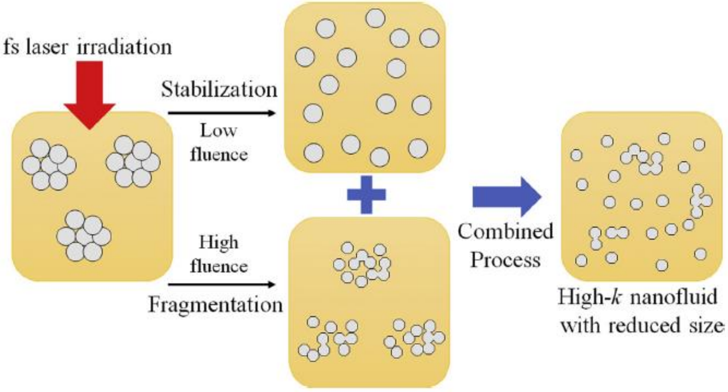

Figure 12 – Schematic concept of the proposed laser process to achieve destruction of titanium dioxide nanoparticles in suspensions [34]

Summarizing the above literature review, we can conclude that for in vivo experiments it is necessary to use pulsed Nd: YAG lasers with a wavelength of 1024 nm, in the femtosecond and nanosecond range with an energy density (fluence) of 0.6 to 11 J/cm^2. These parameters, in theory, will allow the destruction of particles of the pigment TiO^2.

4 Financial management, resource efficiency and resource saving

4.1. Potential results of research work

The purpose of this section is to confirm the technical solutions described in the previous sections, which substantiate the economic necessity and expediency of scientific and technical research.

This study was conducted to identify the optimal parameters of the effects of laser radiation on pigments containing titanium dioxide. The result of the project will serve as the foundation for creating a method for the destruction of light pigments by laser radiation. At the moment, there is no unified and accurate method of destruction of human pigment in human biological tissue, which contains titanium dioxide in its composition, and it does not apply in the Russian Federation.

The results obtained during the study can be applied by cosmetologists to build an optimal plan for a painless procedure for removing permanent makeup (PMU) or tattoos, as well as manufacturers of medical cosmetology lasers to optimize their factory built-in modes. The work can be applied further in medical research centers and in cosmetology clinics.

The target market is called the market segments, which will be the main consumers of the development in the future, and the market segment is called the part of the market or a group of consumers, identified by special common features.

According to the principle “from the general to the particular,” we take the medical field for a common area of application, since the procedure for removing pigment in human biological tissues is classified as a medical operation. The developed technique will be used to optimize the procedures for removing permanent makeup (PMU) and tattoos, therefore, a narrower field of application - cosmetology clinics and beauty salons.

Map of market segmentation is presented in Table 7

Table 7 – Market segmentation map

	Scope of application	
	Production	Cosmetology
Individuals		
Manufacturers of medical equipment		
Medical institutions		

– poorly developed segment

– segment mastered

– segment not mastered

Thus, we can conclude that the main segment of the market is represented by medical cosmetology institutions, to which this development is oriented, as well as enterprises that produce medical laser equipment.

4.1.1 Analysis of the prospects of research using QuaD analysis

Analysis of competitive technical solutions from the standpoint of resource efficiency and resource saving allows us to assess the comparative effectiveness of scientific development and determine the direction for its future improvement.

To do this, we will conduct this QuaD analysis using the scorecard presented below in Table 8.

Table 8 – QuaD analysis of the study

Criteria of evaluation (1)	Weight criteria (2)	Average score (3)	Maximal score (4)	Relative value (3/4)	Weighted average value (5/2)
Energy efficiency	0.05	30	100	0.3	6
Price	0.05	40	100	0.4	8
Market demand	0.2	80	100	0.8	4
Method security	0.15	85	100	0.85	6
Ease of interpretation of the results	0.1	75	100	0.75	7.5
Reproducibility of the results	0.15	60	100	0.6	4
Functional power	0.1	75	100	0.75	7.5
Ability to combine with other methods	0.1	80	100	0.	8

Continuation of Table 8

No need for additional training of staff / technicians	0.05	20	100	0.2	4
Versatility	0.05	70	100	0.7	1.4
Total:	1				**68.4**

Analysis of competitive technical solutions determined by the formula:

$$K = \sum В_i \cdot Б_i,$$

- where K is the competitiveness of scientific research or a competitor;
- Bi– weight of the indicator (in fractions of a unit);
- Bi - the value of the i-th indicator.

The value of K allows you to talk about the prospects of development and the quality of the study. If the value of the indicator is from 79 to 60, then the prospect is above average.

Based on the fact that the prospects of this development are above average, we can conclude that investing in the development and development of this study will give good results. The described method of destruction of pigments based on titanium dioxide will be competitive in the market of cosmetology services.

4.1.2 SWOT-analysis

SWOT analysis is one of the most effective tools in strategic management, which consists in analyzing the external and internal factors of a company, assessing the competitiveness and risks of goods in the industry. The paper conducted a SWOT analysis, the results of which are presented in Table 9.

Table 9 – SWOT Matrix

	Strengths of a research project: S1. Demand for research; S2. The relevance of the study; S3. Availability of high-tech equipment based on TPU; S4. The ability to assess the qualitative response without the involvement of special devices; S5. Low time spent on research	**Weaknesses of a research project:** W1. Imperfect reproducibility of results; W2. The need for special skills in a research group; W3. The high cost of research; W4. The absence of clinical trials of the proposed method; W5. There is no universal criterion for evaluating the validity of the method.
Opportunities: O1. Popularization of color tattoos and permanent makeup; O2. Reducing the cost of equipment; O3. Conducting clinical trials; O4. Improving the performance of laser equipment; O5. Increasing the cost of alternative methods for removing tattoos and PMU	This study is relevant and in demand, and in combination with the growing demand for colored tattoos and the constant development of laser technologies, the project is considered as attractive for entering the market. The extensive technological base of the TPU and the developed cooperation with SSMU will make it possible to perform clinical trials of the method in a short time.	Reducing the cost of equipment will reduce the cost of the study, and the results obtained after conducting clinical trials will form the final criteria for evaluating the validity of the method.
Threats: T1. The emergence of a more advanced competitive method; T2. Inapplicability of results in clinical trials; T3. Changing consumer lifestyle; T3. Lack of sufficient funding.	Possible lack of funding is compensated by the availability of the necessary technological base of TPU and the relevance of the study. Low time spent on research can be a decisive factor in the fight against new competitors.	The emergence of a more advanced method can lead to a loss of research due to its high cost and the need for highly qualified personnel. The possible inapplicability of the method in clinical studies will prevent the establishment of a criterion for its validity.

According to the results of the SWOT-analysis, it can be concluded that in order to develop and improve this research it is necessary to attract additional funding and conduct clinical in vivo studies.

A similar conclusion can be reached when considering the weaknesses of the study: the high cost of the project and further clinical studies, as well as the need to hire qualified personnel, require sources of funding.

Strengths, such as the relevance of the study, its relevance and relatively low time costs, can ensure that the study is attractive in terms of attracting funding. These factors will help to develop opportunities for promoting research in a dedicated market segment, as well as reduce the impact of weaknesses and threats that affect the competitiveness of this work.

4.1.3 Evaluation of the commercialization of research

Table 10 – A form for assessing the degree of readiness of a scientific project for commercialization

№	Criteria	The degree of elaboration of the scientific project	The level of knowledge of the developer
1	The existing scientific and technical background has been determined.	5	5
2	Identified promising areas of commercialization of scientific and technical reserve	5	5
3	Identified industries and technologies (goods, services) for supply on the market	5	5
4	The commodity form of a scientific and technical reserve for presentation on the market has been determined.	5	4
5	Authors identified and their rights protected.	3	4
6	Evaluation of intellectual property conducted	1	1
7	Conducted marketing research of markets	3	3
8	Developed a business plan for the commercialization of scientific research	1	1

Continuation of Table 10

9	Identified ways to promote scientific development to the market	1	1
10	A strategy (form) for the implementation of scientific development	3	4
11	Issues of international cooperation and entry into the foreign market have been worked out.	1	1
12	The issues of using the services of support infrastructure, benefits	2	2
13	The issues of financing the commercialization of scientific research are worked out.	4	4
14	There is a team for the commercialization of scientific research.	3	1
15	The mechanism for the implementation of a scientific project has been worked out.	5	3
TOTAL POINTS		48	41

The assessment of the readiness of a scientific project for commercialization (or the level of knowledge the developer has) is determined by the formula:

$$Б_{сум} = \sum Б_i$$, where

- $Б_{сум}$ – total points in each direction;
- $Б_i$ – score for the i-th indicator.

Analyzing the data from table 4 and the obtained value of $Б_{сум}$, equal to 41-48 points, we estimate such a project as average from the point of view of readiness for commercialization, and the developer’s knowledge is sufficient for its completion.

4.2 Initiation of the project

The aim of the work is to optimize the parameters of laser radiation for exposure to pigments based on titanium dioxide. Pre-project analysis showed that the main market segment of this project are medical cosmetology clinics, and the proposed method of destruction will be competitive.

To initiate a project, you must first define its working group. The data are shown in table 11.

Table 11 – Project working group

№	Full name, position	Role in the project	Functions	Working time, days
1	Razin A.V., Candidate of Physico-Mathematical Sciences, SAMT	Supervisor	The approval of the main sections, the issuance of tasks for execution	6
2	Lichny A.A., student TPU, RSCABS	Graduate student	Execution of tasks	96
3	Губарев Ф.А., Candidate of Engineering Sciences, RSCABS	Project Manager	Verification of the results	1
			Total:	103

The goals of the project, the structure of the project and the organization of the project participants can be described by interrelated hierarchical (tree-like) structures in which the relations between the components can be established: goals - parts of the project - participants, etc.

Table 12 – Objectives and results of a research project

Project goals:	Optimization of laser radiation parameters for exposure to pigments based on titanium dioxide.
Expected results of the project:	The possibility was evaluated and a technique was developed for the destruction of pigments based on titanium dioxide *in vitro.*
Criteria for acceptance of the project result:	Results are repeatable and interpretable.
Requirements for the project result:	Requirements:
	The result was obtained on biological similar media-solvents.
	Achieved destruction of titanium dioxide pigment
	An assessment of the possibility of conducting *in vivo* clinical trials is given.

The project’s goal tree is shown in Figure 21

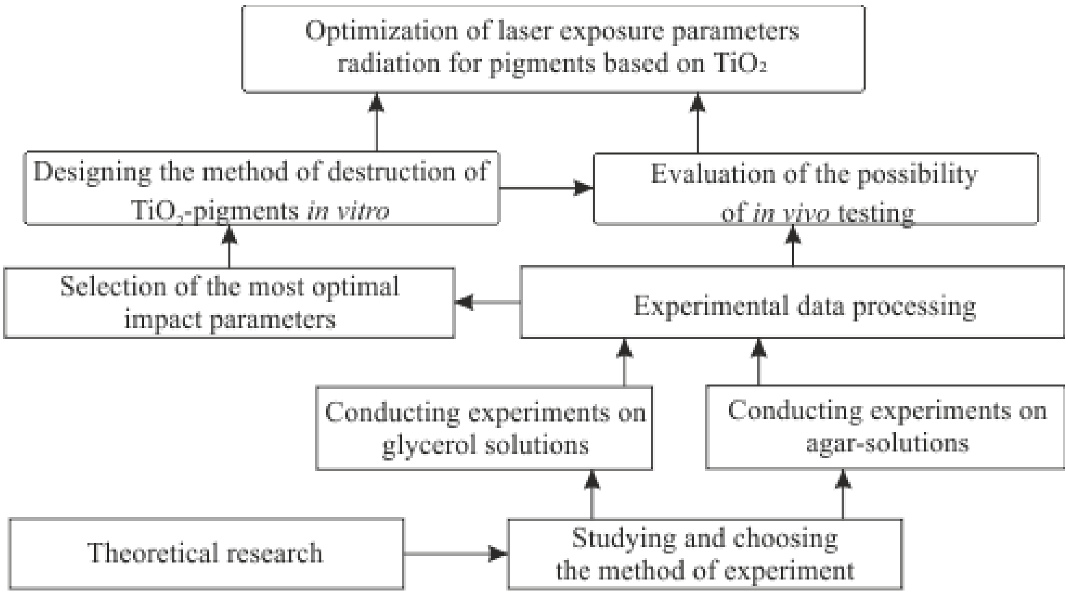

Figure 21 – Project Objective Tree

Thus, having considered the project objectives tree, it can be concluded that in order to achieve the main goal, it is necessary to perform a number of tasks, such as conducting theoretical ascolation, studying the methodology of the experiment, and conducting experiments on control solutions.

4.3. Planning the management of scientific and technical project

4.3.1 Project Plan

A group of planning processes consists of processes that are carried out to determine the overall content of the work, clarify the objectives and develop a sequence of actions required to achieve these goals.

As part of the planning of a research project, it is necessary to build a project calendar and network schedules. The list of stages, works and distribution is presented below in Table 13.

Table 13 – List of stages, work and distribution of performers

Main steps	№ work	Content of work	Position performer
Development of technical specifications	1	Drafting and approval of technical specifications	Razin A.V.
Choice of directions research	2	Selection and study of materials on the research topic	Lichny A.A.
	3	Choosing the direction of research	Razin A.V. Lichny A.A.

	4	Scheduling work on a research topic	Razin A.V.
Theoretical studies	5	Search for information on the composition of pigments for tattoos and PMU	Lichny A.A.
	6	Selection of literature on laser tattoo removal	Lichny A.A.
	7	Study of methods for evaluating qualitative reactions of solutions	Lichny A.A.
	8	Analysis of the subject area	Razin A.V., Lichny A.A.
	9	Systematization and analysis of the information received	Lichny A.A.
	10	Selection of the most appropriate research methodology	Razin A.V.
Practical research	11	Learning the basics of working with laser technology	Lichny A.A.
	12	Construction of the experiment plan	Razin A.V. Lichny A.A.
	13	Conduct an in vitro experiment on prepared samples using Nd: YAG lasers	Lichny A.A.
	14	Analysis of the validity of the experiment and the data obtained	Razin A.V. Lichny A.A.
	15	Create a report on the experiment	Lichny A.A.
Registration of the research results	16	Doing other parts of the job (financial management, social responsibility)	Lichny A.A.
	17	Summing up, verification of examinations	Razin A.V. Gubarev F.A.

4.3.2 Calendar planning

4.3.2.1 Determination of the complexity of the work

To determine the expected value of the complexity we use the formula below:

$$t_{\text{ожі}} = \frac{3t_{\min i} + 2t_{\max i}}{5}, \text{ where}$$

1) $t_{\text{ожі}}$ – the expected complexity of the i-th work man-days.;

2) $t_{\min i}$ – the minimum possible laboriousness of performing the specified i-th work (optimistic estimate: assuming the most favorable set of circumstances), man-days;

3) $t_{\max i}$ – the maximum possible labor-intensiveness of performing a given i-th job (pessimistic assessment: assuming the most unfavorable set of circumstances), man-day.

4) After we have calculated $t_{ожі}$, the duration of each work in working days is calculated:

$$T_{p_i} = \frac{t_{ожі}}{Ч_i}, \text{ where}$$

1) T_{pi} – the duration of one job, work days;

2) $t_{ожi}$ – the expected complexity of doing one job, man-day

3) $Ч_i$ – the number of performers performing simultaneously the same work at this stage, pers.

4.3.2.2 Development of a research schedule

When developing a schedule for conducting a scientific study, it is advisable to use a Gantt chart - a horizontal tape chart, on which work on a topic appears to be lengthy segments, characterized by dates of the beginning and end of the work.

To calculate the calendar coefficient:

According to the production calendar (for a 6-day working week) in 2019, 365 calendar days, 299 working days, 66 days off / holidays.

$$k\text{кал} = \frac{\text{Ткал}}{\text{Ткал} - \text{Твых} - \text{Тпр}} = \frac{365}{365 - 66} = 1{,}22 \text{ , where}$$

1) $T_{кал}$ – number of calendar days per year;

2) $Т_{вых}$ – number of days off per year;

3) $Т_{пр}$ – the number of holidays in the year.

All results obtained during the calculations are listed in Table 8.

Table 14 – Timeline indicators of research

Task title	The complexity of the work									Duration of work in working days T_{pi}			Duration of work in calendar days $T_{кi}$		
	t_{min}, man-days			t_{max}, man-days			$t_{ожi}$, man-days								
	Razin	Lichny	Gubarev	Razin	Lichny	Gubarev	Razin	Lichny	Gubarev	Razin	Lichny	Gubarev	Razin	Lichny	Gubarev
Drafting and approval of technical specifications	1	-	-	2	-	-	1.4	-	-	2	-	-	2	-	-
Selection and study of materials on the research topic	-	14	-	-	21	-	-	16.8	-	-	16	-	-	20	-
Choosing the direction of research	1	1	-	1	1	-	1	1	-	1	1	-	1	1	-
Scheduling work on a research topic	1	-	-	1	-	-	1	-	-	1	-	-	2	-	-
Search for information on the composition of pigments for tattoos and PMU	-	5	-	-	7	-	-	5.8	-	-	6	-	-	7	-
Selection of literature on laser tattoo removal	-	7	-	-	10	-	-	8.2	-	-	9	-	-	10	-
Study of methods for evaluating qualitative reactions of solutions	-	4	-	-	5	-	-	4.4	-	-	4	-	-	5	-

Continuation of Table 14

Analysis of the subject area	1	1	-	2	2	-	1.4	1.4	-	1	1	-	1	1	-
Systematization and analysis of the information received	-	4	-	-	6	-	-	4.8	-	-	5	-	-	6	-
Selection of the most appropriate research methodology	-	5	-	-	10	-	-	7	-	-	7	-	-	9	-
Learning the basics of working with laser technology	-	10	-	-	14	-	-	11.6	-	-	12	-	-	14	-
Construction of the experiment plan	1	2	-	1	3	-	1	2.4	-	1	1	-	1	2	-
Conduct an in vitro experiment on prepared samples using Nd: YAG lasers	-	10	-	-	21	-	-	14.4	-	-	14	-	-	17	-
Analysis of the validity of the experiment and the data obtained	1	1	-	1	1	-	1	1	-	1	1	-	1	1	-
Create a report on the experiment	-	4	-	-	7	-	-	5.2	-	-	5	-	-	6	-
Doing other parts of the job (financial management, social responsibility)	-	12	-	-	19	-	-	14.8	-	-	15	-	-	18	-
Summing up, verification of examinations	1	-	1	2	-	2	1.4	-	1.4	1	-	1	1	-	1
									Total:	8	97	1	9	107	1

Table 15 – The calendar schedule of the study

№ работ	Task title	Performer	$T_{кi}$, Cal. days	Duration of work											
				February			March			April			May		
				1	2	3	1	2	3	1	2	3	1	2	3
1	Drafting and approval of technical specifications	Razin A.V.	1.7												
2	Selection and study of materials on the research topic	Lichny A.A.	20.5												
3	Choosing the direction of research	Razin A.V. Lichny A.A.	0.6 0.6												
4	Scheduling work on a research topic	Razin A.V.	1.22												
5	Search for information on the composition of pigments for tattoos and PMU	Lichny A.A.	7												
6	Selection of literature on laser tattoo removal	Lichny A.A.	10												
7	Study of methods for evaluating qualitative reactions of solutions	Lichny A.A.	5.4												
8	Analysis of the subject area	Razin A.V., Lichny A.A.	0.9 0.9												
9	Systematization and analysis of the information received	Lichny A.A.	5.8												
10	Selection of the most appropriate research methodology	Razin A.V.	8.5												
11	Learning the basics of working with laser technology	Lichny A.A.	14.2												
12	Construction of the experiment plan	Razin A.V., Lichny A.A.	0.6 1.5												

Continuation of Table 15

13	Conduct an in vitro experiment on prepared samples using Nd: YAG lasers	Lichny A.A.	17.6
14	Analysis of the validity of the experiment and the data obtained	Razin A.V., Lichny A.A.	0.6 0.6
15	Create a report on the experiment	Lichny A.A.	6.3
16	Doing other parts of the job (financial management, social responsibility)	Lichny A.A.	18.1
17	Summing up, verification of examinations	Razin A.V. Gubarev F.A.	0.9 0.9

Lichny A.A. - Razin A.V. – Gubarev F.A. –

4.3.3 Budget scientific and technical project

When planning a scientific and technical research budget, a reliable and complete reflection of all types of expenses related to its implementation should be provided. When forming the research project budget, the cost grouping is used according to the following items:

1) material costs;

2) the basic salary of the performers of the topic;

3) additional salary of the performers of the topic;

4) depreciation deductions;

5) contributions to extra-budgetary funds (insurance contributions);

6) overhead costs.

4.3.3.1 Calculation of material costs

This article includes the cost of all materials used in project development. Calculation must be made for all performers.

Table 16 – Material costs

Title	Unit of measurements	Amount	Price per piece, rub	Cost of materials, ($З_М$), rub.
Office expenses	Rub.	1	300	300
Laboratory supplies	Rub.	1	800	800
Titanium dioxide	Rub.	1	185	185
Glycerol	Rub.	2	22	44
Agar	Rub.	2	41	82
Total:				**1411**

Total for the item "Material costs" - 1411 rubles.

4.3.3.2 Calculation of depreciation

This section considers all costs that are associated with the acquisition of equipment necessary for carrying out research work. But for this study, the equipment was not purchased separately, so depreciation of equipment that was already available and used for experiments should be calculated.

There are several ways to calculate depreciation, but the simplest is linear depreciation. We use the classifier of fixed assets for depreciation groups, approved by Government Decree No. 1 of 01/01/2002. to calculate the depreciation of the equipment from Table 17.

The depreciation is calculated using the following formula:

$$З_{об} = \frac{Ц \cdot F_ф}{F_н \cdot F_{cc}}$$, where

- Ц- equipment price, rub.;
- Fн - nominal time fund (working time per year), h.;
- Fcc - equipment life cycle, years;
- Fф - the actual time of employment of equipment, h.

$$F_Н = (365 - T_{вых}) \cdot t_{раб} = (365 - 118) \cdot 8 = 1976 \text{ ч.}$$

Table 17 – The cost of depreciation of equipment

№	Equipment title	Price per one equipment, rub.	Life cycle, years	Occupancy time, h	The cost of depreciation, rub.
1	Laser LQ-929	1 200 000	6	15	1518
2	Laser SL235	586 000	6	15	741
3	Microscope	120 000	3	6	121
4	Computer	45 000	3	936	7105
				Total:	9485

Total for the item "Calculation of depreciation" - 9485 rubles.

4.3.3.3 Basic salary of the performers of the topic

This item includes the remuneration of the research supervisor and the engineer. The salary of the head is 33664 rubles without the regional coefficient, and the engineer 21760 rubles without the regional coefficient.

Thus, the salary is calculated by the following formula:

$$З_{зп} = З_{осн} + З_{доп}, \text{ where}$$

1) $З_{осн}$ – basic salary;

2) $З_{доп}$ – additional salary.

$$Зосн = Здн \cdot Тр, \text{ where}$$

1) $З_{дн}$ – average daily salary of an employee, rubles;

2) Тр – the duration of the work performed by the employee, work days.

The average daily salary is calculated by the formula:

$$З_{дн} = \frac{З_м \cdot М}{F_д}, \text{ where}$$

1) $З_м$ – monthly salary of an employee, rubles.;

2) М – the number of months of work without vacation during the year (with a vacation of 24 working days M = 11.2 months, 5 days a week; with a vacation of 48 working days M = 10.4 months, 6 days a week);

3) $F_д$ – valid annual fund of working time of scientific and technical personnel, work day.

Table 18 – The balance of the working day

Working time	Razin	Lichny	Gubarev
Calendar number of days	365	365	365
The number of non-working days - weekend - holidays	66	66	66
Loss of working time - vacation - absences due to illness	56	56	56
Valid annual working time fund	243	243	243

Monthly salary of an employee:

$$З_м = З_{тс} \cdot (1 + k_{пр} + k_д) \cdot k_р, \text{ where}$$

1) $З_{тс}$ – salary at the tariff rate, rub.;

2) $k_{пр}$ – premium coefficient of 0.3 (i.e. 30% of $З_{тс}$);

3) $k_{д}$ – коэффициент доплат и надбавок составляет примерно 0,2 – 0,5 (in scientific research institutes and industrial enterprises - for the expansion of service industries, for professional skills, for harmful conditions: 15-20% of $З_{тс}$);

4) $k_{р}$ – district coefficient equal to 1,3 (for Tomsk).

Table 19 – Calculation of basic wages

Performers	Зтс, rub	Зм, rub	Здн, rub	Тр, work days	Кр	Зосн
Lichny A.A.	21760	28288	1210	97	1.3	117370
Razin A.V.	33664	43763	1140	8	1.3	9120
Gubarev F.A.	33664	43763	1140	1	1.3	1140
					Total	127630

Total for the title "Basic salary" - 127630 rubles.

4.3.3.4 Additional salary of the executive system

The costs of additional wages for the executors of the topic consider the number of surcharges provided for by the Russian Federation Labor Code for deviations from normal working conditions, as well as payments related to the provision of guarantees and compensations.

The calculation is made according to the following formula:

$$З_{доп} = k_{доп} \cdot З_{осн}, \text{ where}$$

$k_{доп}$ – the coefficient of additional wages is assumed to be 0,13.

$Здоп(Razin\ A.V.) = 1186(rub.)$

$Здоп(Lichny\ А.А.) = 15258(rub.)$

$Здоп(Gubarev\ F.A.) = 150(rub.)$

Total for the title "Additional salary" - 16590 rubles.

4.3.3.5 Deductions to extra-budgetary funds (insurance deductions)

This item of expenses reflects obligatory deductions according to the standards established by the Russian Federation legislation to the state social insurance, pension fund and medical insurance from the costs of employees.

The amount of payments to extra-budgetary funds is determined on the basis of the following formula:

$$З_{внеб} = k_{внеб} \cdot (З_{осн} + З_{доп}), \text{ where}$$

$k_{внеб}$ – coefficient of deductions for payment to extra-budgetary funds, equal to 30% (0,3).

$$Звнеб(Razin\ A.V.) = 3432(rub.)$$

$$Звнеб(Lichny\ \text{А.А.}) = 39780(rub.)$$

$$Звнеб(Gubarev\ F.\text{А.}) = 400(rub.)$$

Total for the item "Deductions to extra-budgetary funds" - 43600 rubles.

4.3.3.6 Overhead

Overhead costs consider other expenses of the organization that are not included in the previous cost items: printing and photocopying of research materials, payment of communication services, electricity, postal and telegraph expenses, reproduction of materials, etc. Its value is determined by the following formula:

$$З_{накл} = (\textstyle\sum_{статей 1 \div 5}) \cdot k_{нр}, \text{ where}$$

$k_{нр}$ – overhead coefficient.

The overhead coefficient can be taken in the amount of 16%.

Total for the item "Overhead" - 31570 rubles.

4.3.3.7 Forming a budget for a research project

Table 20 – Estimated research project budjet

Item of expenditure title	Amount, rub.	Cost share, %
1. Material costs of STR	1411	0.6
2. Depreciation	9485	4.2
3. The costs of the basic salaries of the performers of the topic.	127630	55.4
4. Costs for additional salary of the topic performers	16590	7.2
5. Deductions to extra-budgetary funds	43600	18.8
6. Overhead	31570	13.8
Total:	**230286**	**100**

4.3.4 Project risks

Risk is the possibility of the occurrence of some adverse event that entails the occurrence of various kinds of losses. A unified risk classification project does not exist. We can single out the following main groups of risks inherent in almost all projects: political, economic, social, technological, environmental, financial, organizational, marketing, personnel, technical.

To begin with, the main risk groups of the project are determined, it is explained what each risk group is.

Table 21 – Definition of risk

№	Risk name	Risk description
1	Political	No risk
2	Economic	A change in the exchange rate entails a sharp rise in price for the electronic equipment used in the study.
3	Social	No risk
4	Ecological	Negative impact of the equipment used in the study on the environment
5	Technological	The emergence of more advanced tattoo removal technology
6	Financial	Insufficient research funding
7	Organizational	The difficulty of providing premises for research

Continuation of Table 21

8	Marketing	Inadequate pricing assessment in the market of cosmetic services
9	HR	Lack of trained staff
10	Technical	Equipment failure

Then, the risk probability is estimated using the risk probability scale and the loss level assessment scale. The result of this stage is presented in the form of tables 22 - 23.

Table 22 – Risk Probability Assessment

№	Risk name	Risk probability estimate (low, medium, high)
1	Political	Low
2	Economic	Medium
3	Social	Low
4	Ecological	Low
5	Technological	Low
6	Financial	Medium
7	Organizational	Medium
8	Marketing	High
9	HR	Medium
10	Technical	Low

Table 23 – Loss assessment

№	Risk name	Loss assessment (low, medium, high)
1	Political	Low
2	Economic	Medium
3	Social	Low
4	Ecological	Low
5	Technological	Medium
6	Financial	High
7	Organizational	Medium
8	Marketing	High
9	HR	Low
10	Technical	High

After that, fill in the table "Matrix of the probability of risks / losses" on the basis of the scale and develop the main measures to reduce the risk.

Table 24 – Key risk reduction measurements

№	Risk name	Risk reduction measures
1	Political	Not required
2	Economic	If possible, use domestic equipment, software and hardware

Continuation of Table 24

3	Social	Not required
4	Ecological	To be guided by the existing standards of disposal of research objects, as well as equipment in case of its malfunction
5	Technological	Not required
6	Financial	Publication of the research and implementation of an active advertising campaign aimed at large cosmetology clinics and manufacturers of laser medical equipment.
7	Organizational	An advance pre-project analysis of the presence of scientific research institutes on the necessary parameters of the room and / or the availability of equipment.
8	Marketing	Hiring employees with sufficient qualifications for a detailed pre-project market assessment
9	HR	Additional training for staff participating in the study
10	Technical	Timely maintenance, careful handling and repair of equipment as needed

Thus, in this section, the risks associated with conducting this scientific and technical study, as well as measures to reduce them, were considered.

4.4 Description of potential effect

Over the past century, the trend of decorating your body with tattoos and permanent makeup has increased dramatically. According to studies, at the moment about 25% of the world population have tattoos. In addition to improving the technology of tattooing and reducing the cost of such services, the range of various pigments introduced to customers under the skin has also increased.

Over time, tattoos change their social susceptibility, pattern geometry, or fade. In connection with the development of laser technology in aesthetic medicine, it is possible to remove the injected and natural pigment by acting on it with selective laser radiation. However, today there is no definite and exact method of destruction of light pigment in human biological tissue due to the fact that the white color reflects any visible radiation. It carries aesthetic discomfort, and often entails social problems.

A review of the literature has shown that similar studies have practically not been carried out before, and the nature of the color change of pigments based on titanium dioxide, which is part of most of them, has not been precisely established. Since the evidence of this method has not been fully investigated, there are practically no works like this.

In this section of the work it was determined that the potential consumers of the results of the study will be clinics of aesthetic medicine. The results of the SWOT analysis showed that the strengths of the project such as the relevance of the study, its relevance and relatively low time costs can ensure that the project is attractive in terms of raising funds. QuaD-analysis showed that the prospects of this development are above average, and the evaluation of commercialization reveals the readiness of the project as an average. In addition, the research topic participants (3 people) were identified, and a scientific and technical study was planned with the development of a research schedule: 17 stages of the study took 1 day for Gubarev F.A., 8 days for Razin A.V., and 97 days for Lichny A.A. In addition, a scientific and technical project budget was calculated for several expenditure items. The total cost amounted to 230286 rubles. On top of this section, risks were considered for current scientific and technical research.