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University teaching laboratory on laser physics, photonics and fiber optics

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Abstract

International laser Center of Moscow State University offers teaching setups for undergraduate students and students of retraining courses who apply photonics, lasers, and optical communication methods in different fields. Each teaching task is targeted to make a student carry out a real experiment. Most of laboratory works are intended both for phenomena demonstration and for in-depth study of physical mechanisms. The developers of the laboratory works tried to link them to the concepts from other physics courses: quantum mechanics, electricity and magnetism, solid-state physics. Laboratory experience with lasers and photonics reinforces ideas learned in these courses.

Keywords

Education in optics, practicum, photonics, lasers, nonlinear optics, spectroscopy, fiber optics.

Summary

In Russia we can see trends in teaching students toward to substitution virtual computer environment for real laboratory experiment. For students of optics and laser physics it means more practice in changing parameters of computer simulations than in adjustment of optical elements and tuning laser setup. We do not think it is good for training of highly qualified experts both in engineering and science. The development of the teaching laboratories with real experimental setups is very important both for training specialists and to form correct natural scientific world view of students.

International laser Center of Moscow State University accepts students from physics faculty and retraining students and provides them facilities to work on a scientific project in one of more than dozen experimental laboratories. Besides, we have a constantly developing teaching laboratory with laser and optics setups meant for practical classes for undergraduate students, refreshing courses, and to retrain specialists who apply photonics, lasers, and optical communication methods in different fields (biology, chemistry, medicine, etc.). We can also provide teaching equipment and manuals to recreate practicum outside ILC MSU.

The laboratory works mainly concern optical experiment and can be used in practical classes as a support for basic and specialized courses in the universities or other educational institutions in the fields of laser physics, nonlinear optics and spectroscopy, optical communications and photonics. Each teaching task is targeted to make student carry out a real experiment in the specific area. Most of laboratory works are intended for phenomena demonstration and for in-depth study of physical mechanisms.

The developers of the laboratory works tried to link them to the concepts from other physics courses, such as quantum mechanics, electricity and magnetism, and solid-state physics. Laboratory experience with lasers and photonics reinforces ideas learned in these courses and allows for spiral learning of important concepts.

All the tasks can be sorted by subject in several groups: Basic course of optics, Laser physics, Signal recovery and data processing, Nonlinear optics and spectroscopy, Fiber optics. The first group is designed for entry-level students and includes experimental study of the foundations. The other laboratory works are designed for upper year students of the corresponding specialties.

Here we present a brief description of teaching experiments designed and realized in Moscow State University.

Optics. Basic course.

Geometrical optics.

This experiment enables students to understand the basics of geometrical optics. An optical set up having one or several lenses allows observing the sharp image of the light source. By measuring the system linear dimensions one can calculate focal lengths and other parameters of lenses in use.

Polarization of light.

In this laboratory work students study the polarization states of light. A simple set-up with diode laser, photo-detector, polarizer, and birefringent plates permits students to investigate different state of light polarization, e.g. elliptical, circular, and linear.

Fresnel Diffraction.

In this laboratory work students become acquainted with diffraction patterns by different objects and corresponding theory in Fresnel approximation. An object is illuminated by diode laser beam passed through a divergent lens. Students can observe the diffraction pattern on a screen and investigate the light intensity distribution in the screen plane using a photo-detector.

Fraunhofer Diffraction.

This experiment familiarizes students with basics of diffraction phenomenon and its description in Fraunhofer approximation. A plane monochromatic wave of light (laser beam) interacts with an investigated object. Obtained diffraction pattern is registered by a computer controlled system. The following data processing allows to determine the parameters of the object.

Laser physics.

Holography.

This laboratory experiment familiarizes students with the practical method of recording holograms of real transparent objects. First, students are suggested to build and adjust a simple experimental set-up containing He-Ne laser, a beamsplitter, mirrors, and several transparent objects. Then they cover the set-up with light-tight box and record a hologram on a special photoplate. After developing the photoplate students study the virtual and real image reconstruction in reference beams with different wavelength and spectrum.

Optical modulation.

In this experiment the students study the principles of modulation of light. Modulators have important technological applications in fiber optics and optical communications. In the first part of the experiment the electro-optical modulator is studied. Applying a voltage to the crystal results in changing of the indices of refraction and, hence, the polarization of the transmitted light. The acousto-optical modulator (AOM) is then studied. A sound wave, inside the AOM quartz crystal, is created by a piezoelectric transducer resulting in a volume diffraction grating.

Laser Beam Characterization.

The measurement of M2 is very popular nowadays because this parameter is invariant throughout the propagation of the beam and quantitatively compares the propagation characteristics of the real beam to those of a pure TEM00 for the Gaussian beam. Students learn how to make correct measurements of the main parameters of a laser beam such beam parameters as beam center, diameter, ellipticity, divergence angle, beam propagation factor M2, Relay distance etc. according to international standard ISO 11146 “Test method for laser beam parameters: Beam width, divergence angle and beam propagation factor”. During this task students are asked to measure beam center and beam diameters as first and second moments of the intensity distribution function correspondingly. The algorithm of measurements of M2-parameteris could be based on double or multiple beam diameters.

Compact micro joule laser radar and aerosol monitoring technique.

In this laboratory work students study the operation of compact laser radar based on a diode laser as a light source with eyes-safe level of output power and avalanche photodiode operating in photon counting regime. In contrast to the traditional technique of remote sensing with analog signal registration, this set-up uses only digital circuits without signal preamplifiers, and digital data processing, storage, and presentation. Extremely low level of pulse energy in the laser beam and presence of noise requires statistical approach for signal detection with preassigned criteria when signal-noise ratio is much less then unity.

Nonlinear optics and spectroscopy.

Optical harmonics generation and optical parametric oscillator.

Nonlinear optical effects such as second harmonic generation (SHG), optical mixing, and optical parametric oscillations are studied in this experiment. Nonlinear optical crystals can be used to sum and difference optical frequencies to create light with different wavelengths. Using basic equipment set-up students investigate the second harmonic generation in detail. They study the phase matching conditions for SHG, where the fundamental and the second harmonic waves travel inside the crystal at the same velocity. They measure the second harmonic power as a function of angle between the beam and the optical axis. Then they study the influence of the crystal type, its length, and radiation input power on the efficiency of SHG. Also they can measure the beam parameters for fundamental and second harmonic radiation: pulse shape and width, average power, and beam profile, which are strongly affect the conversion efficiency of SHG. Additional equipment set-up is used for third (and forth) harmonic generation and optical parametric oscillator (OPO).

Lock-in technique in pump-probe spectroscopy.

This experiment deals with fundamentals of lock-in technique for measurements of small signals in nonlinear spectroscopy using the pump-probe method. A pump beam modulates the transmission of a solid sample to be measured with a probe beam. The pump and probe beams interact in the sample through thermal nonlinearity. The basics of the thermal nonlinearity are studied. Two continuous wave lasers with different wavelengths are used as in this experiment, and the pump beam is modulated by a mechanical chopper.

Fourier Transform IR spectrometer.

This experiment targeted to explain the concept of FTIR spectrometer and details of light spectrum measurement in near and middle infra red region. Students measure the control interferogram without sample and interferogram with sample, calculate the spectra with different windowing methods, and obtain determined transmittance and absorbance spectrum of the sample. Also they learn about the different photodetectors commonly used in IR spectroscopy.

Fiber optics.

Chromatic dispersion in optical fibers.

In this work the physical nature of chromatic dispersion is studied. The main goal is giving and idea of spectral dependence of chromatic dispersion in standard fibers, dispersion-shifted fibers, and to acquaint students with the measurement technique. During this lab students analyze different approximations for spectral dependence of signal delay and measure the length of single mode optical fibers.

Integrated losses in components of fiber optics communication lines.

The experiment is aimed to acquaint students with physical mechanisms of losses in optical communication lines and familiarize them with experimental details involving fiber optics. They study basic types of losses in fibers (absorption, linear and nonlinear scattering, radiation losses), losses in input couplers and fiber junctures.

Characterization of back scattering in optical fibers.

In this laboratory work students learn physical mechanisms reasons of scattering in optical fibers, and measuring technique for spectral and power characteristics of backscattering with spatial and time resolution. The work aimed to acquaint students with basic types of scattering in optical fibers: Rayleigh scattering, scattering induced by fiber inhomogeneities, scattering at fibers flat ends and at junctures. Measurements of backscattering magnitude are carried out using pulse technique ensuring spatial resolution. Applying heterodyne technique students can measure magnitude and frequency of different scattered components.

Measurement of optical fibers parameters by optical time domain reflectometer.

Optical time-domain reflectometer (OTDR) is based on light scattering phenomena and has wide spread applications for measurements of decay, losses, and length of fiber optics communication lines. This equipment serves for fiber optic cable production, optical fiber assembling and use, and can be applied in laboratory as well as in field conditions.

Polarization mode dispersion and interferometric methods of its measurement.

In the laboratory work students study the physical mechanisms of polarization mode dispersion (PMD) and methods of PMD measurement. Students familiarize with various properties of polarization maintenance fibers and fibers applied in communication lines. A PMD-meter is used for characterization of fiber optics systems with high-rate data transmission.

Ytterbium doped fiber laser.

The laboratory work familiarizes students with operating principles, experimental realization, and output characteristics of a single mode fiber optic laser with diode pumping. In this work students measure the spectrum, output power, watt-ampere characterization of the laser operating in continuous wave. They learn the optical scheme of the laser, the structure of active fibers allowing the efficient coupling of pump with dopant, the properties of distributed mirrors based on Bragg diffraction, and semi classical laser theory. Special attention is paid to how various factors affect the conversion efficiency of the laser.