Virtual Instrumentation for Laser Products Certification

Speaker/Author: Dan G. SPOREA
National Institute for Laser, Plasma and Radiation Physics
Magurele, Atomistilor St. 111, RO-76900, Romania
Phone: + 40 745 75 95 45 ; FAX : + 40 21 423 17 91
sporea@ifin.nipne.ro

Abstract

As Romania is preparing to join the EU's internal market, the demand for the characterization/ certification of laser-based products increased significantly, mostly for medical and optical communication devices. In order to face this challenge, our laboratory started the process for its accreditation as testing laboratory, according to ISO 17025. Within this frame, accurate evaluation of laser beam parameters is mandatory. To support this demand, we developed several set-ups for laser beam characterization under PC control, based on standalone equipment. Virtual instruments to control these set-ups were built using the graphical programming environment LabVIEW, provided by National Instruments. The paper describes some of our results, and illustrates the application of the virtual instrumentation concepts to the evaluation of various laser systems used in medicine, art restoration, robotics/ remote control, and communications.

1. Socio-economic and legal background for laboratory accreditation

The wide spread use of laser systems into the economic and social life (industrial material processing, optical fiber communications, medical practice, industrial metrology and non-destructive testing, environmental monitoring) requires more stable and reproducible laser beams, sometimes designed on custom demand. For this reason, accurate evaluation of laser beam parameters such as power, energy, power density, wavelength, transversal/longitudinal mode structure is mandatory.

On the other side, at European scale, a new strategy concerning safety standards was developed, in relation to the ***New Approach*** [1]. From the perspective of the impact of newly introduced HiTech products on the consumer market, laser-based products are of special interest. By their intrinsic characteristics (mono-chromaticity; directivity; narrow emission bands; CW, pulsed or modulated operation; wavelength tuning capability; a large spectrum of emission bands available, from UV to far IR), and by their complex biologic effects on human tissues, laser products present potentially high hazards for users. A special attention has to be paid to laser products used in medicine, because in this case high exposure doses are implied, well above the maximum permissible exposure for human safety. In health care facilities (operating theaters, laser-based diagnostics/investigation centers, laser therapy rooms) both the medical doctor and the patient are subjected to high risks. European Union's Directives prohibit the introduction on the market of hazardous products without prior certification. From this point of view, a very strict evaluation of laser products has to be observed, in relation to their classification according to possible risks for the consumer. Laser-based products fall under the legal conditioning of several EU's Directives:

- the “Low Voltage Directive”;
- the “Medical Devices Directive”;
- the “Products Safety Directive”, in the case lasers are embedded into consumer products such as toys or laser pointers.

On the EU’s market, the safety operation of laser products is reinforced by EN 60825 series European Norms and their amendments [2]. For laser medical products a Technical Report issued by the IEC TC 76 has to be observed, too [3].

EU’s documents regarding the association of Central and Eastern Europe countries with the Union impose the development of a national quality infrastructure (calibration and testing laboratories, products certification, market surveillance, existence of notification bodies, mutual recognition, etc.) [4]. Within this frame, the development of calibration/ testing laboratories is part of the Romanian Government policy in joining the EU single market [5]. In Romania, at national level, the “Low Voltage Directive” is implemented by two orders, one issued by the Ministry of Industry and Resources (No. 184/6.06.2001) and the other by the Ministry of Labor and Social Protection (No. 395/6.06.2001). The calibration/ certification of instruments performing laser power, energy and wavelength measurements are under state control as stipulated by The Romanian Bureau of Legal Metrology’s decision, supported by a governmental document (published in Buletinul Oficial No. 287 bis/23.10.1997). The three physical quantities are involved in the evaluation of laser related hazards. In the mean time, Law No. 90/1996 on norms for safety working conditions includes some requirements related to working places associated to laser risks.

Based on these documents and willing to prepare the country for the ascension to the EU, the Romanian Government initiated a national programme aiming to support the development of quality infrastructure – the Research and Development Programme INFRAS. On a competion base, the programme offers financial support to research institutes and entities belonging to the quality infrastructure:

- to develop calibration and testing facilities;
- to prepare national norms according to EU’s standards;
- to organize intercomparisons;
- to set-up traceability schemes;
- to acquire or build working standards;
- for personnel training (i.e. on measurement uncertainties, best practice, etc.).

The main novelty of the programme consists in the introduction, for the first time in Romania, of laboratory accreditation based on ISO 17025.

In this frame, our Institute obtained a grant for a project to prepare its Laser Metrology and Standardization Laboratory for the accreditation according to ISO 17025, as testing laboratory for laser-based products. On the other hand, our project fulfills also a stringent requirement of the Romanian Ministry of Health concerning the need for technical evaluation of medical laser devices in use. At this moment, our Laboratory is recognized by the Ministry of Health’s notification body (SVIAM), in charge with medical products, as the main supplier of testing services for laser-based medical instrumentation. Another growing market in Romania for laser related testing services refers to the optical communications systems, both optical fiber-based and free space. Having these opportunities to access the market, we are targeting the accreditation of the Laboratory in relation to laser power, laser energy and laser wavelength tests.

2. Laboratory set-up

Within the project frame, apart from the preparation of quality system documents, we started to develop a facility able to carry out investigations on lasers and laser-based devices, covering most of the spectral ranges, as it concerns lasers power, energy, wavelength and beam quality (transversal/ longitudinal mode structure). For better data acquisition, processing and recovering we based our methodology on automatic PC acquisition, using serial or parallel instrumentation control. Various virtual instruments and user-friendly interfaces were designed based on the National Instruments LabVIEW graphical programming environment [6].

Figure 1 illustrates the general set-up we are using for laser products evaluation. It includes: several type of laser sources (gas, solid-state, semiconductor), appropriate measuring heads for laser power or energy measurements, a CCD cameras for laser beam analysis, the appropriate PC interfaces (for data acquisition, image acquisition, instrumentation control), computer network boards.

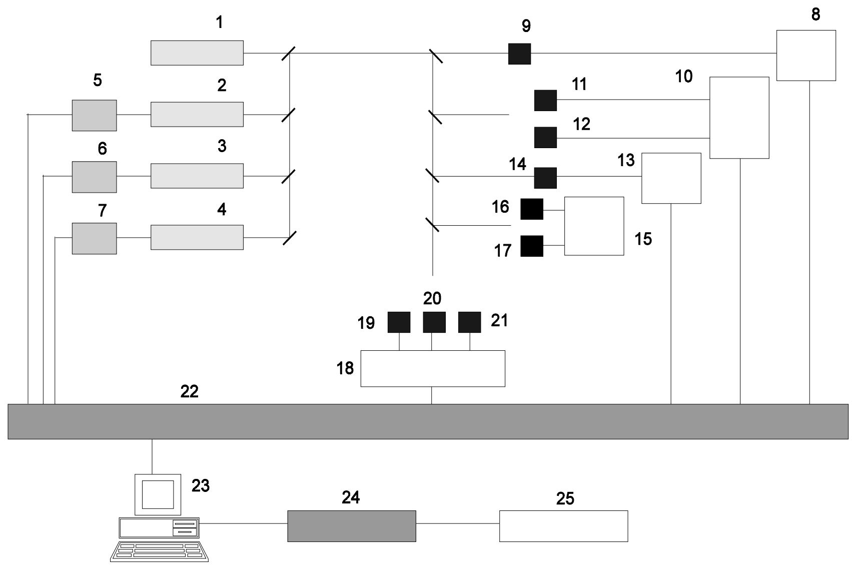


Figure 1. The basic of the experimental set-up for laser beam characterization: 1 – gas laser, 2 – solids-state laser; 3 – semiconductor laser; 4 – laser array; 5 – pumping system; 6 - laser driver/temperature controller; 7 – high power driver; 8 – wavelength meter; 9 – wavelength measuring head; 10 – laser power meter; 11 – semiconductor power head; 12 – thermopile power head; 13 – laser beam analyzer; 14 – CCD camera; 15 – laser energy meter; 16 – thermopile head; 17 – pyroelectric head; 18 – PC bus; 19 – data acquisition board; 20 – instrumentation interface; 21 – image acquisition; 22 – bus drivers; 23 – PC; 24 – network; 25 – Internet connection.

For power measurements a dual-channels instrument was employed which accommodates "smart heads", so that calibration constants are memorized into the detecting device EPROM. The same facilities are available for energy measurements. In the mean time, for highly divergent laser beams a calorimetric type power meter and a compact laser energy meter are available, with quite large input apertures (30 mm clear diameter). All these instruments permit investigation of laser beams in the spectral range from 190 nm to 20 μm, laser powers from 30 nW to 150 W, and laser energy from 2 μJ to 10 J. Laser pulses frequency can be measured up to 5 kHz. For the visible and near-IR range (400 – 1100 nm) a 200 ps temporal resolution can be obtained to visualize laser pulses, while a 70 ps resolution is available for the IR range (900 – 1650 nm). Some heads (such as the 3 W thermopile one) have electrically calibrated capabilities, too. In some situations, divergent, high power density laser beams can be evaluated with an integrating-sphere head, with coating reflectivity of 98 % in over the 420 – 1100 nm range [7]. The dual channels equipment is very flexible enabling us:

- to perform differential measurement;
- to keep a channel as working standard;
- to evaluate simultaneously laser beams having different power/ energy levels (as it is the case of frequency multiplication, or semiconductor laser pumping of solid-state lasers).

The laser power/energy meter with some measuring heads (thermopile, photodiodes, pyroelectric) were calibrated at some renamed national institutes of metrology in Europe: PTB - Germany, National Physical Laboratory – UK, Swedish National Testing and Research Institute – Sweden, in the frame of some cooperation or European programmes.

The dual channels devices can be controlled by the PC over serial or GPIB connections, while the calorimeter and the compact energy meter work only with serial (RS 232) communication.

We are able to perform calibration of laser power meters in our Laboratory by using several Si-based “trap detectors” (10 x 10 mm and 18 X 18 mm detector area), previously calibrated at several laser wavelengths, by the Swedish National Testing and Research Institute against a cryogenic radiometer [8]. A thermopile transfer standard is employed to obtain instrumentation calibration at various laser wavelengths [9]. Data are acquired from the “trap detectors” or from the transfer standard with a PC-based, general purpose acquisition board AT-MIO-16E2 (16 analog inputs/ 12 bits/ 500 kHz, 2 analog outputs/ 12 bits/ 1 MHz, two interval timers, 8 digital input/ output ports, equipped with appropriate LabVIEW drivers) [10].

In the case of laser diodes used in some medical applications or in the case of semiconductor laser diodes operating in ionizing radiation environments, we are working with a programmable laser diver/controller. The instrument is able to monitor driving electrical powers up to 3.5 W, at the maximum driving current 500 mA, with 7.6 nA resolution, 3.5 μA ripple noise, photodiode monitoring current up to 20 mA, and compliant voltage of 5 V. The laser mount temperature can be controlled in the range from - 20 ^{0}C to + 80 ^{0}C, with a resolution of 0.01 ^{0}C [11], [12].

For the laser beam transversal mode structure evaluation we are using, according to the case, a standalone instrument with serial/GPIB control [13]or a PC-based, single board analyzer [14]. Both instruments operate either with a trivial black and white CCD camera or with a professional, triggerable one. The last solution is employed in connection to repetitive pulses laser systems. The analyzer can be triggered by the laser pulse or could trigger laser firing, in order to achieve a stable acquired image in the instrument volatile memory. Because the standalone equipment has no non-volatile memory or data storage equipment (floppy disk or hard disk drive) and because a very simple data processing software is distributed by the producer we were forced to develop a complex software programme for 2D and 3D data representation/ manipulation.

Lasers wavelengths are evaluated with a dual-detector head wavelength meter, operating from 450 nm to 1100 nm, in CW and pulse modes, with an accuracy of 0.5 nm and resolution of 0.1 nm. The detecting sensitivity is 20 μW for CW and 10 μJ for pulse operation, respectively. For this instrument only serial communications in taking mode is available [15].

Semiconductor lasers longitudinal mode structure is estimated with an optical fiber mini spectrometer coupled through a 400 μm core diameter multimode optical fiber to an integrating sphere. The spectrometer has three channels 200 – 650 nm (1.5 nm spectral resolution), 650 – 850 nm (0.5 nm resolution), and 850 – 1140 nm (0.5 nm resolution). Variable integrating time interval can be used (from 3 ms to 60 s), with boxcar and averaging capabilities. The instrument connection to the PC is made either through the serial port or through the USB connection [16]. The instrument can be calibrated and has the appropriate software for laser diodes spectral radiance measurements.

The calibration for the mini spectrometer and the laser wavelength meter could be performed in our Laboratory with two frequency stabilized iodine cell He-Ne lasers, previously checked at BIPM.

3. Virtual instruments

The software we implemented is a complex package for data acquisition/ manipulation, to be used in the characterization of laser systems, based on the graphical programming software environment LabVIEW. A modular approach was used, and several virtual instruments were developed along with the appropriate user interfaces. Depending on the particular case of each instrument, we either used basic equipment commands to build instrument drivers, or we relayed on the instrument drivers provided by the producer to develop virtual instruments (Vis) for data acquisition, processing, storage, retrieval, manipulation and display.

For the laser power meter, the software programs we designed correspond to two operation modes: the terminal mode (Figure 2) and the remote control mode. The "*Operation Mode*" switch enables selection of the way the operator interacts with the instrument. The terminal mode was used to further develop basic virtual instruments in order to operate the power and energy meter, both with the RS-232 and the GPIB interfaces. In this mode, the user enters the desired commands in the "*Terminal Command*" window, and forces the execution of instrument specific instructions in a step-by-step manner, by pushing the *"Send"* pushbutton. In this way, newly developed virtual instruments can be easily debugged, as the graphical user's interface (GUI) echoes user's commands in the *"LaserStar Response"* window.

In the remote control mode, the GUI offers to the operator three choices:

a) the virtual instrument mirrors completely the power/ energy meter display and all softkeys are available to the user (*MDMSK* – mirrored display mode with softkeys);

b) the virtual instrument mirrors the power/ energy meter display and dual-channels data acquisition could be done on two, chart-type graphs (*MDMDA* – mirrored display mode with data acquisition);
c) data acquisition on two independent channels is in operation, while the virtual instrument displays in real time the instant values of the acquired data in a numeric format (*RTDDM* – real-time digital display mode).

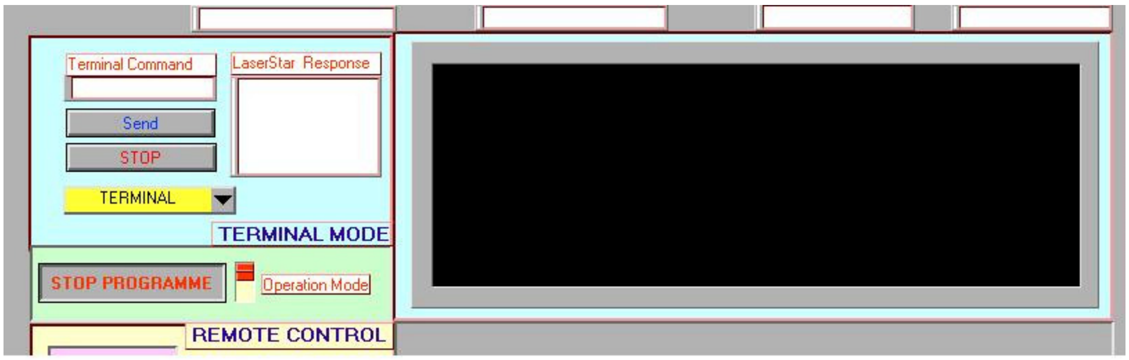


Figure 2. The GUI for the "terminal" operation mode.

MDMSK (Figure 3) is a low speed operation mode, and is useful when remote control/set-up of the power/ energy meter is desired, because it makes possible both the selection of the instrument operation mode non-programmatically, and the real-time visualization on the PC monitor of the instrument status. In this way, the operator gains the complete control of the instrument functions, through the GPIB connection. The virtual instrument mimics exactly the real instrument appearance, so that the personnel accustomed with the instrument display has no difficulties with the remote operation. We are using this mode with experiments sensitive to thermal noise introduced by the operator presence near by the measuring set-up (i.e. calibration operations involving the thermopile transfer standard or other very sensitive surface absorber detecting heads).

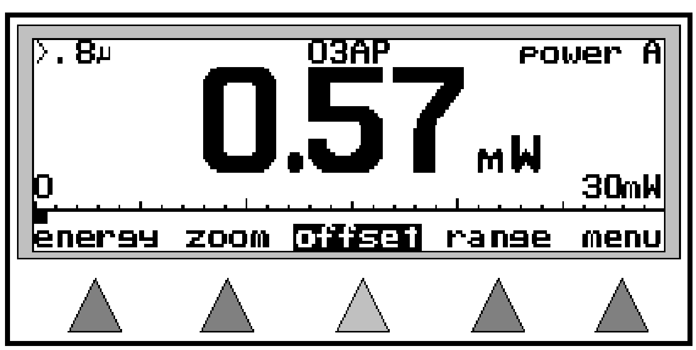


Figure 3. The GUI for the *MDMSK* operation mode.

When the visualization in graphical form of capture data and instrument status monitoring is needed simultaneously, the *MDMDA* mode is recommended, as far as it provides to the operator

Figure 4. a – The stability of the output power for a frequency stabilized He-Ne laser.

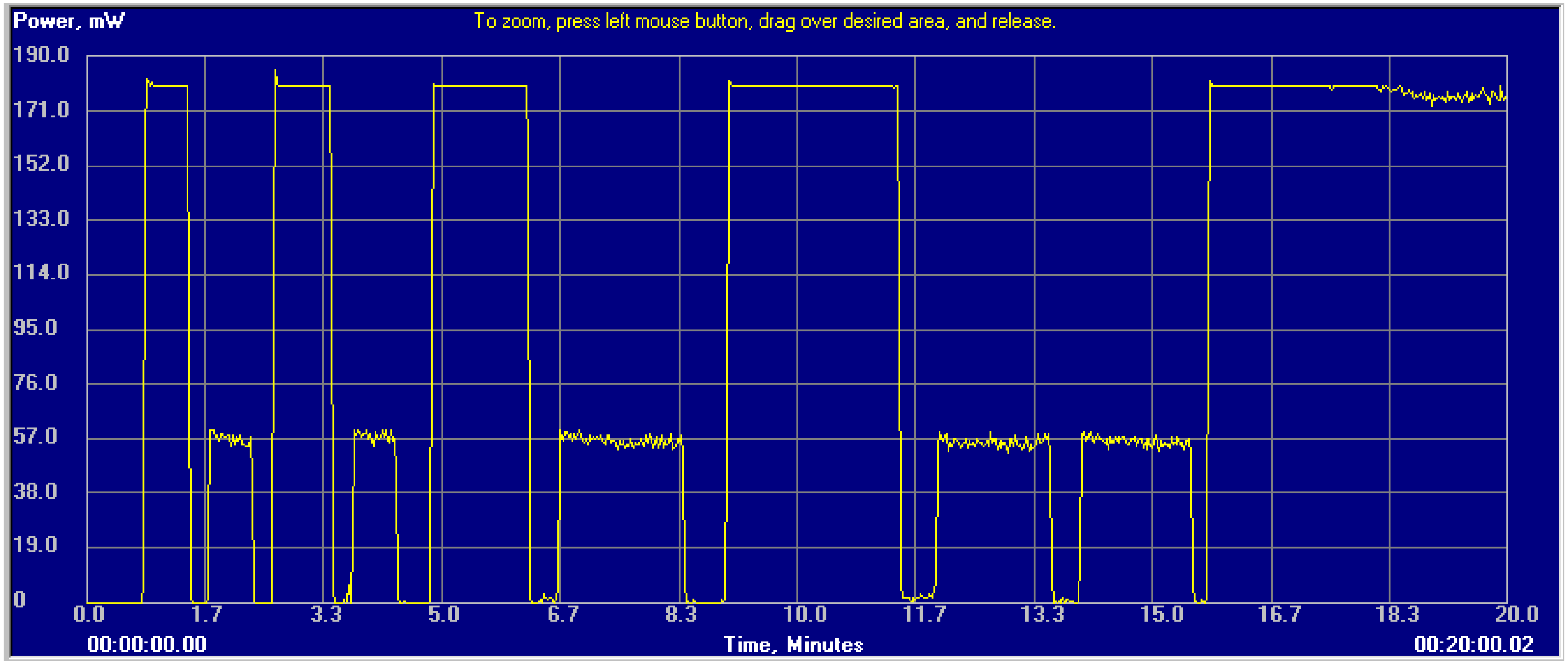


Figure 4 b – The switching characteristics of a laser diode medical device.

concurrently the replica of the instrument display along with the temporal variation of acquired data on two graphs. Figure 4 illustrates such a graphical representation of:

a) the temporal stability of one of the iodine-cell stabilized He-Ne standards;
b) the reproducibility of laser power switching between full power and 30 % full power in the case of a diode laser medical product used in photo-dynamic laser therapy.

If the instrument status information is not essential, but a higher updating rate is required, the *RTDDM* mode (Figure 5) has to be used, as it offers a dual-channel digital representation of acquired data in real time.

Both the *MDMDA* and the *RTDDM* modes made possible, simultaneously with the visualization of the gathered data, the graphical representation of the temporal variation of the input parameter (power, energy, ratio of powers or energies, frequency corresponding to the measured laser beam(s)). These functions are selected by the "*Configuration"* menu list.

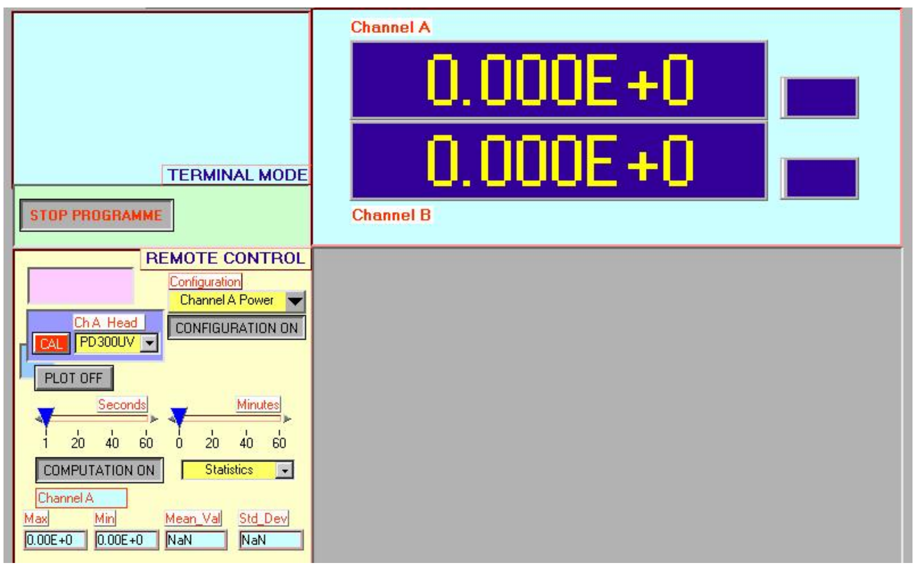


Figure 5. The GUI for the *RTDDM* operation mode.

The user can program the time-base for the graphical representation by two linear pointer slides for minutes and seconds. When the button "*PLOT*" is "*OFF*", no graphic is generated. As the selection is turned to "*ON*", one or two graphs are displayed according to the selected configuration. The selection of one specific configuration operates also on the instrument, and changes its operation mode (power/ energy/ ratio/ frequency). In this way, the complex interaction of the operator with both the virtual instrument for displaying data and with the measuring instrument itself is not transparent to the user. As the "*COMPUTATION*" selector is activated data on one or two channel(s) are processed and the maximum, minimum, mean values and the standard deviation are displayed, for the case "*STATISTICS*" option is selected. If this selection is turned to "*dB*", measuring results are indicated as decibels. Not shown in the pictures there are some fields available to introduce data related to the investigation conditions: date, time, product identification code, user name, etc. Data can be saved and recovered either in numerical form or in graphical format.

Depending on the type of measuring head coupled to channel "A", the user can include in the processed results some calibration factors associated to the head in operation, through the "*CAL*" option. In this case, calibrated measurements, traceable to foreign national institutes of metrology, are performed.

In Figure 6 an example of the VI used to acquire data from the wavelength meter is presented, in relation to the evaluation of wavelength stability for an IR (976 nm) medical device. Two available graphs made possible the representation of the temporal variation of the wavelength to be measured. The user can chose to display either the wavelength variation, or the wavelength variation along with the modification in time of its mean value. In the upper side of the interface, data to identify the acquisition are available (date, time, file name, and user identifier). On the left side, the computed maximum, minimum, mean values and the standard deviation are represented. When the "*CAL*" option is selected, all measurements are corrected with the appropriate correction factors. From time to time, the instrument calibration was checked against a frequency stabilized He-Ne. Data can be saved and loaded to/from the hard disk. The signal level available on the detector head of the instrument is indicated by the bar graph in the lower part of the GUI. In the case the input laser signal is too low, the bar graph indication falls to zero and video and audio warning message are generated.

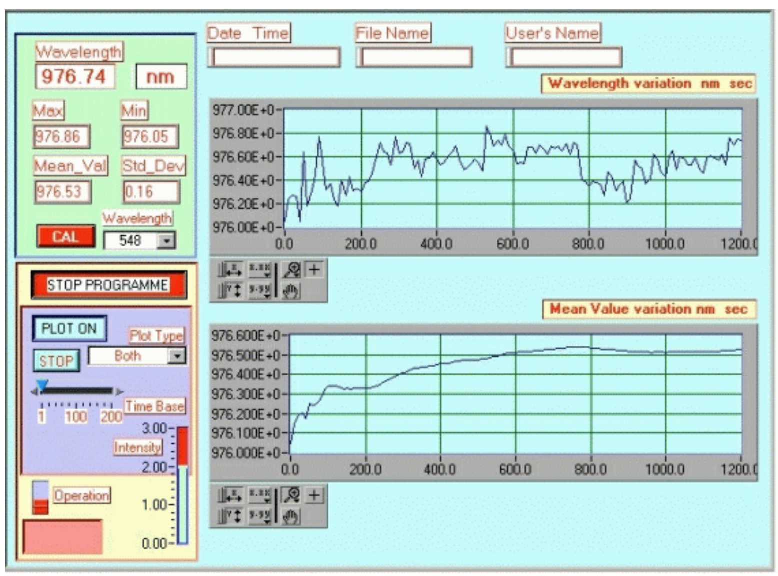


Figure 6. Wavelength stability for a medical laser device.

In the case of the laser beam analyzer, the interface mimics (Figure 7) the appearance and the functions of the real instrument controls (functions and localization of the keys, acquired data representation). Additionally, because of its virtual structure, the interface makes possible the selection of the type and the parameters of the communication with the PC, the downloading and the saving of image data, the selection of data representation (bitmap vs. TIFF files format). In our case, the GPIB (IEEE 488.1) connection was used. A vertical analog scale, located on the left side of the display area signals the status of data transfer from the instrument to the PC. The user has a remote access to all the instrument functions: menu selection, run/stop, printing, zooming, panning, etc. On the graphical 2D display the acquired images, representing the laser transversal mode structure, are indicated in a pseudo-color representation. The amplitude of the acquired data, being represented in a color scale (levels shown on the vertical bar placed on the right side of the display), is running from indigo to red. As an additional function to those performed by the real instrument, the display data could be manipulated by special functions placed under the display area.

The complete interface which was developed includes also some additional facilities for image representation and processing:
a) image data low-pass filtering;
b) hot-spots localization, as they are referred to the pick value;
c) additional 3D data manipulation – rotation, tilting, scaling;
d) power/energy histogram representation;
e) equal-power level contouring;
f) transfer of computation results for the laser beam analyzer parameters - Gauss fit, elliptical beam computations, top hat rectangle results;
g) data/image file management, including time, date and user identification.

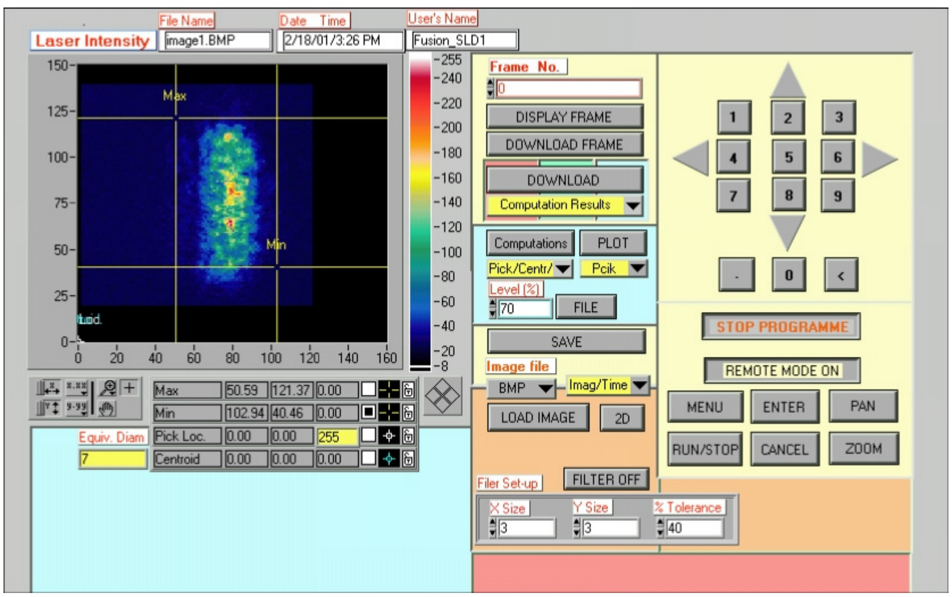


Figure 7. The graphical user's interface for the laser beam analyzer.

The 3D representation of laser beam cross section was applied to evaluate the possibility to couple a laser diode to an optical fiber for the case of a medical device. As indicated in Figure 8, the laser diode case temperature produces a lateral shift of the beam as well as beam defocusing, reducing drastically the coupling efficiency. Another interesting test based on the laser beam analyzer is related to the investigation we performed on a micro solid-sate laser developed in our Institute for art restoration. The laser beam profile illustrated in Figure 9 indicates the presence, in the output beam, of the pumping laser diode emission superposed over the micro laser radiation. The useful radiation has a quasi-Gaussian shape, while the spurious pumping radiation appears as an offset in the picture. This finding helps in the evaluation of energy measurement uncertainties in the case of this micro laser.

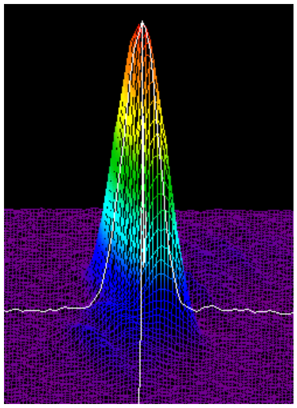
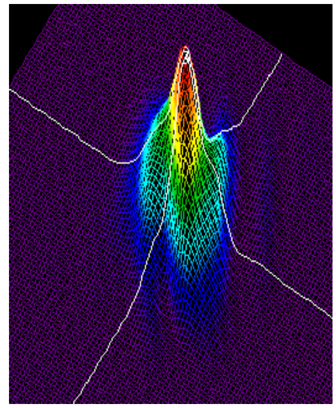
 

Figure 8. Laser diode mode structure at: a – 16 ^{0}C case temperature; b – 34 ^{0}C case temperature, for the same driving current of 32 mA.

For the interface we developed an efficient use of the display area is possible, as all the above mentioned data manipulation/ representation address the same display regions, by time/ function sharing. Examples of the display area sharing function are given in Figures 10, 11 and 12, where, according to the measurement performed, on the same location can be displayed either the power density histogram, the beam point stability or cross sections through the 3D beam profile.

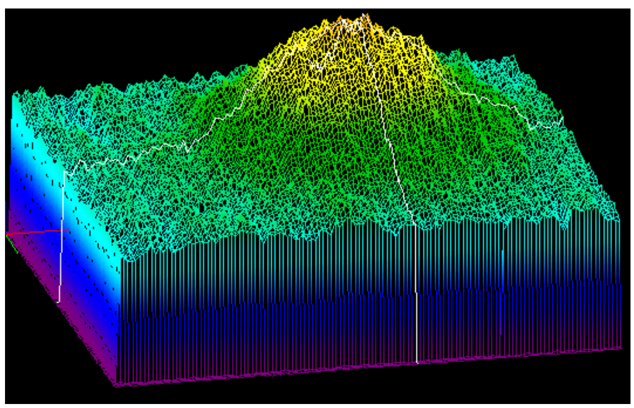


Figure 9. Presence of the emission from the pumping laser diode in the micro solid-sate laser output signal.

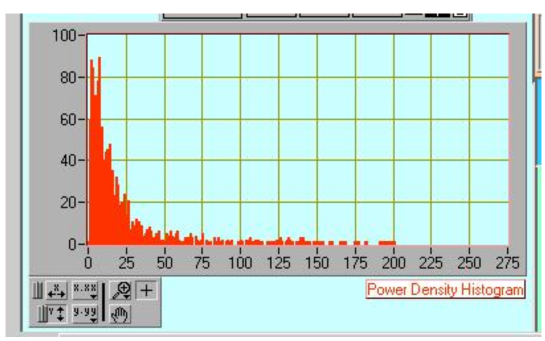
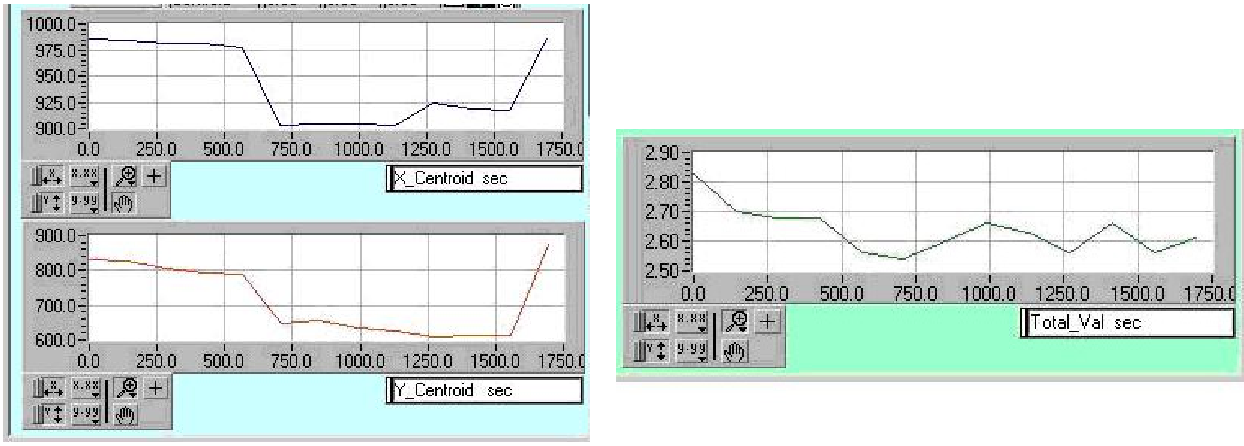


Figure 10. The representation of the laser power density histogram.



a b

Figure 11. The temporal variation of the centroid coordinates (a) and total power (b), as they are acquired from the laser beam analyzer, and displayed by the virtual instrument.

As we are testing various laser diodes for medical applications we also developed two VIs for remote handling of a laser diode driver/ controller. One of them sets the driving conditions (direct current, various upper/ lower limits, current resolution, etc.) and monitors laser parameters such as: the voltage across the laser, the embedded photodiode photo-current, while the other sets and reads the temperature controller mount parameters (heating element current, amplifier gain, close-loop constant, upper/ lower temperature limits. In Figure 13 is given as an example the user’s interface for the temperature controller. A similar VI is employed for the current control. The operator can select from a list the laser diode type and the VI automatically sets the control appropriate limits. The selected temperature regime can be reached either through automatic tracking or by manual control. Most of the parameters can be change on the fly.

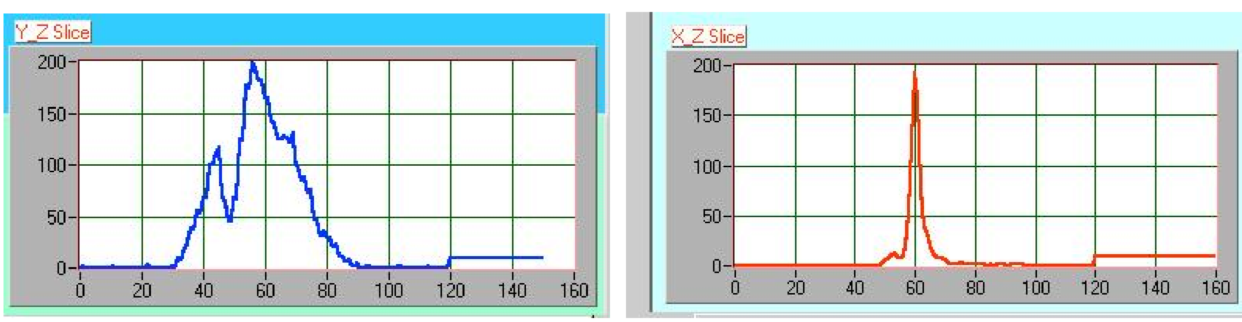


Figure 12. X and Y sections through the 3D image of a laser beam

From the virtual front panel, three operation modes can be selected:

- constant temperature;
- temperature increase;
- temperature decrease;

along with the change parameters (gain, speed, increment, etc.).

The above presented VIs for laser diodes control were also used for the characterization of semiconductor lasers subjected to gamma-ray and electron irradiation, as we investigated the possibility to incorporate them in the future remote handling devices and robotic arms.

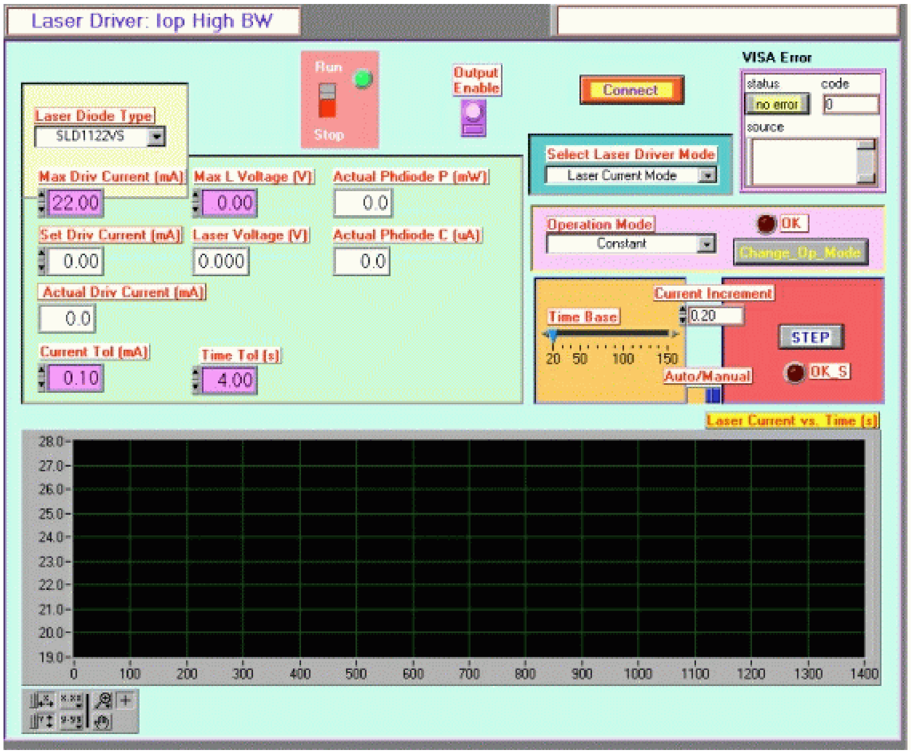


Figure 13. The user’s interface for the temperature controller VI.

An interesting example concerning tests performed on laser diodes as it concerns their longitudinal mode structure is offered in Figures 14 and 15, where our last minute results on radiation induced changes in devices which can be embedded in nondestructive testing experiments and free-space communications systems are illustrated. We have to underline that, in this particular case, the pictures were not obtained with our VIs, but with the software provided with the optical-fiber spectrometer. In Figure 14 is depicted the influence of gamma-ray irradiation on the spectral bandwidth of an AlGaInP QW laser diode (λ = 670 nm, I_d = 50 mA, T_c variation from 16 to 35 ^{0}C, total radiation dose of 2 MRad), while Figure 15 indicates the build-up of several longitudinal lasing modes upon gamma-ray irradiation in a GaAlAs double heterostructure device (λ = 850 nm, I_d = 20 mA, T_c variation from 16 to 35 ^{0}C, total radiation dose of 2 MRad). In each case, laser diodes were driven at the same current before and after the irradiation. As the case temperature increases, the spectral characteristics move to the right.

In the case of the semiconductor laser diode working at 850 nm all the monomode bands are associated to the emission before irradiation, at temperatures increasing from left to the right. The spectra obtained after gamma-ray irradiation have a multimode structure and are slightly shifted to the left. Based on this observation, emitting spectra can be coupled in pair for interpretation (i.e. the yellow line - before the irradiation makes a pair with the green line obtained after 2 MRad dose exposure).

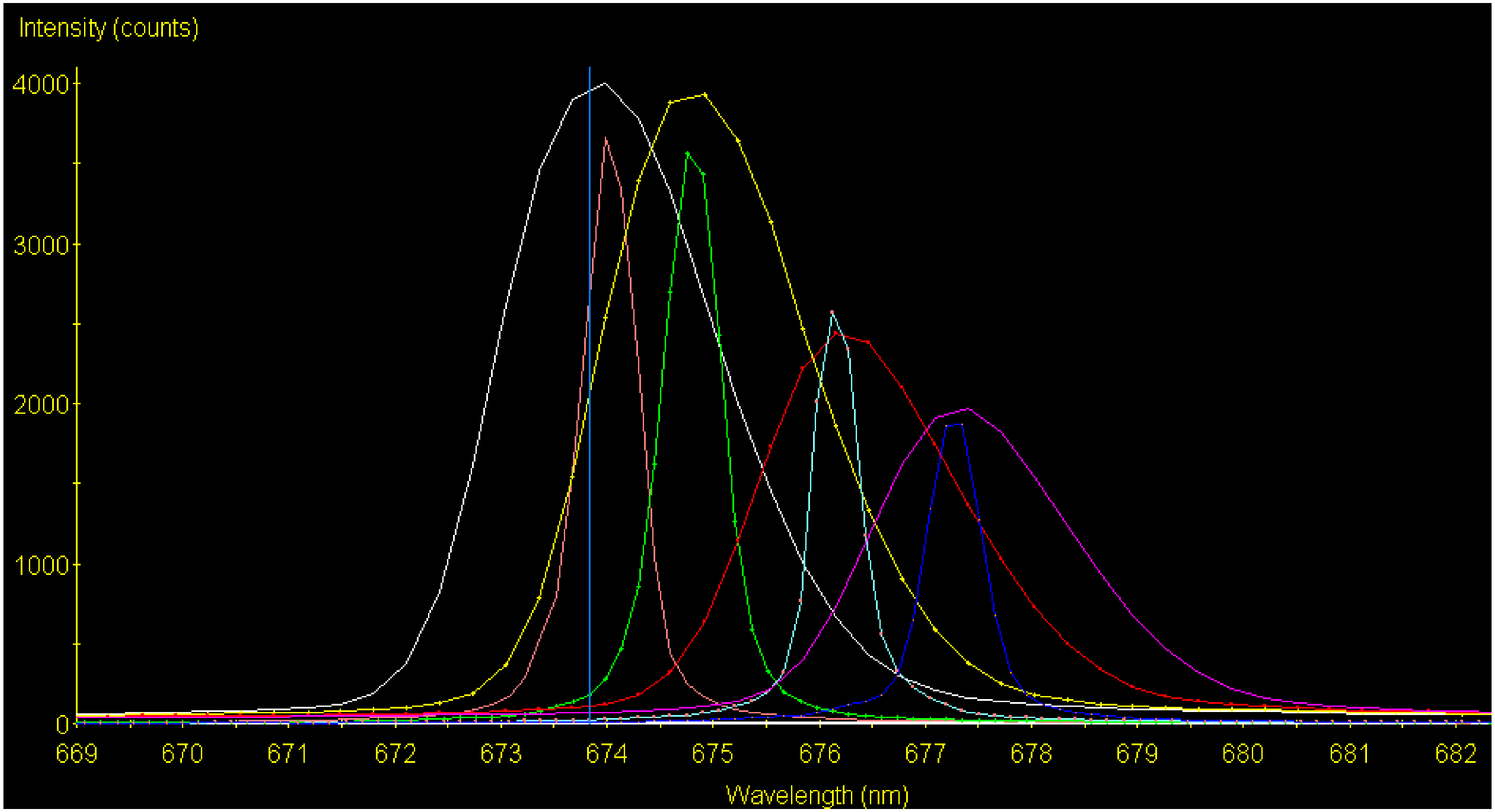


Figure 14. The narrowing of the spectral bandwidth of a laser diode after gamma-ray irradiation.

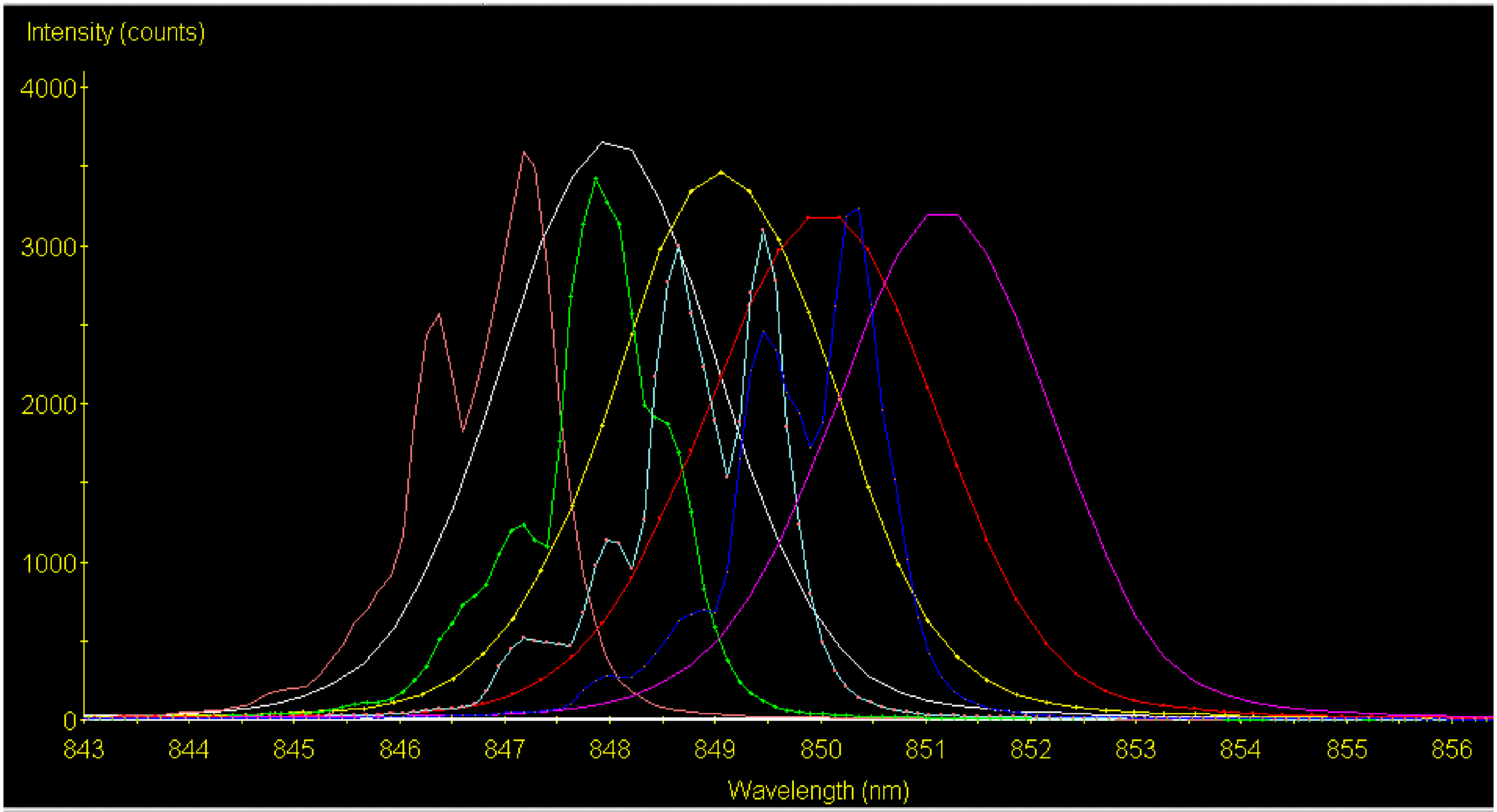


Figure 15. The build-up of multimode longitudinal structure in gamma-ray irradiated semiconductors lasers.

For the laser diode operating at 670 nm (Figure 14) the broader emitting bands correspond to non-irradiated device, while the narrow bands appear after the diode was subjected to gamma-ray irradiation. The maximum of the emitted radiation has minor changes upon irradiation, so that radiation spectra pairs (before and after irradiation) can be easily identified (i.e. the yellow line corresponding to the laser emission before irradiation, and the green line associated with the same laser diode after gamma-ray exposure).

Our future research will focus on the improvement of the VIs we developed, on the preparation new VIs for special instruments we are using (i.e. the optical-fiber spectrometer, some equipment for optical fiber components characterization), and on the overall integration of the above presented functions into a more general software set-up.

4. Acknowledgements

The author wishes to acknowledge:

- the financial support from the INFRAS research programme for the accreditation of the Laboratory, grant No. 51/2001;
- the financial support of the European Union in the frame of the Fusion Programme, grant No. ERB 5005 CT 990 101/1999.

The author wants to thanks:

- Spiricon Inc., Logan, USA for its donations;
- National Instruments, Austin, USA for its permanent support.

5. Disclaimer

The content of this communication is the sole responsibility of its author and it does not necessarily represent the views of the European Commission or its services.

6. References

1. *Guide to the implementation of directives based on the New Approach and the Global Approach*, European Commission, Luxembourg: Office for Official Publications of the European Communities, 2000, ISBN 92-828-7500-8.
2. *Safety of laser products,* EN 60825 series.
3. *Guidelines for the safe use of medical laser equipment*, EN 60825-8 TR, 2000.
4. *Preparation of associated Central and Eastern European states for the integration into the Union single market*, Annex to the "White Book", Brussels, 1995.
5. *Report on the progress in preparing the accession to the European Union September 2000 - June 2001*, Romania Government, Bucharest, 2001.
6. *LabVIEW User Manual*, National Instruments, Austin, USA, 1992.
7. *LaserStar User Manual* and *Ophir Heads for Laser Power/Energy Measurements*, Ophir Optonics, Jerusalem, Israel, 2000.
8. *Calibration Certificate of Optical Radiometer*, Swedish National Testing and Research Institute, Boras, Sweden, 2002.
9. *CW Calibration Certificate*, Laser Instrumentation Ltd., Furnham, UK, 2002.

10. *AT-MIO E Series User Manual, Multifunction I/O Boards for the PC AT*, National Instruments, Austin, USA, 1995.
11. *Model 6000, Laser Controller, Operation and Maintenance Manual,* Newport Corporation, Irvine, USA, 1996.
12. *Computer Interfacing Manual,* Newport Corporation, Irvine, USA, 1996.
13. *LBA-100 Laser Beam Analyzer Operator's Manual*, Spiricon Inc., Logan, USA, 1996.
14. *LBA-300PC Laser Beam Analyzer Operator's Manual*, Spiricon Inc., Logan, USA, 1996.
15. *WaveCHeck Wavelength Metter Manual,* Angewandte Physik & Elektronik GmbH, Berlin, Germany, 1999.
16. *Optical Fiber Spectrometer Operation Manual*, Ocean Optics, Dunedin, USA, 2000.