SETUP FOR QUANTUM CASCADE LASERS CHARACTERISATION USING THE LABVIEW PROGRAMMING ENVIRONMENT

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Abstract. The paper presents the implementation of a setup for the evaluation of mid-IR quantum cascade lasers using LabVIEW. Opto-electronic characteristics are monitored as function of current and temperature: voltage-current, emitted optical power-current, wavelength-current, optical spectrum-current, laser emitted beam. Temporal stability of the wavelength and optical power can be also investigated.

Key words: quantum cascade laser, electrical and electro-optical characteristics, LabVIEW.

1. INTRODUCTION

Since the advent of quantum cascade laser (QCL) diodes demonstrated for the first time by the J. Faist and F. Capasso at Bell Laboratories in 1994 [1] and so far, these devices have earned an important role in research and industry. Their performances were achieved by using semiconductor technology design and manufacturing with nanometre accuracy [2].Their transition from laboratory to real-life applications were made after 2000, when they knew a great success providing special features in a wide range of fields such as: spectroscopy, optical telecommunications, electronics, medicine, chemistry, etc. [3-5]. They also contributed to: environmental monitoring– (remote sensing of atmospheric gases and pollutants) [6-7], health (medical diagnostics), security, standoff detection of explosives, drugs, etc. [8, 9]. Their wide dynamic range, extended spectral emission ranges (mid-IR to THz) and excellent sensitivity, combined with room temperature operation assisted researchers and end-users to overcome some technological obstacles, enabling the presence of this technology on a large-scale market. When they are used in multi-laser systems as for example spectroscopy for gas or pollutants tracing, QCLs, are used to identify and quantify the complex organic molecules, such as those of toxic or explosive chemicals or drugs [5, 10].

These lasers having a beam power up to several watts (in recent versions), are generally mono mod, with quite a large tunability, high spectral density, extended time of life (> 10,000 hours) and are associated with a low energy consumption [11, 12].

These laser diodes have been extensively studied both in research laboratories and industry. Particular applications require well know specifications of each components, which is achieved by characterizing with high precision the output optical power, the emitted central wavelength and spectrum, along with device beam quality. Preliminary characterization of each wavelength of interest is one of the first steps of spectroscopic experiments and is necessary every time when new samples needs to be analysed [13-15].

In industrial processes general characterization of laser diodes consider the application related wavelength and the tenability, devices being evaluated according to its operating conditions; for each selected wavelength the user modifies the driving current and operating temperature in order to obtain the main characteristic such as: current-voltage, current-emitted optical power, or wavelength and power stability in time, etc. [16].

On the other hand, in research, a more detailed analysis is required for spectroscopic experiments, medical applications, detection of pollutants and for this reason, measurements are made in some situation prior to each experiment. In most cases, all these measurements of optical power, wavelength, power, voltage, spectrum, beam profile are done separately, operation which takes quite a long time, have low accuracy, especially when it is required to have a set of measurements for each feature. In such situations, one of the common problems is represented by the repeatability of the measuring conditions (e.g. mounting of the device into the measuring setup), human error being the major cause of low accuracy of the results. This paper presents a packed setup which can assure higher accuracy and reproducibility of measurements.

To improve the performances and a decrease the testing time LabVIEW programming environment was used to integrate the control over several equipments. LabVIEW programming was extensively used from complex experiments [17] to educational packages [18]. Our approach assures also the portability of the application. The proposed software package for the automation of experimental setup easy the task of developer of QCL-based instrumentation in the fields of spectroscopy, chemistry, nuclear physics, optics, electronics, etc. [19-23].

By integrating several complex instruments (laser driver temperature controller, power meter, wavelength meter, spectrum analyzer, laser beam analyzer) into single setup, high speed, reliable and human error free measurements can be performed.

2. EXPERIMENTAL SETUP

For the implementation of the experimental setup (Fig. 1) a laser diode driver and temperature controller (TEC) from Thorlabs was used, having the following performances: current control range – up to 5 A; compliance voltage – 20 V; TEC current range from -15 to +15 A; TEC compliance voltage > 15 V; TEC maximum power > 225 W; controlled temperature range from -55 to +150 ^{0}C. All tests run the QCL in CW mode, for a driving current variation from 0 to 250 mA. The laser beam passes through a LWIR-AR coated collimating lens (NA=0.85) mounted into a XYZ translation stage and was focused by a Ge lens with a focal length of 70 mm. Additional beam splitters redirect the laser beam towards the measuring instruments. Optical power measurements were done with by an Ophir Nova II display coupled to the 3A-FS detector head (spectral range 0.19 -2 0 μm; clear aperture – 9.5 mm; power noise level – 4 μW; power linearity ± 1.5 %; power accuracy ± 8 %; 30 min; maximum thermal drift – 30 μW). The Bristol Optical Spectrum Analyzer model 721B-XIR (spectral range from 2 to 12 μm; absolute accuracy ± 1 ppm; standard spectral resolution – 12 GHz; S/N > 30 dB) was employed to acquire emitted spectra and to evaluate the central wavelength. The Ophir/ Spiricon Pyrocam III (sensitivity wavelength range from 1.06 to 3000 μm; 124 X 124 elements; pixel size 85 μm X 85 μm; pixel spacing 100 μm X 100 μm; LiTaO3 sensing material was used for diagnostics and analysis of the laser beam profile. For a complete beam profile characterisation a translation table with a travelling range of 30 cm was used. Appropriate measures were consider to limit the power density at the entrance of each instruments, according to manufacturer's recommendations.

Instrumentation control and data acquisition was performed under LabVIEW command of a PC. The control of the power meter, laser diode controller and OSA was performed through USB ports, while the Pyrocam was connected by FireWire coupling. For each instrument, the 64-bit VIs library provided by the manufacturer was use, by integrating them into a complex VI which is presented further.

The operation QCL laser diodes is based on their quantum wells structure allow more precise wavelengths tuning for spectroscopic use. The characterization at each wavelength could be a time consuming task, especially when investigations on the driving current and case temperature are considered. Another important issue can be the reproducibility of these measurements as instruments are switched to another wavelength. Simultaneously measurement for several parameters under similar conditions helps to avoid additional problems associated to repeated alignments of the setup and diminishes the associated errors. The proposed setup and the associated software package proved to be a viable solution to the mentioned problems, and recommend such type of investigations as a reliable set of tests. The developed program is compatible for all instrumentation used, as the LabVIEW VIs belong to NI bookstore, this being one important compliance requirement.

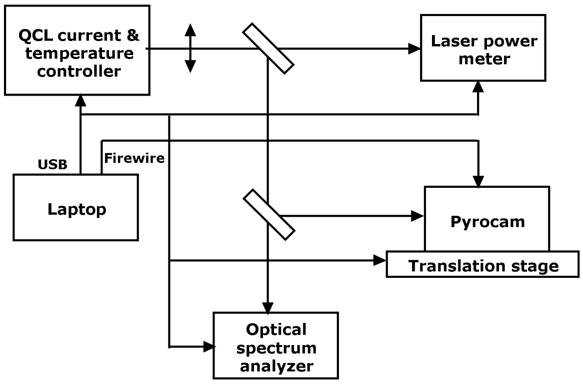

Fig. 1 – Sketch of the experimental setup.

The program is structured in operating *three windows*, each designed to perform specific parts of the entire process. The schematic of the main flowchart is illustrated in Fig. 2.

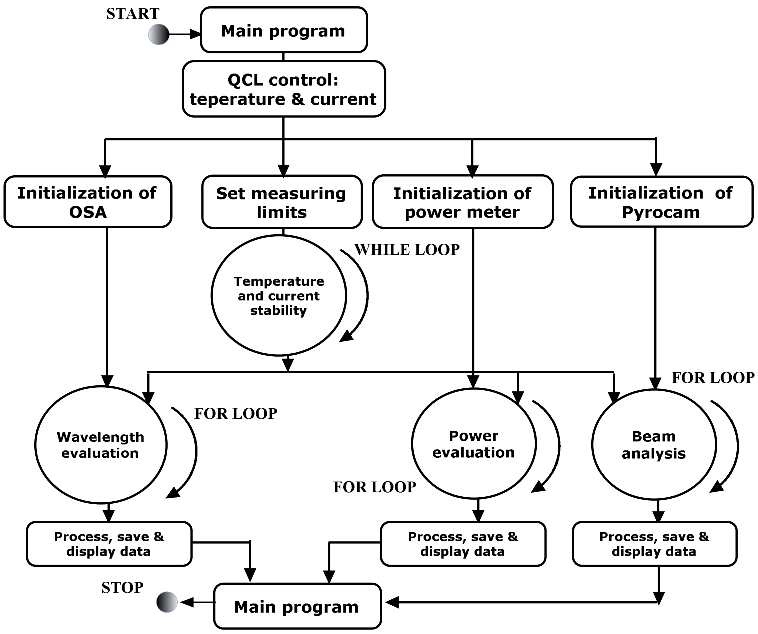

Fig. 2 – Flow chart of the LabVIEW program used for the QCL characterisation.

First window: Using the libraries supplied by the measuring instruments together with those associated to the QCL controller was developed the first part of the program in which by varying the driving current intensity between certain values, at various temperatures, the voltage, the emitted optical power, the central wavelength, the optical spectrum and the beam profile were measured. Once the computer system is connected to all instruments, the measurements are run by selecting the USB port corresponding to each device. On the main interface the upper and lower operating limits can be selected for the current and the temperature, as well as the increment step between two consecutively measurements.

One of our main concerns was to improve the measurement accuracy up to 4 decimals, and for this purpose the deviation limit was computed in each instance. This limit can be further increase to 6 decimals, the controller limit, but the obtained results will include also the internal noise of the controller. This change depends on the type of experiment run and on the desired precision, correlated to the expected measuring time. To fulfil this requirement, we designed a subVI, associated to actual measurement step for temperature, current and voltage parameters. As a precaution, the program does not execute until the user will confirm the procedure and the software will not proceed to the next measuring step until the desired accuracy is not reached.

The program starts at the pre-stet values of temperature and laser current, values passed to the controller. First, the temperature is stabilized at the required accuracy and confirmed by the lighting of a button; the stream reaches its set value and confirmed this result by lighting a green LED. Once these accomplished, the measurement loops for voltage, optical power, wavelength and beam profile starts. Always on the VI screen will be displayed the measured values of interest. The acquired data are automatically saved in an external file where it can be further accessed by the user. The results' plotting is done automatically.

By the end of the measurement, four graphs, namely current intensity vs. voltage, current intensity vs. optical power, current intensity vs. wavelength, 2D or 3D beam profile are displayed, all depending as function of the temperature values set for this investigation (Fig. 3). For current intensity values <1 mA, the acquired data for the optical power and the wavelength are too small, being under the noise level, and for this reason they do not pass the threshold condition. In order to introduce instruments protection and to have a correct data acquisition process, a delay during the temperature change and between optical power/ wavelength measurements was introduced to synchronize the equipments, because they have different response time.

The user interface is friendly and easy to operate. Before the first running, the operator should introduce the input parameters and select the paths for saving data. As a precaution, the VI will sent a warning message if the set parameters exceed the limits allowed for the DUT, in order to prevent the device damage.

Additionally, if an error is detected, the program will stop the execution and save data. In the running period the user can observe data flow which is periodically updated in the output parameters panel. Monitoring the QCL's beam profile is an important step for users because a multimode operation can induce problems in the application setup. For the purpose of such an evaluation, four different types of representation of the beam profile are introduced. The intensity color map is a rapid method to see if the beam is saturated or not, as hot-spots can damage the optical path components.

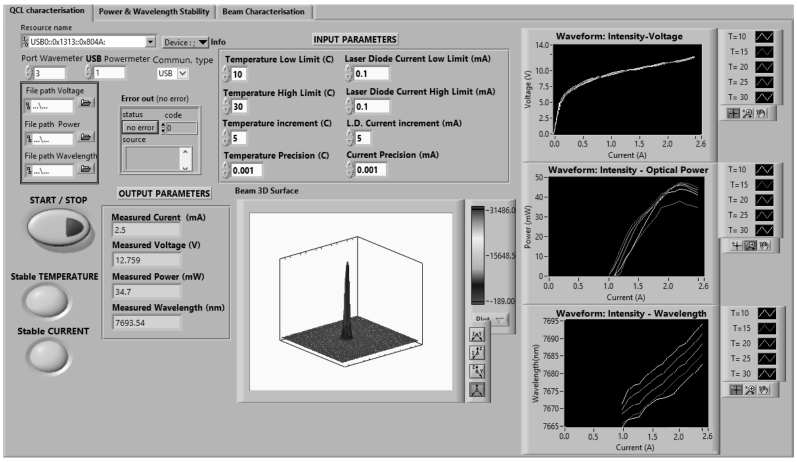

Fig. 3 – Front panel user's interface.

The second window reproduces in the first phase the measurements for the previous window, and additionally provides information on the temporal stability of the optical power and central emitted wavelength. The measurements are collected at specified intervals, when the program regularly measures optical power and wavelengths values, in a continuous mode, for the set temperature and current intensity (Fig. 4).

This step is important and necessary especially in the biodetection type applications of proteins, when the molecule of interest is located at a specific wavelength, and the measuring time has to be long enough [8-11]. To support this type of applications, in this window the software performs continuous measurements in step of 2 seconds, for both type of measured data. For such tests, the set parameters are 1.1 mA and of 20 ^{0} Celsius, for a 50-50 beam splitter. In the tests we run, the optical power was constant with small deviation in the first minutes of running. The measured wavelength presents frequently deviations at the forth decimal with a maximum deviation of 1.84 nm. This small change in wavelength can appear from the photons and dust interaction, human presence, laboratory environment perturbations, etc., considering the sensitivity of the OSA.

The errors variation is also monitored during the measurements to prevent data loss or other problems as the drop of the instruments power supply.

Fig. 4 – Example of optical power and wavelength stability measurements.

The third window (Fig. 5) shows a more detailed analysis of the laser beam profile. For this test a translation table was used to determinate the beam divergence.

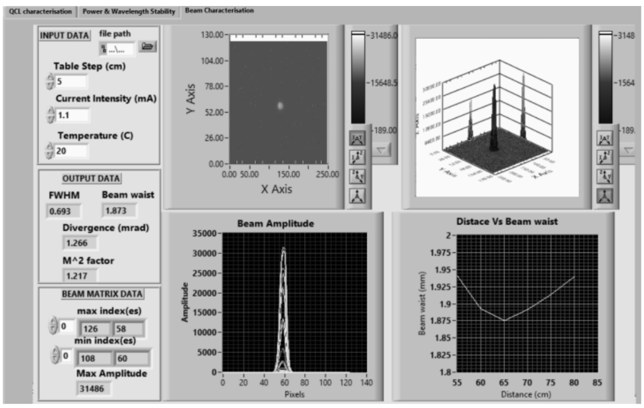

Fig. 5 – Example of a QCL beam characterization.

At every step the VI save a .csv file for the beam profile and after calculus gives the FHWM. With this results the user can determinate the beam profile, beam intensity, beam waist, the theoretical and the measured divergence and the propagation factor. At every step the user can see the beam profile and beam intensity. These types of analyses are used to determinate the right distance where the beam is focused or how it is propagated in free space and other environments as gases (oxygen, nitrogen).

3. DISCUSSIONS AND CONCLUSIONS

Laser diodes are quite sensitive to changes in temperature and driving current. Setting values outside a rather narrow range may result either in the destruction of the diode or in the degradation of the experimental setup performances. The program we developed brings accuracy to the measurements made on QCL for their performances evaluation and greatly reduces the testing time. It offers flexible opportunities to the operator to choose in order to make the appropriate tests according to each application specifications. The program can easily be used to characterize a wide range of QCLs, by estimating their wavelength tuning capabilities under driving current and case temperature modification.

The program was tested in the case of a QCL designed to detect molecules of methane or ammonia which have spectrum lines in the QCL wavelength range and also are among the risk factor chemicals. We found that its works very efficiently as it concerns the reproducibility, accuracy and duration of a complete test. In the above measurements, the main characteristics of optical power, wavelengths and beam profiles were determined by current variation and temperatures. Wavelengths ranging from 7.665 to 7.695 μm were scanned with 4 decimals precision for a temperature between 10- 30 ^{0} Celsius. The OSA can measure absolute laser wavelengths to an accuracy of ± 1 part per million but it has been found that the repeatability rate at this value cannot be reached in a normal laboratory environment due to noise and other interactions. Measurements obtained to a precision of 4 decimals can be reached in a relatively short time ~ 10 minutes for a complete measurement, associated to the operating *first window*. The time required for an accuracy of 5 decimal can be reached in about 20 minutes, under the same running conditions. The accuracy of the temperature has a deviation of ± 0.0001 ^{0}C, but the current stability at the 5-th decimal is cannot be kept constant for very long time. Once the while loop receives the confirmation for the set conditions, current intensity and temperature stability at the desired accuracy, the program performs the measurement for voltage, optical power, wavelength and beam profile.

The program can be extremely useful not only in laboratory measurements but also in the manufacturing industry tests, as the manufacturer must provide to the user data detailing device parameters for specific applications. Within this context, using the presented setup and just changing the DUT measurements can be easily performed and results save as user's data sheets.

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