Automated Characterization of an Erbium Doped Fiber Laser Pumped by a Laser Diode

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Abstract. *A software was developed to automate the characterization of a fiber laser pumped by a laser diode. It was developed in LabVIEW and is capable of capturing the laser threshold value, stability of the laser wavelength and saving all the spectrums raw data to further analyze if needed, all this without the need of an operator present. Consequently, reducing the spurious measurements inserted in the system when people are around the experiment. There is the possibility of changing the resolution of the spectrum analyzer depending on the application because the logic is written to use the status byte which is generated in the GPIB bus to synchronize the commands. The previous works in the laboratory usually used the embedded printer in the spectrum analyzer to save the a visual data or a flop disk to save the raw data, reducing the productivity and increasing the time of work compared to this automation.*

Keywords: *Optical Fiber Laser, Automation, Characterization, GPIB, Laser Diode.*

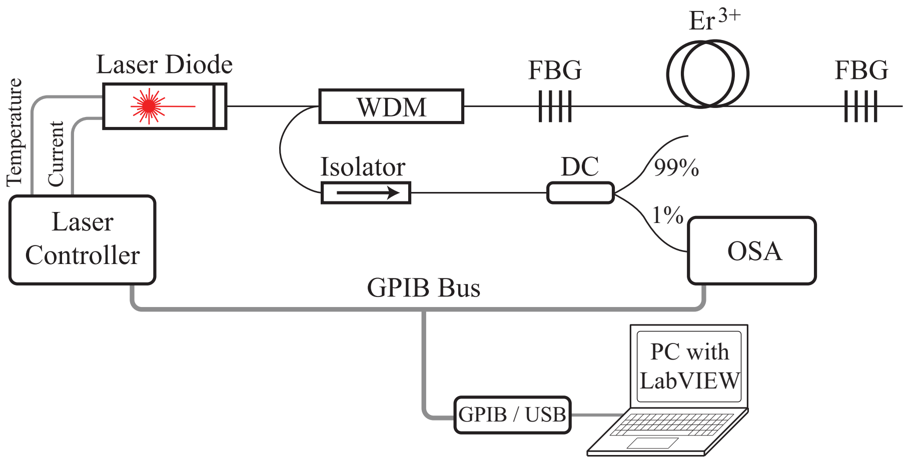
1. INTRODUCTION

The Subdivision of Photonic Sensors (EFO-S) in the Institute of Advanced Studies (IEAv) works to develop optical sensors such as, interferometers, accelerometers and gyroscopes. These sensors need an optical source to work and in the majority of the studies this light source is a laser or a super luminescent diode (SLD). It is important that the light source is characterized and stable, otherwise it can introduce noise in the sensor measurements. There was constructed an Erbium doped fiber to be used as light source in some of those sensors.

A laser works by stimulated emission of photons oscillating in a cavity that contains an amplifier medium (Svelto, 2010). In an Erbium doped fiber laser, as the name suggests, the amplifier medium is an optical fiber doped with the ion Er^{3+} which is optically pumped by a laser diode with wavelength of 980 nm. The resonant cavity is made by the own fiber and limited by two fiber Bragg gratings (FBG) that work as mirrors, as shown in Fig.1.

The doped fiber coil is pumped by the laser diode and is connected to a wavelength-division multiplexer (WDM) that allows the 980 nm wavelength to pass through to the doped fiber and only returns the wavelength outside this spectrum (higher than 1300 nm). The laser output is in the 1300 nm or higher output of the WDM, which is connected to a 99:1 directional coupler, the 1% output is connected to the optical spectrum analyzer (OSA) and the 99% output is the power laser source used in the sensors.

Figure 1 – Laser setup.

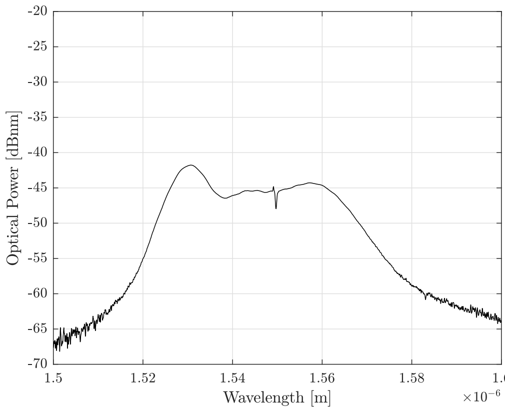


Source: Author.

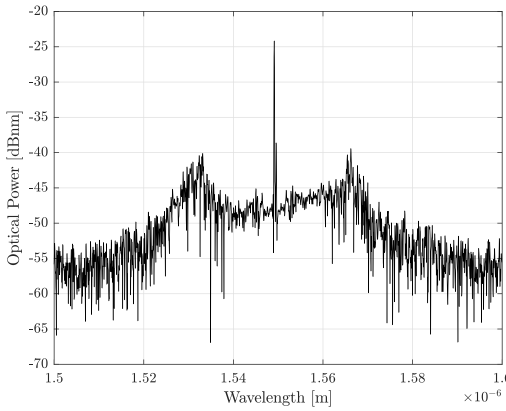
When the pumping is not powerful enough to generate a population inversion (threshold condition to continuous laser operation), the result is a wideband spectrum of the fluorescence from the Er^{3+} (spontaneous emission), Fig.2a (note that there is a dip in the spectrum which is result of the cavity made by the two FBG). This can be used to replace the SLD in some applications, since both sources provide a well amplified wideband light. After the threshold is reached the spectrum has a well defined wavelength of emission and much higher power, Fig.2b.

The power of the laser is proportional to the length of doped fiber and pumping power. The wavelength of the laser

Figure 2 – (a) Spectrum of fluorescence before threshold and (b) spectrum of laser action after threshold.



(a)



(b)

Source: Author.

depends on the reflection spectrums of the two FBG and their reflections are affected by temperature changes. Once the temperature changes result in a length change of the fiber, it consequently changes the peak wavelength of reflection from each FBG (Udd and Spillman, 2011).

The characterization of such laser consists in understanding the behavior of the peak wavelength changes and what is the threshold of the laser in terms of a variable that the operator can control. In this setup the variable is the current of the laser diode. Optical sensors, e.g. interferometers, are very sensitive and capable of measuring sub-nanometric spatial displacement (Martin *et al.*, 2017). This displacement is calculated based on the wavelength of the laser source. Therefore, a reliable measurement entrusts knowing the exactly value of wavelength and if it changes by some reason.

In order to characterize the laser, many spectrums must be acquired from the laser. Collect all these spectrums can be a very fatiguing task, because it is repetitive and can last several hours. Moreover, when a person is nearby and interacting with the laser it is likely that noise is being introduced to measurements. Thus, the motivation to automate this process.

A communication via GPIB bus was chosen due to most of the laboratory instruments already have it integrated. It is a parallel bus able to connect up to 15 instruments, to use the bus via USB port from PC a converter GPIB/USB is needed.

There are advantages in using LabVIEW to code this logic compared to other commonly used languages. The software was made to the development of sophisticated measurement, test and control systems (NI, 2014), in this principle the program coded by the user has the name of virtual instrument (VI). Most of the communication protocols are already embedded in the software as VI blocks, such as, RS-232, GPIB and TCP-IP. There are also native blocks to process the collect data. Most of instrument's manufacturers provides libraries to their instruments.

Then, there is the front panel of the VI to present the information in a graphical interface, this is a great advantage for those who don't want to spend time and resource learning or programming an interface in a textual programming language. In LabVIEW, to emulate any instrument from a laboratory is as simple as drag and drop the screens and buttons to the desired place. Allowing to create virtual instruments with customs screens and functions accordingly to the application, being that a sophisticated instrument or a minimalist one.

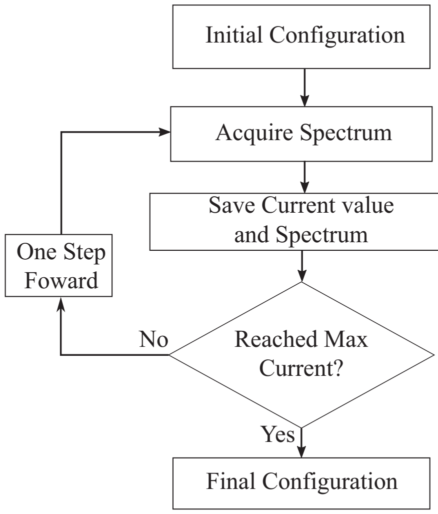
The logic is programmed in the block diagram of the VI, where blocks are connected through wires and communicate by data flow. LabVIEW process the code from left to right and from top to bottom, always following the data flow, a block will only send data if all the input data already arrived in the required inputs. Once the logic is graphically programmed and follows a data flow not a stream sequence as in text, that create the possibility of multicore processing with easy implementation. If there is two while loops in the block diagram with input variables independent from one another, each loop will be automatically processed by one core of the CPU.

2. METHODOLOGY

The Spectrum Analyzer used in this work is Advantest Q8347 with IEEE 488.1. The Laser Diode Controller is ILX Lightwave LDC-3722B with IEEE 488.2. Laser Diode is Oclaro LC95L74P-20R with butterfly mount to connect to the laser controller. The USB to GPIB interface Agilent 82357B.

First, there was developed a flowchart with the basic structure of the logic to better organize the algorithm in main groups, Fig. 3. Those groups were later used as main subVI in LabVIEW. The subVI can run as a VI or run inside another VI. Programming a VI with well defined tasks and connections allows the construction of a modular code that can be easily repaired and upgraded if necessary afterwards.

Figure 3 – Flowchart.



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2.1 Algorithm

An algorithm was written using pseudo-code (Algorithm 1). It is a detailed version of the flow chart that includes more specific commands to the devices, however still in a generic form. This step helps to later choose the best LabVIEW programming structure to be applied.

Algorithm 1 Data acquisition algorithm in pseudo-code.

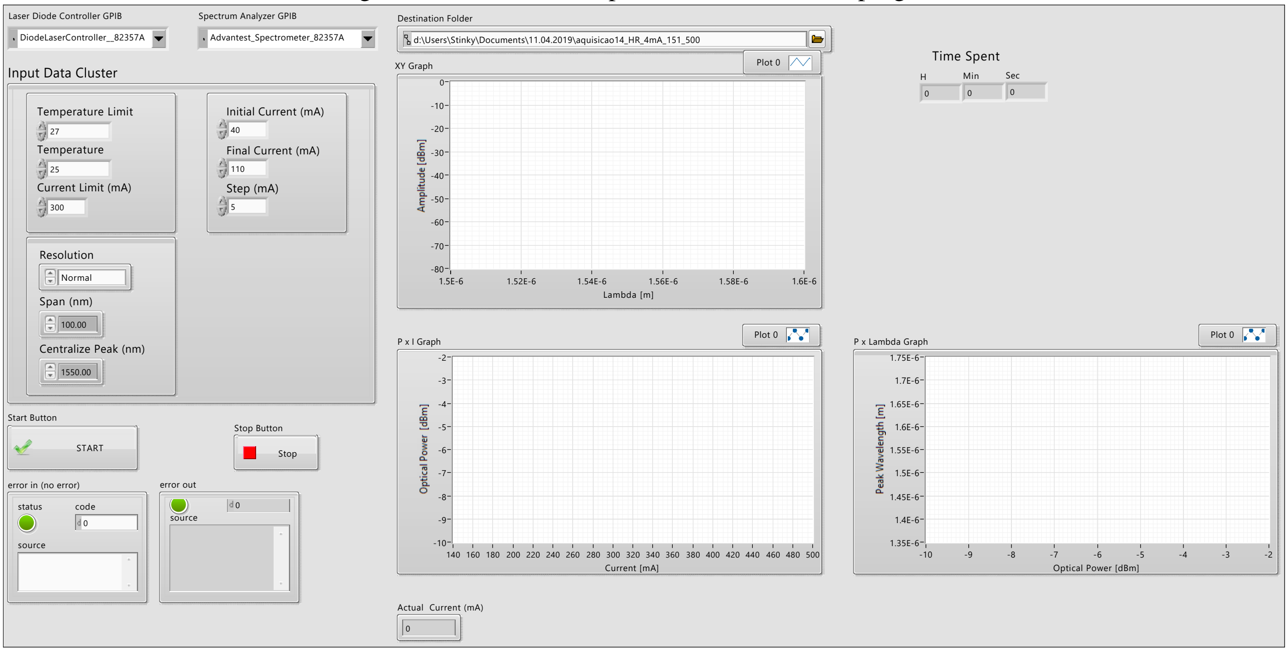
$osa \leftarrow$ Spectrum analyzer GPIB address;
$cont \leftarrow$ Laser controller GPIB address;
Choose destination folder;
$T_{max} \leftarrow$ Maximum laser temperature;
$I_{safe} \leftarrow$ Maximum current for safe operation;
$temp \leftarrow$ Operating temperature of laser;
$I_{min} \leftarrow$ Initial current of measurement;
$I_{max} \leftarrow$ Final current of measurement;
$step \leftarrow$ Step value;
$res \leftarrow$ Resolution mode;
$span \leftarrow$ Span value;
$mid \leftarrow$ Peak value to centralize spectrums;
Define Celsius as unit of temperature $\rightarrow cont$;
$T_{max} \rightarrow cont$;
$temp \rightarrow cont$;
Define current as laser power control $\rightarrow cont$;
$I_{safe} \rightarrow cont$;
$I_{min} \rightarrow cont$;
$span \rightarrow osa$;
$peak \rightarrow osa$;
$res \rightarrow osa$;
Turn on Status Byte transmission $\rightarrow osa$;
Set automatic reference level $\rightarrow osa$;
Turn on temperature control $\rightarrow cont$;
Turn on laser $\rightarrow cont$;
Wait 1000 ms; ▷ Time to allow laser stabilization.
$I_{actual} \leftarrow I_{min}$;
$i \leftarrow 1$; ▷ Iteraction counter.
while $I_{actual} < I_{max}$ **do**
    $I_{actual} \rightarrow cont$;
    Wait 100 ms;
    Read X-axis $\rightarrow osa$;
    Wait for Status Byte clearance value;
    File(i, column 1) $\leftarrow$ X-axis;
    Read Y-axis $\rightarrow osa$;
    Wait for Status Byte clearance value;
    File(i, column 2) $\leftarrow$ Y-axis;
    File(i, column 3) $\leftarrow I_{atual}$;
    File(i, column 4) $\leftarrow$ Peak wavelength value;
    File(i, column 5) $\leftarrow$ Peak intensity value;
    Save lvm file;
    $I_{actual} \leftarrow I_{actual} + step$;
    $i \leftarrow i + 1$;
end while
$I = 0 \rightarrow cont$;
Wait 1000 ms;
Turn off laser $\rightarrow cont$;
Clear GPIB Buffer;

2.2 LabVIEW Program

The Virtual Instruments (VI) were developed in LabVIEW using the logic represented in the flow chart and in the algorithm. Making each step in the flow chart as a subVI, and each subVI executing a series of specific commands (NI, 2003, 2013).

The main VI front panel of the program is shown in Fig. 4. This is the window that the final user will interact with, after the code is checked and debugged there is no eminent reason to access the block diagram. Unless, changes in the logic are necessary. All the data must be inserted in the control entries before sending the start signal, as explained in the methodology section. After starting the application the user must only wait, without changing any parameter. There is a Stop button to stop the operation at any time. Since the time of measurement depends on the resolution, initial current, final current and step of current chosen by the user, it can take a long time to finish. Since there isn't necessary the presence of a person during the experiment, when the program finishes a sound alert will go on to warn the user. There is also a time indicator in the front panel, which is updated after each iteration of the reading loop indicating how much time has passed since the start of the program.

Figure 4 – Main VI front panel of the LabVIEW program.



Source: Author.

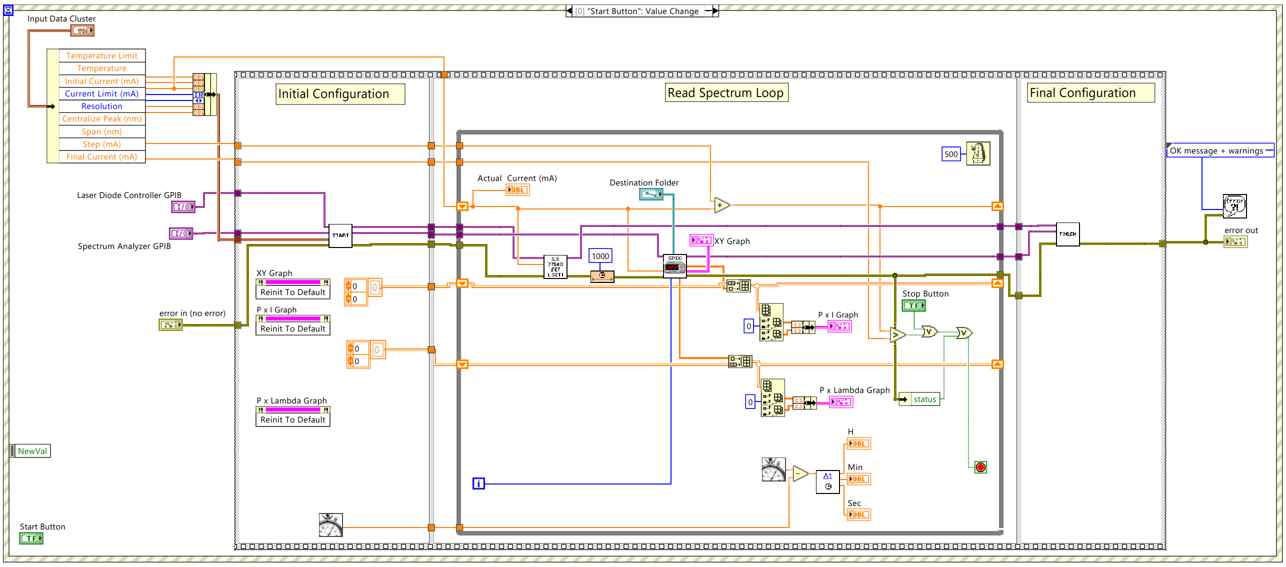
The block diagram is represented in Fig. 5, inside this block diagram there are all the subVI needed in this experiment. Inside few of the subVI are other subVI. The lowest level of subVI are those provided by the instrument manufacturers to execute the most used functions of each instrument, and converting the data stream to a readable format. It is easy to notice in this block diagram the division among the three main groups (initial configuration, read spectrum loop and final configuration).

In the initial configuration, outside the already mentioned tasks in Algorithm 1, there are invoked property nodes to reinitialize the graphs from the previous data collection and 2D arrays of doubles are initialized. In the read spectrum loop, there were used shift registers to append the peak wavelength and peak power to the 2D arrays initialized in the initial configuration. Allowing to plot and show in real time the variation of these data to the user. The final configuration turn off the laser diode and clears the GPIB bus.

The Fig. 6 is the block diagram of the subVI that collects the measurement data from the spectrum analyzer. Each iteration saves the full spectrum (which is also shown in the front panel) in an individual lvm file inside the chosen folder. The name of the file to be saved is forced to have the iteration number from the counter of the while loop in the main VI.

The Fig. 7 is the block diagram of the subVI made to synchronize the commands in the spectrum analyzer, because the device has the IEEE 488.1 protocol implemented, it does not have all the handshakes and communication protocol standardized as the next GPIB generation devices. So, a low level command to read the Status Byte was used with a VISA block from LabVIEW and empirically discovered that during the measurement the Status Byte is 0 and after it finishes there is a transient to 65 and then goes to 1, indicating the data is ready to be read in the bus. In devices that have GPIB IEEE 488.2 (e.g. laser diode controller), all this logic is already implemented in the protocol of communication and there are higher level commands to accomplish this synchronization.

Figure 5 – Main VI block diagram of the LabVIEW program.



Source: Author.

Figure 6 – Reading data SubVI block diagram.

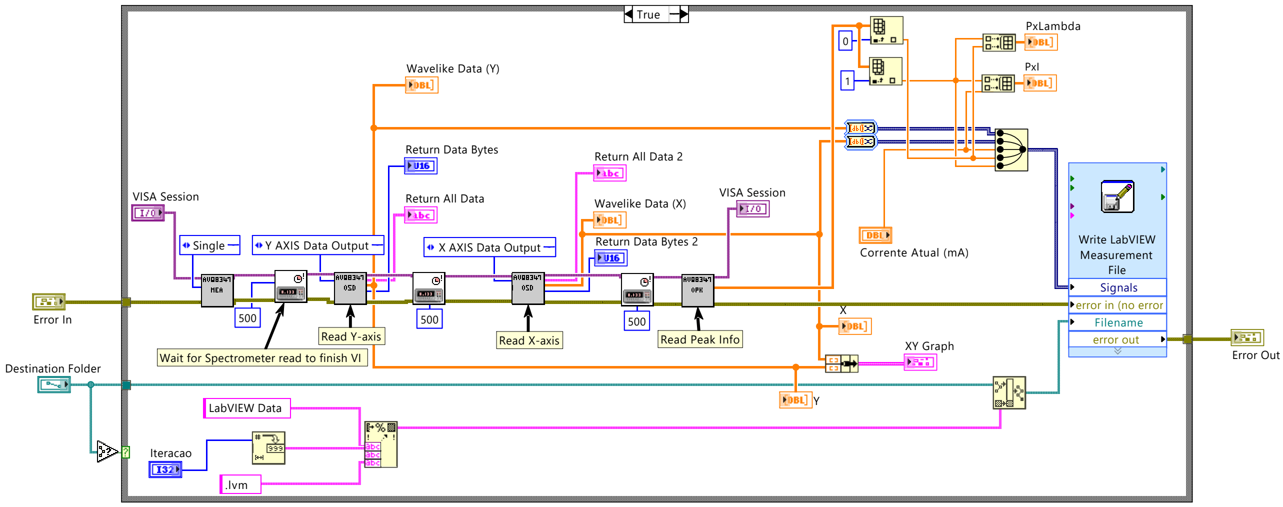


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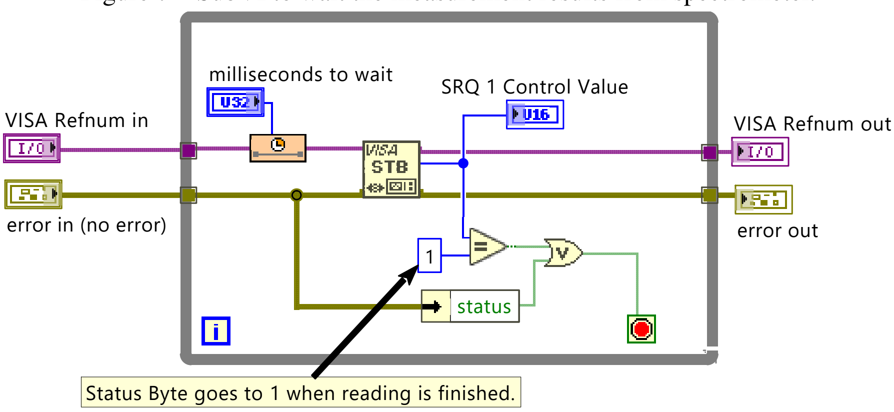
Figure 7 – SubVI to wait the measurement results from spectrometer.

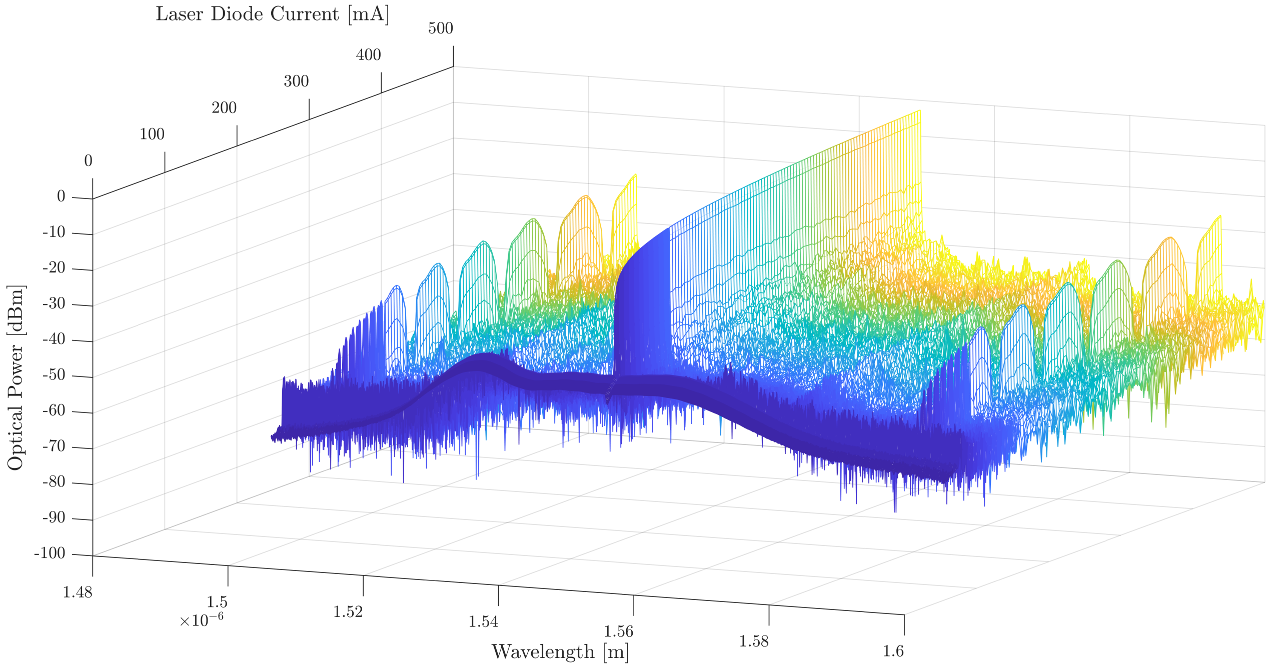


Source: Author.

3. RESULTS

The data collected in a complete execution of the program is shown in Fig. 8. In this particular initial configuration chosen by the user, there are 179 exhibited spectrums represented, with each spectrum containing 1730 measurement points. To properly analyze the data and minimize the accountability of spurious measurements, these spectrums were collected 10 times and then the standard deviation was calculated among the measurements to check the stability of the laser in question, as well as the repeatability of the automated data collection.

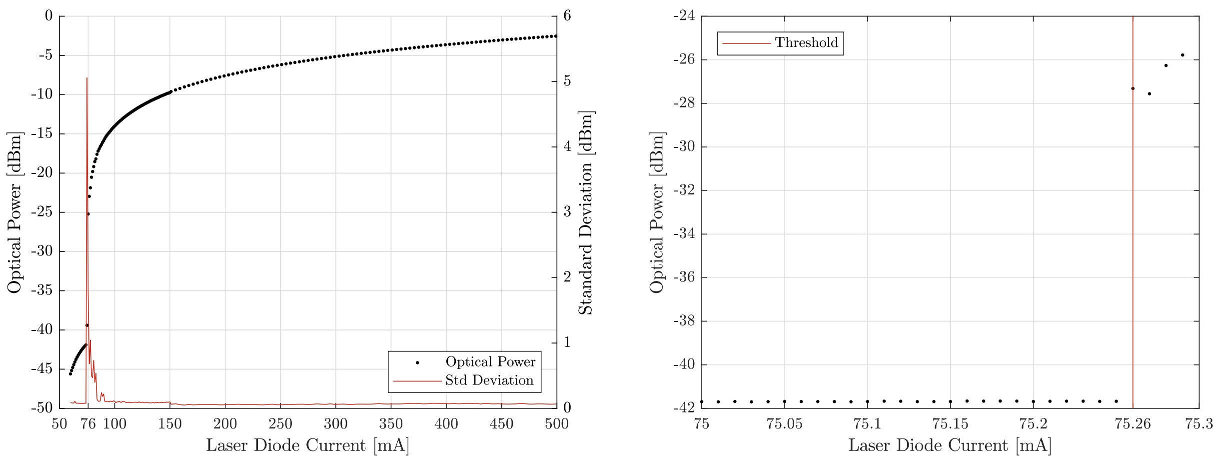
Figure 8 – Spectrums collect by one execution of the program with 1 mA step from 60 mA to 150 mA and 4 mA step from 151 mA to 500 mA.



Source: Author.

The Fig. 9 shows the threshold condition to the fiber laser in terms of current injected in laser diode and it is a transfer function of an indirect modulation of the laser optical power. In the Fig.9a, the mean value of threshold is in 76 mA and in Fig.9b using a smaller resolution of 0.01 mA, it was found a threshold of 75.26 mA.

Figure 9 – Plots of optical power in the output of the fiber laser by applied current in the diode laser. (a) Full acquisition, (b) zoom in the laser threshold zone.



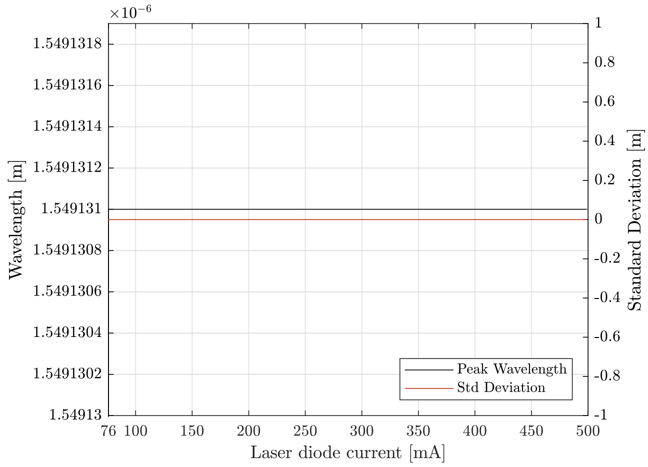
(a)

(b)

Source: Author.

The Fig. 10 shows a stable peak wavelength from the 10 data collection, with calculated standard deviation of zero. Meaning that the spectrum analyzer does not reach the necessary resolution to detect changes in this experiment.

Figure 10 – Applied current in the diode laser by variation of peak wavelength of the Er^{3+} doped fiber laser.



Source: Author.

4. CONCLUSION

The automation is working and can be applied to other lasers that work with the same laser controller and spectrum analyzer used in this project, otherwise commands must be changed accordingly to instrument's manual, but the structure of the code remains the same. It is possible to implement control theories in the automation to lock the laser power and have a stable light source to sensors.

5. ACKNOWLEDGEMENTS

The first author would like to thank for the grant 2019/04679-4 from São Paulo Research Foundation (FAPESP) and IEAv for allowing the students to use the laboratories from EFO-S and all the equipment available in them.

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