Effect of Temperature Change on the Performance of Laser Diode at 450 nm for Submarine Optical Communications

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Abstract: Optical communications usually require precise temperature control systems as junction temperature may dramatically influence the emission parameters of a laser diode. Recently, challenging optical applications, such as micro-satellite or underwater monitoring, need for small and low power solutions making it difficult to use complex temperature control systems. Accordingly, in this paper we explored the use of a small and passive copper heat sink to control the temperature and stabilize the transmission of GaN laser diode emitting around 450 nm. The results of a reliable thermal characterization for the various operating conditions showed the effectiveness of this simple solution.

1 INTRODUCTION

In recent years underwater communications have had increasing interest in the study and development of wireless communication systems. The main communication technologies used are based on acoustic waves, electromagnetic waves and optical pulses. In addition to strategies following separated approaches, hybrid systems are being studied more and more. Examples of recent studies can be found in (Lodovisi et al., 2018), (Farr et al., 2010), (Han et al., 2014). These allow the communication to be adapted to the conditions of water turbidity, so as to have the system always functioning and with high bit rate performance, above all by using optical communication technology.

An overview of recent UOWC (Underwater Optical Wireless Communication) developments is reported in (Kaushal and Kaddoum, 2016). It can be seen how the use of lasers allows high bit rates to be reached, performance also varies in dependence on the modulation format. An overview is also given to lasers operating in the blue-green spectrum. The systems that implement optical modems on devices for submarine optical communications are mainly based on the use of LEDs(Light Emitting Diode), some examples are reported in (Moriconi et al., 2015), (Doniec and Rus, 2010). The LEDs allow for a wider illumination beam, less difficulty in pointing between transmitter and receiver, but at the expense of a maximum bit rate of tens Mbit/s. The use of transmitters based on laser technology makes it possible to achieve much higher bit rates, hundreds of Mbit/s even up to Gbit/s.

Being able to use different technologies in a submarine system, both separately and simultaneously, allows high performance with the possibility of transmitting almost in real time.

In (Lee et al., 2015),(Wu et al., 2017), some experimental measurements are reported which are based on the use of laser diodes for underwater optical communications. An example of high bit rate performance, using a GaN semiconductor laser is reported in (Chi et al., 2016). In (Najda et al., 2016) different applications of GaN lasers in submarine optical communications are reported. An overview of GaN devices and their use is given in (Akasaki, 2013). These nitride-based devices are robust in harsh environments and allow us to save a significant amount of energy.

Being able to use different technologies in a submarine system, both separately and simultaneously,allows high performance with the possibility of transmitting almost in real time.

In the field of the optical-acoustic hybrid system, which Venus is equipped (Moriconi et al., 2015), we are studying the implementation of the second optical channel, consisting of a GaN semiconductor laser

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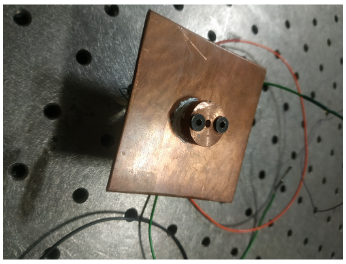
with a wavelenght around 450 nm for transmission at high bit rates. Advantages of the choice of a GaN semiconductor laser are low cost, ease of implementation and high frequency modulation.

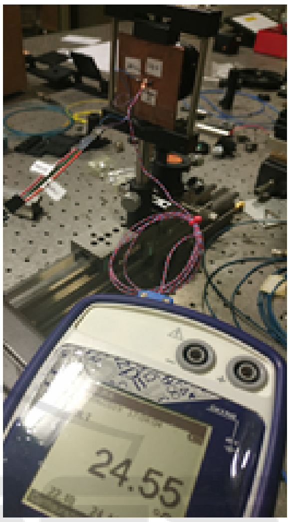
The junction temperature changes affect the performance of the laser diode in different ways, acting an wavelength, emitted optical power and optical spectrum in modulation regime. The reliability of the diodes is dependent on the junction temperature. From (Lee and Velasquez, 1998) it emerges that the optical power decreases as the junction temperature increases. This is the reason why it is necessary a system that keeps the temperature stable and dissipates the heat. In (Lee et al., 2015) the laser diode was mounted in a TO5 package surrounded by a large aluminum heat sink. In (Wu et al., 2017) the system temperature control consists of a copper support, a TE cooling device and a thermistor to maintain the temperature at at 25°C to stabilize the output dynamics of the blue LD (Laser Diode).

There are several methods for measuring junction temperature (Siegal, 2002),(Karim, 2004) . There is the possibility of carrying out indirect measurements based on the optical power emitted or evaluating shifts of wavelength. Other methods are those of determining the thermal resistance of the device or using the transient measurement method (Hwang et al., 2007). This laser transmitter can be used to achieve high-bit rate communication underwater links by robot with limited payload. For example the Venus (Moriconi et al., 2015) is a small device for which it is necessary to limit payload and consumption of the devices. The system must be as simplified as possible in the design. To simplify our system as much as possible, we have realized a simple copper heat sink. In this article we present experimental measurements to characterize the laser using the heat sink. Our aim is to have a system that is as limited as possible with respect to electronics, but capable of reaching at least 100 Mbit/s.

The article is organized as follows: section 2 presents the experimental set up; section 3 presents the experimental results and finally the conclusions are shown in section 4.



(a) Heat sink



(b) Thermocouple

Figure 1: Images of the heat sink and thermocouple.

2 EXPERIMENTAL SETUP

This section shows the setup carried out and the measurement methodology followed. For the dissipation of heat, we have made a copper plate with a 6 cm * 6 cm size , 1 mm thich, perforated in the center to house the laser. In the front we have fixed a copper cylinder with a diameter of 1.6 cm and a thickness of 6 mm, perforated to allow the emission. Conductive paste was placed between the plate and the cylinder. Figure 1a shows an image of the heat sink realized.

To perform temperature measurements as close as possible to the junction we have fixed a thermocouple with copper conductive adhesive tape on the pin of the laser case, as can be seen from Figure 1b. We constantly monitored the temperature of the device by driving the laser with a continuous current, and by varying the current value between 50 and 100 mA using a modular controller.

For each driving current value we took the temperature measurements every minute in the first five minutes, and then every five minutes until the temperature stabilized. At the same time, we monitored both the wavelength laser emission on the optical spectrum analyzer, to evaluate possible wavelength shifts, and the dissipation of heat on the heat sink plate through a thermo-camera, Figure 2 show the spectrum emission of laser diode.The equipment used to record spectrum is Ando AQ-6315A Optical Spectrum Analyzer.

Figure 3 shows the block diagram of the implemented setup to evaluate the laser behaviour when the driving current is continuous.

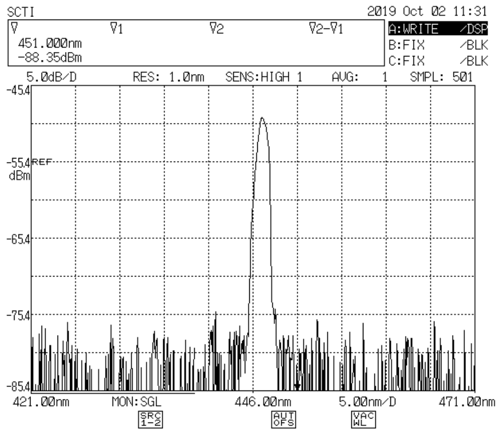


Figure 2: The spectrum emission of laser diode.

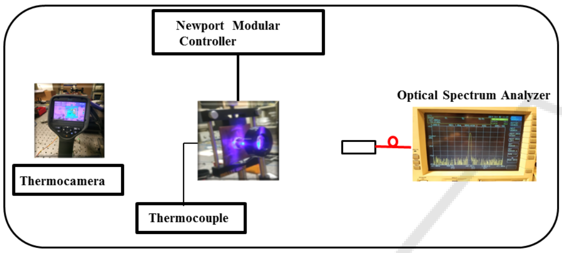


Figure 3: Block diagram of the implemented setup for measurements driving the laser by controller.

We repeated the same measures described above also moving the thermocouple inside the conductive paste to avoid the possible temperature disturbance due to the contact of the surrounding air. The final temperature values reached and the trend of the temperature increase were substantially the same as those we measured with the thermocouple fixed on the case pin.

The only difference that emerges is that the temperature stabilizes after about 90 minutes, compared to 30 minutes for the other measurement. In this case the contact with the surrounding air could influence the stabilization dynamics. We performed measurements to evaluate possible temperature changes by directly modulating the laser, with generated signal frequencies ranging between 1 and 100 MHz. At the same time, we evaluated the value of the signal received on an electrical spectrum analyzer. We used a Bias Tee to directly modulate the laser. The generated signal was a sinusoid with a variable frequency. At the receiver site we used an inversely polarized photodiode to detect the signal.

Figure 4 shows the setup scheme implemented to perform the measurements.

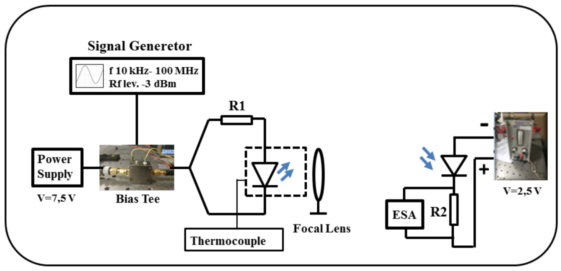


Figure 4: Block diagram of the implemented set up for measurements driving the laser directly.

3 EXPERIMENTAL RESULTS

In this section, the obtained results are reported and described. The first measure performed was the current power characterization of the laser housed in the heat sink. Figure 5 shows the result obtained.

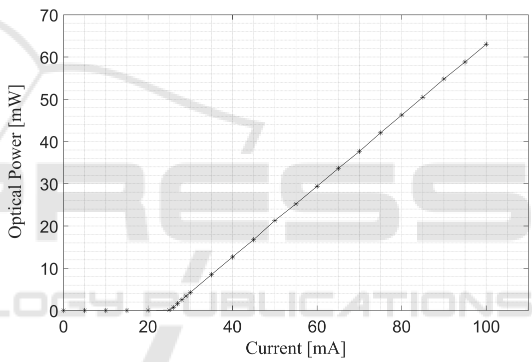


Figure 5: Laser response.

Figure 6 shows the junction temperature measurements as a function of time by driving the laser with a continuous current equal to 50, 60, 75 and 100 mA. From the trend it can be noticed that the temperature increases mainly in the first 5 minutes (about 2 degrees Celsius), it increases by another degree for the next fifteen minutes, after which it tends to stabilize. The value of the final temperature reached is independent of the driving current of the laser, substantially reaching the same temperature value.

Simultaneously with the junction temperature measurements we verified the emission of the laser peak to check eventual shifts of wavelength. Figure 7 shows the values of the laser emission wavelength, in correspondence with the temperature values recorded for different driving currents of the laser. From the measurements carried out it emerges that the emission wavelength maintains substantially constant. It slightly tends to increase as the driving current increases and the temperature increases, but not signif-

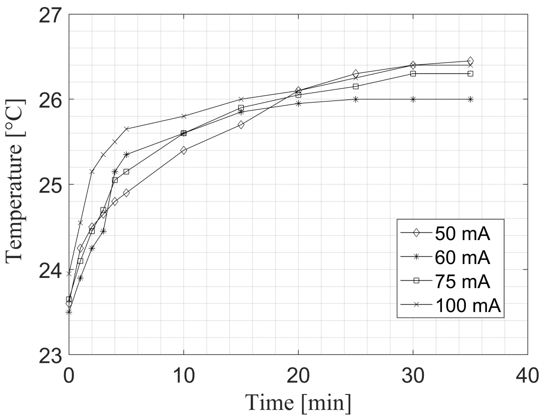


Figure 6: Temperature trend for different driving current.

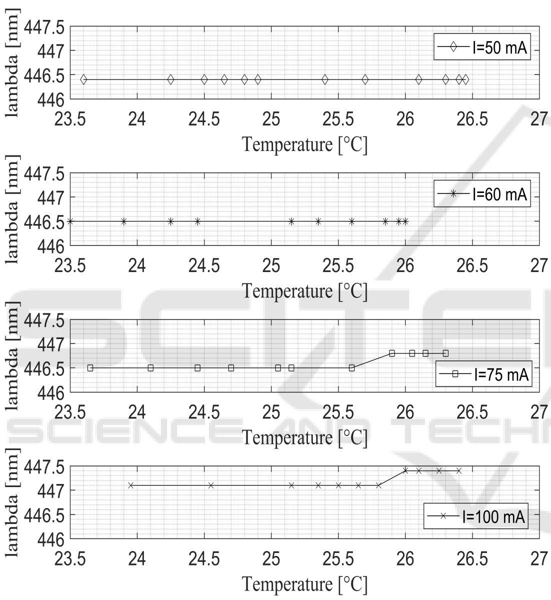
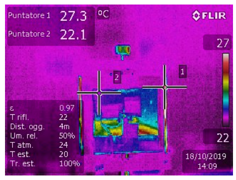


Figure 7: Wavelength vs Temperature Behaviour.

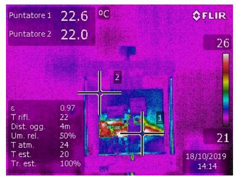
icantly or to limit the performance of the data transmission system.

Figure 8 shows the images provided by the thermo-camera to evaluate the behavior of the heat sink, while driving the laser at 75 mA. The image is shown with the laser off, the laser on after 5,15 and 35 minutes switching on. It can be seen how the heat is evenly distributed and without reaching temperatures above about 26°. In one point of the heat sink a higher temperature was monitored, but in any case not higher than 32° which did not affect the temperature of the registered junction.

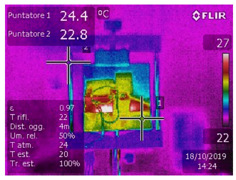
After having carried out an analysis on the possible effects of temperature piloting the laser with a direct current, we carried out measurements to evaluate the behavior of the laser while it was modulated.



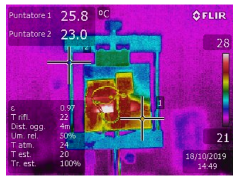
(a) laser off



(b) 5 minutes from laser switch on



(c) 15 minutes from laser switch on



(d) 35 minutes from laser switch on

Figure 8: Images of the thermo-camera after different laser lighting.

Figure 9 shows the junction temperature trend as the frequency of the generated signal varies. Before increasing the modulation frequency, we have waited for the detected junction temperature to stabilize. The same behavior of the laser controlled in direct current was noticed, reaching the same temperature values. From the measurements carried out it emerges that, at least up to 100 MHz, once the laser stabilizes in temperature, the modulation does not produce any significative modification of the stabilized temperature of the laser.

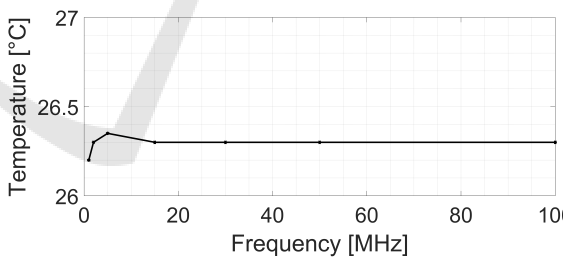


Figure 9: Temperature trend for different frequencies of the generated signal.

Figure 10 shows the trend of the normalized optical power to the power transmitted as a function of the modulation frequency. We have normalized the optical power detected on the ESA with respect to the optical power transmitted at the laser bias current of 75 mA. The trend shows how, apart from an initial peak due to of the photodiode spectral response, the power trend slightly tends to decrease with the increase in frequency, but remains around the same values.

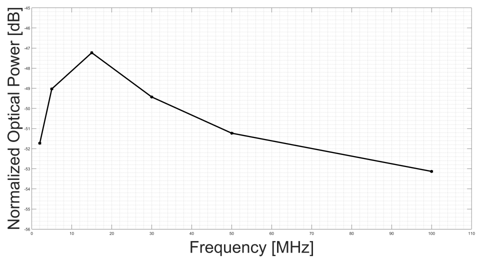


Figure 10: Normalized optical power to the bias point against modulation frequency.

4 CONCLUSIONS

Compact and low power systems are two fundamentals requirements for systems operating in particular scenarios such as underwater communications with mini vehicles. To that end we assessed the feasibility of using a simple, compact, and passive copper heat sink to control a GaN laser diode emitting around 450 nm. Actually, the junction temperature reaches a suitable steady-state behavior either driving the laser with a continuous or sinusoidal waveform.

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