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Transmitter with quantum cascade laser for free space optics communication system

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Abstract. The paper presents results of experimental tests of the quantum cascade laser from Alpes Lasers company in terms of its application in the optic communication system in an open space. The measurements involved the current – voltage characteristics while measuring also the average power of emitted radiation, and spectral characteristics for different temperatures and different laser pulse durations. The duration of laser pulses was matched to parameters used in telecommunication interfaces. The construction of the transmitter module which uses the tested laser is also presented.

Key words: optical link, quantum cascade laser, laser communications.

1. Introduction

One of the main limitations of commercially available optical communication systems in an open space (Free Space Optics), using radiation with wavelengths of 0.8 microns and 1.5 microns, is their sensitivity to adverse weather conditions. A promising step in the progress of construction of these systems is the development of transmitter and receiver systems operating in the wavelength range of 8–12 microns. This radiation has a low absorption caused by the gases typically present in the atmosphere, and lower attenuation induced by a mist of small particle aerosols. For many years, one of the major technological barriers preventing the development of FSO systems operating in this area was the lack of suitable radiation sources.

The turning point came in 1971 when Kazarinov and Suris gave the idea of the work of quantum cascade lasers [1]. In 1994, J. Faist and F. Capasso presented the first results of experimental investigations of QCL lasers [2]. Since then there has been significant progress in the development of these lasers, working in both the mid and far infrared (3–24 microns) [3]. Polish researchers play also an important role in the development of these lasers [4–6]. These lasers have the properties (spectral range, power, weight, power consumption) which enable their use in optical communications systems transmitters. The first studies on the possibility of using these lasers to build FSO were conducted by Bell Labs [7, 8]. In the Institute of Optoelectronics MUT there are also carried out researches on QCL lasers for FSO systems. Initially, QCL laser from Cascade Technologies Company was used [9, 10]. Unfortunately, realizable pulse repetition frequency was relatively small (< 100 kHz) and confined to a pulse with a small ($< 1\%$) fill factor of the pulse [11, 12], that definitely limited the bandwidth, and forced the need for data transfer protocols based on *return to zero* (RZ) code.

An important part of the conducted research is, therefore, a thorough analysis of the usefulness of currently available cascade lasers in data systems.

2. Cascade laser research

The main determinants of choosing the right laser for use in FSO is the spectral range of radiation, the maximum power in the pulse, the maximum operating frequency, and duty cycle. Actually, there are several types of high-power cascade lasers operating in a pulsed mode, continuous, or continuous and pulsed modes [12]. Based on analysis of data submitted by manufacturers and their availability it is assumed that the most effective source of radiation is a cascade laser from Alpes Lasers company, model sbcw2968. This laser can work in either pulsed or quasi-cw (high duty cycle) mode. The maximum average power for -30°C for the cw mode is 300 mW, and while operating with 40% fill factor – of about 200 mW. Along with the laser manufacturer also provided a functional control system. This system consists of laser housing, laser diode driver, the power supply module, and the temperature control unit. Figure 1 shows the block diagram of laboratory equipment used for power and driving of cascade laser with measuring elements (generators, power supplies, detection modules [13, 14] and oscilloscope). In order to maintain the proper operating temperature the laser uses a two-stage thermoelectric cooler. This cooler allows the stabilization of laser temperature within the range from -40°C to $+80$°C. The thermoelectric cooler is also assisted by forced liquid cooling. The generator provides driving of the laser pulses of given parameters. A bias-T system was used for biasing of the laser system. It provides a constant current of under threshold value (no generation of radiation), and allows to generate the driving current pulses to obtain laser action.

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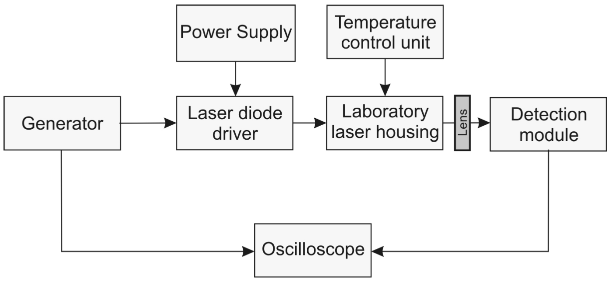

Fig. 1. Block diagram of power supply and control of QCL laser from Alpes Lasers company

In the first stage of the study dependence of the power of laser radiation on the parameters of laser supply and temperature was measured. In these studies high-voltage power supply (500 V, 15 ns–10 μs, $dc = 0.1\%$) from AVTECH, Tektronix oscilloscope, and VIGO SYSTEM detector characterized by band of 50 MHz were used (Fig. 2).

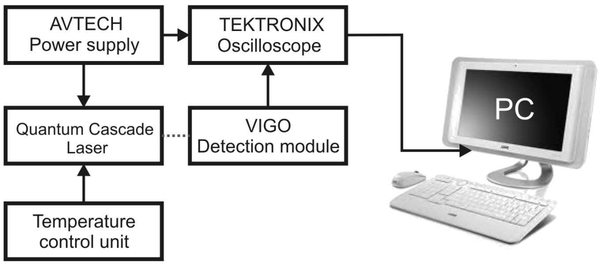

Fig. 2. Scheme of laboratory setup for determining the power characteristics of laser radiation depending on the parameters of laser supply and temperature

Figure 3 shows the measured current-voltage characteristics and the peak optical power as a function of current flowing through the laser structure, for several values of temperature and duty cycle of 0.1%.

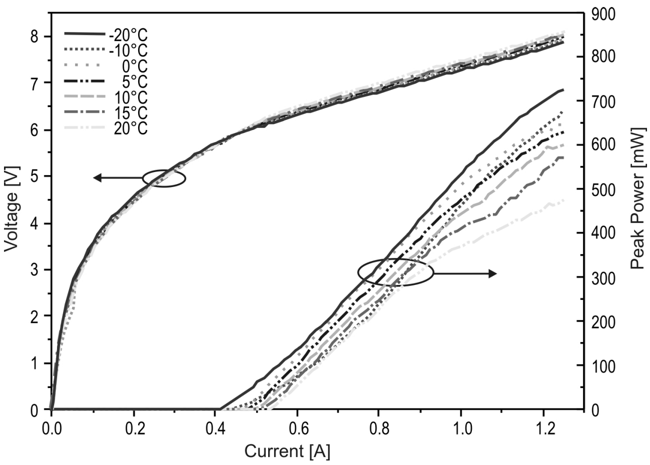

Fig. 3. Current-voltage characteristics and the peak optical power as a function of laser control current

It results from these characteristics that the rise of laser temperature causes a decrease in the peak power of radiation, and an increase of the threshold current.

It turned out during measurements that an important issue using cascade lasers was a provision of a suitable (efficient and low inertial) cooling system.

The next stage of research was to determine the spectral range of laser radiation. This laser, according to manufacturer's specifications, was optimized for a wavelength of 8.4 microns. Laser spectral measurements were carried out at the Institute of Electron Technology in Warsaw, using a Nicolet 8700 Fourier spectrometer from Thermo Scientific. Figure 4 shows the picture of the measurement set used for determination of spectral characteristics.

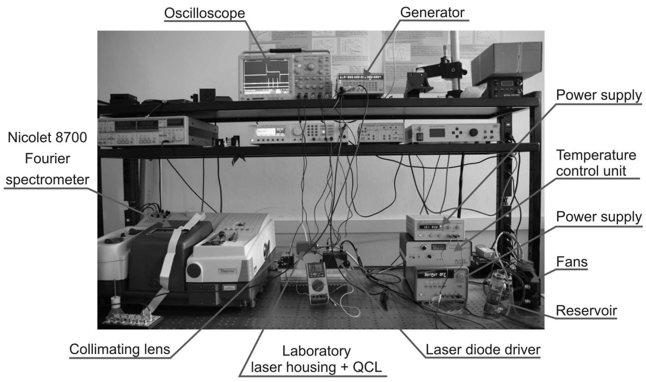

Fig. 4. Measurement setup for determining the spectral characteristics of the QCL laser

An analysis of the impact of changes in the driving voltage amplitude on the shape of the spectral characteristics of the QCL laser was performed. The test results are shown in Fig. 5.

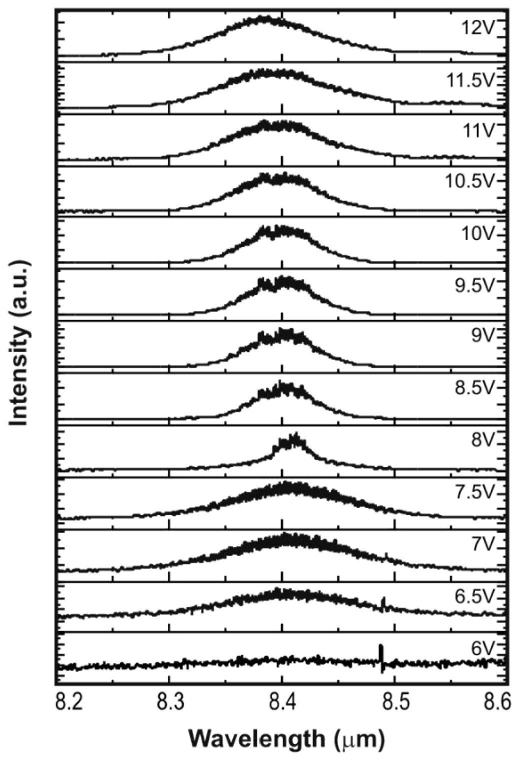

Fig. 5. Influence of the driving voltage amplitude on the shape of the spectral characteristics of the tested laser

Measurements were made for the repetition frequency of 1 MHz, pulse duration of 100 ns, and the temperature of −20°C. The driving voltage was changed in the range 6–12 V. Measurements were made without collimating lens.

As it is apparent from the spectral characteristics the laser emits multimode radiation. Spacing between successive longitudinal modes are 2.4 nm. This value agrees well with the expected ones for the resonator of this length. However, a change in the driving voltage amplitude substantially affects the scope and shape of the spectral characteristics of the tested laser. The increase in the driving voltage amplitude causes the initial narrowing of the spectral characteristics, and then expands it again, and moves the entire characteristic in the direction of shorter wavelengths. This effect is a consequence of quantum effects associated with the increasing value of the electric field biasing structure.

The analysis of the impact of the driving pulse duration on the shape of the spectral characteristics of the tested laser was also conducted. Measurements were taken without the collimating lens for repetition frequency 100 kHz, 12 V driving voltage, and the temperature of −20°C. The results are shown in Fig. 6.

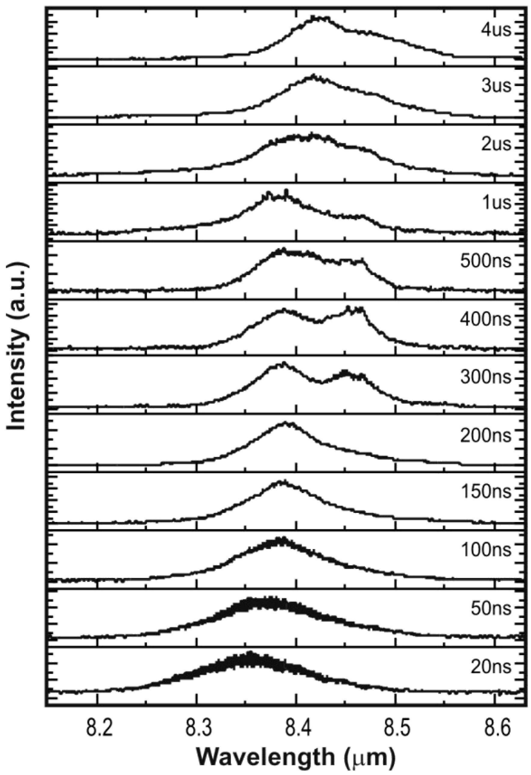

Fig. 6. Influence of the driving pulse duration on the shape of the spectral characteristics of the tested laser

Studies have shown that a change in the pulse duration significantly affects the scope and shape of the emitted spectrum. An increase in the pulse duration causes the characteristic spectral broadening, and shift the spectral characteristic towards longer wavelengths. The observed effect is related to temperature wavelength retuning. The increase of pulse duration gives a significant rise of the temperature of the laser active region. For long pulse durations it is expected that temperature rise of the active region up to a few dozen or more degrees can be observed.

Measurements of spectral characteristics using *Time Resolved Spectroscopy* system were also carried out. Measurement of temporal spectral characteristics were performed for driving pulse with a duration of 100 ns, pulse repetition frequency of 50 kHz, 12 V driving voltage, and temperature of −20°C. Optical pulse was sampled at 5ns, while the total measurement time was 280 ns. Test results are shown in Fig. 7.

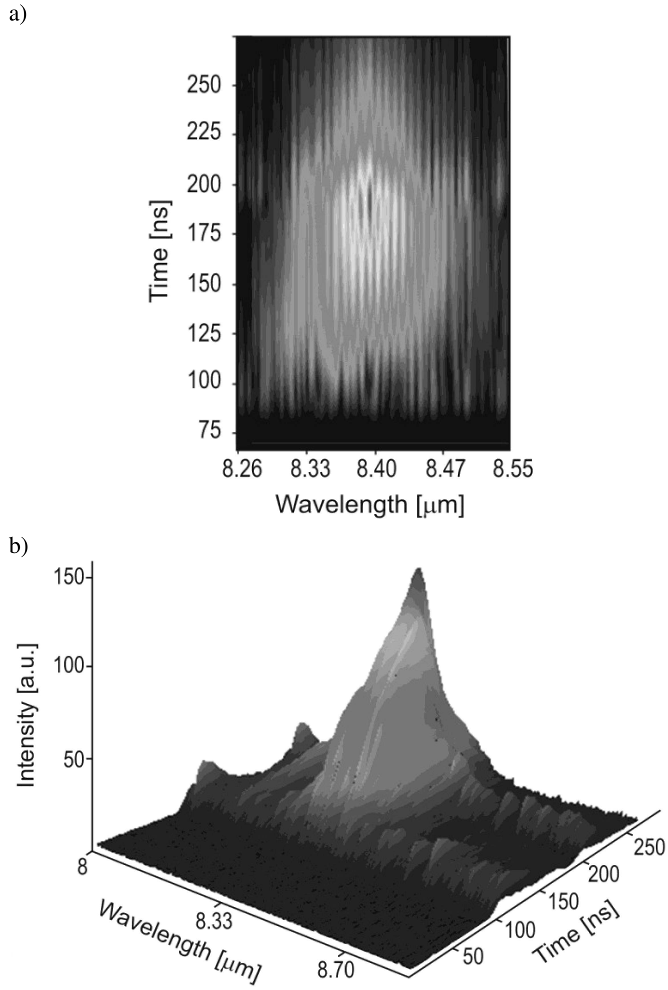

Fig. 7. Time – spectral characteristics for the driving pulse with a duration of 100 ns, pulse repetition frequency of 50kHz, 12V driving voltage, and temperature of −20°C – 2D view (a) and 3D view (b). (Ordinate axis – another spectrum measured at an interval of 5 ns)

As it is shown in Fig. 7, the tested laser emits a single group of longitudinal modes in the short pulse duration operating conditions.

3. The design of a FSO transmitter

The tested quantum cascade laser with the controller and the detector with accessories were placed in specially designed casing.

The casing construction significantly affects the performance of the designed link. When designing this component following factors were taken into account:

- minimal size and weight,
- mobility,
- ease of installation,
- the possibility of easy adjustment.

Figure 8 shows a photography of the designed transmitter module. This module consists of an optical laser head LLH, laser driver LDD400, beam forming system, liquid cooling system and adjustment system (VIS laser and telescope).

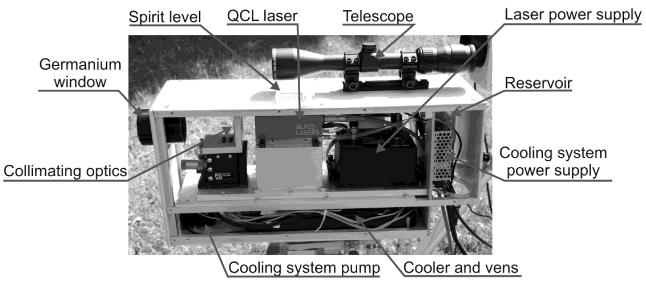

Fig. 8. Construction of the FSO transmitter module

The transmitter module allows to emit a modulated radiation beam of corresponding energy-spatial parameters. It operates with external power supply and thermoelectric cooler controller.

The transmitter system was equipped with a telescope and visible light laser, whose optical axes are adjusted with the axis of the transmitter optical beam (QCL laser).

For the high data range of FSO system, the beam divergence should be as lowest possible as it is required. That is why, in the transmitter appropriate collimating optical elements ought to be applied. In this regard, an external optical system consisted of a single germanium lens with a diameter of 25 mm and 25 mm focal length was used. It was mounted in the precisely regulated holder enabling the laser alignment.

4. Summary

The main task of the work was to determine the optimum parameters of the QCL laser analyzing the possibility of its use in FSO link.

The presented results include the characteristics of the control voltage and peak power changes as a function of current flowing through the laser structure and the temperature of the laser, and the designation of the spectral characteristics.

The researches show that the maximum peak power generated by the laser is achieved with 8 V bias voltage. Then, the laser has a current of 1.2 A and the peak power is about 730 mW. These parameters are obtained during laser operation at $-20°$C.

The analysis of the impact of changes in the driving voltage amplitude on the shape of the spectral characteristics of the QCL laser shows that the increase in the driving voltage amplitude causes the initial narrowing of the spectral characteristics, and then expands it again, and moves the entire characteristic in the direction of shorter wavelengths. The spectrum shifts by about 0.75 microns.

The analysis of the impact of the driving pulse duration on the shape of the spectral characteristics of the tested laser shows that an increase in the pulse duration causes the characteristic spectral broadening, and shift the spectral characteristic towards longer wavelengths. In this case the spectrum shifts by about 0.25 microns.

Studies have shown that although the laser retunes to the change in driving voltage amplitude, and driving pulse duration it is still working in the third atmospheric transmission window. The study shows that the sbcw2968 laser from Alpes Lasers can be successfully used in the FSO link.

The design of the transmitter modules is also presented. While designing a mechanical system following factors were taken into account: dimensions and weight of equipment, ease of installation and adjustment of both systems, as well as its applicability in conditions outside the laboratory.

In order to facilitate adjustment of transmitter-receiver system a telescope and VIS laser were used. The study shows that in order to ensure optimal working conditions it is necessary to provide additional thermoelectric coolers hot side cooling. Therefore a liquid cooling system in closed circuit was used.

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