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XIII SYMPOSIUM ON OPTICS & BIOPHOTONICS
APPLICATIONS OF LASER MOLECULAR IMAGING AND MACHINE LEARNING V

AN ARDUINO BASED LASER WAVELENGTH TUNING SYSTEM FOR TDLAS OF CARBON DIOXIDE

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Relevance

The anthropogenic impact on the atmosphere has intensified since the pre-industrial era, leading to a significant increase in greenhouse gas emissions. This has resulted in a more than 50% amplification of the greenhouse effect. Carbon dioxide (CO_2) is one of the most prevalent of these gaseous pollutants, with atmospheric concentrations currently at approximately 405 ppm and exhibiting an annual growth rate of 2-3 ppm. Consequently, accurate CO_2 monitoring is indispensable for enhancing environmental sustainability and improving patient outcomes in relevant medical applications.

Tunable Diode Laser Optical-Acoustic Spectroscopy (TDLAS-OAD) represents a robust analytical technique for monitoring atmospheric CO_2 concentrations. The near-infrared (NIR) spectral region between 1565 nm and 1590 nm is considered optimal for monitoring CO2. This spectral window contains strong CO_2 absorption bands that are free from significant interference from other atmospheric constituents, most notably water vapor (H_2O).

A variety of commercially available NIR laser sources operate within this range. However, a majority of these systems rely on manual tuning of the radiation wavelength. This presents considerable limitations regarding the precision and operational convenience of the measurements. Therefore, the development of a simple and cost-effective remote control system for wavelength modulation is a pressing research and development priority.

Aim of the research

Development of a remote control system for tuning the generation wavelength of an ML2540-1570 NIR diode laser for detecting the CO_2 absorption line.

Materials and Methods

A commercially available near-infrared (NIR) diode laser module, model ML2540-1570 from LTT LLC (Minsk, Belarus), was used as a source for CO_2 monitoring. This module has a central emission wavelength of 1570 nm and an average output power of 4.5 mW. In standard configuration of ML2540-1570, the wavelength can be adjusted in two modes: by use of Pulse-Width Modulation of the supply voltage or manually, by adjusting an analog potentiometer and measuring the corresponding voltage, which indicates the operating temperature of the laser diode. The wavelength range which corresponds to the formal mode is presented in Table 1.

Table 1 – The ML2540-1570 wavelength range corresponding to the Pulse-Width Modulation of the supply voltage

Pulse-Width Modulation rate , kHz	wavelength, nm
2	1570,2
10	1571
20	1570,8
30	1570,2
40	1569,7

As can be seen from the Table 1, the wavelength variation is less than 1 nm. In the second adjustment method, this wavelength tuning is achieved by altering the temperature of the laser diode, which is done by rotating a potentiometer located in the "CONTROL" zone on the rear panel of the laser (Figure 1).

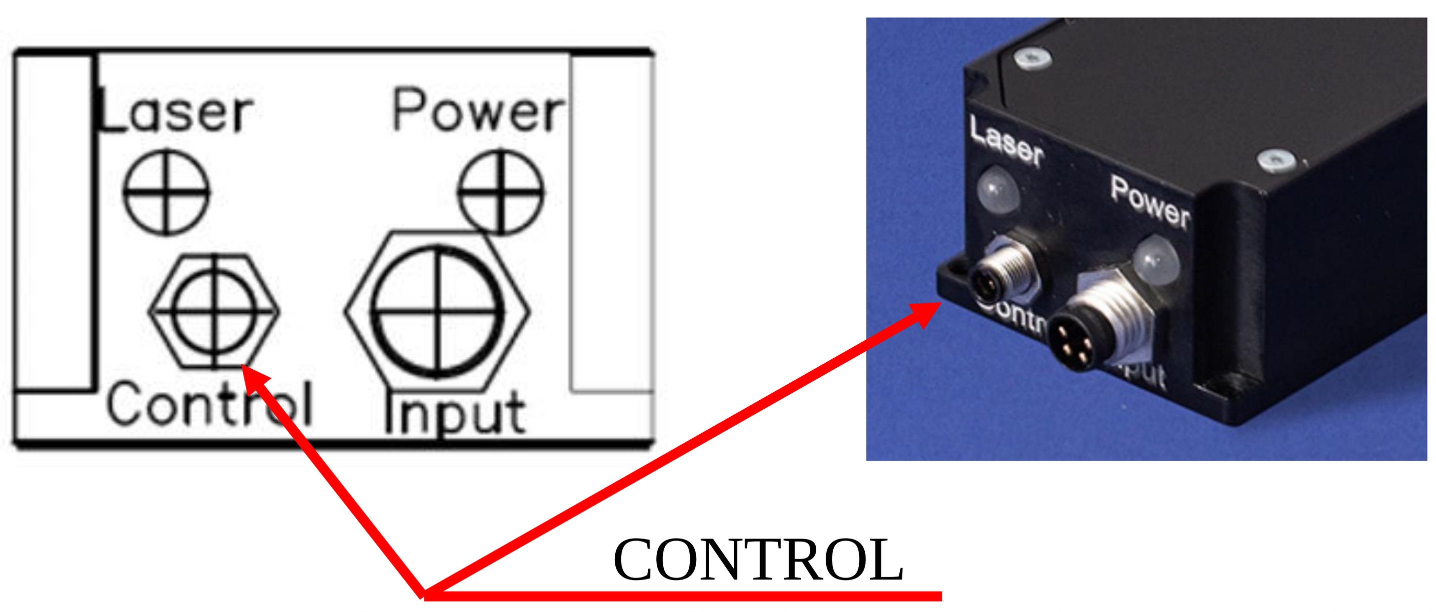

Figure 4 – Potentiometer/thermostat for controlling the temperature of ML2540-1570 laser diode

Results

Manually adjusting the laser wavelength by rotating the potentiometer is inconvenient during an experiment. Therefore, we developed a remote wavelength tuning system. This system is based on an Arduino Micro programmable microcontroller and an AD5243 digital potentiometer (Figure 2). The terminals of the digital potentiometer were connected to the laser module, replacing the factory-installed multi-turn potentiometer. The AD5243 digital potentiometer has a resistance of 100 kΩ and offers 256 adjustment positions.

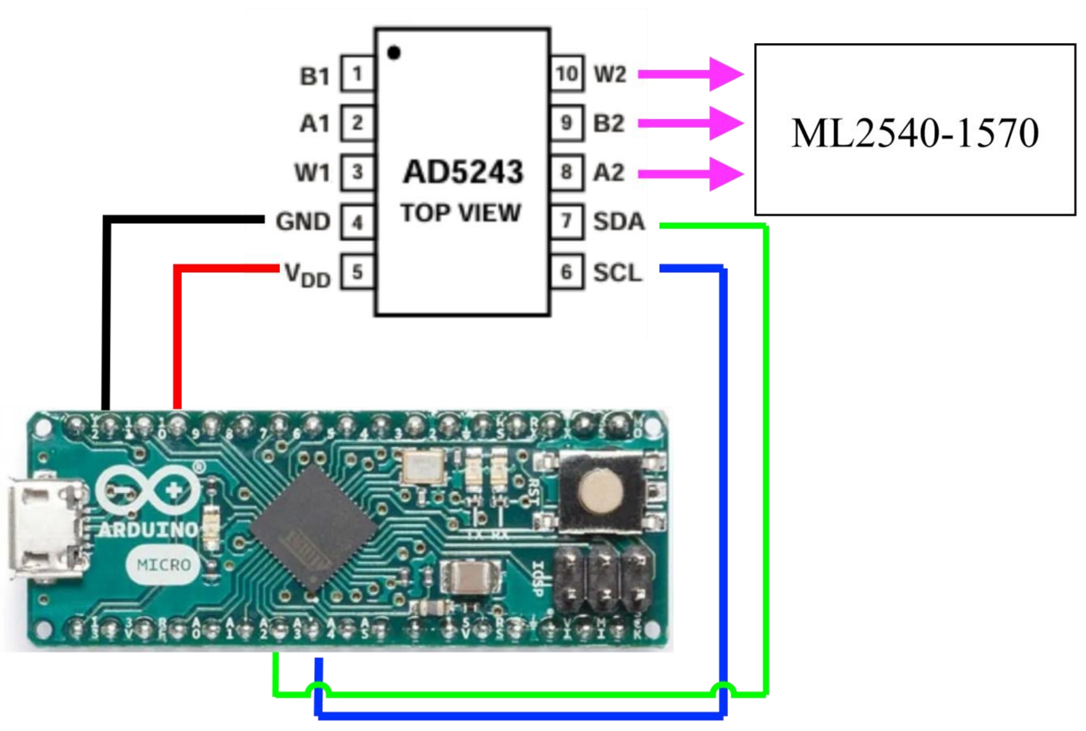

Figure 2 – Schematic view of the remote control system for tuning the wavelength of the laser module

The results of the emission wavelength measurements as a function of the voltage from the digital potentiometer are presented in Figure 3. The wavelength tuning range was determined from 1568 nm and up to 1571.5 nm, with a possible resolution of 0.014 nm.

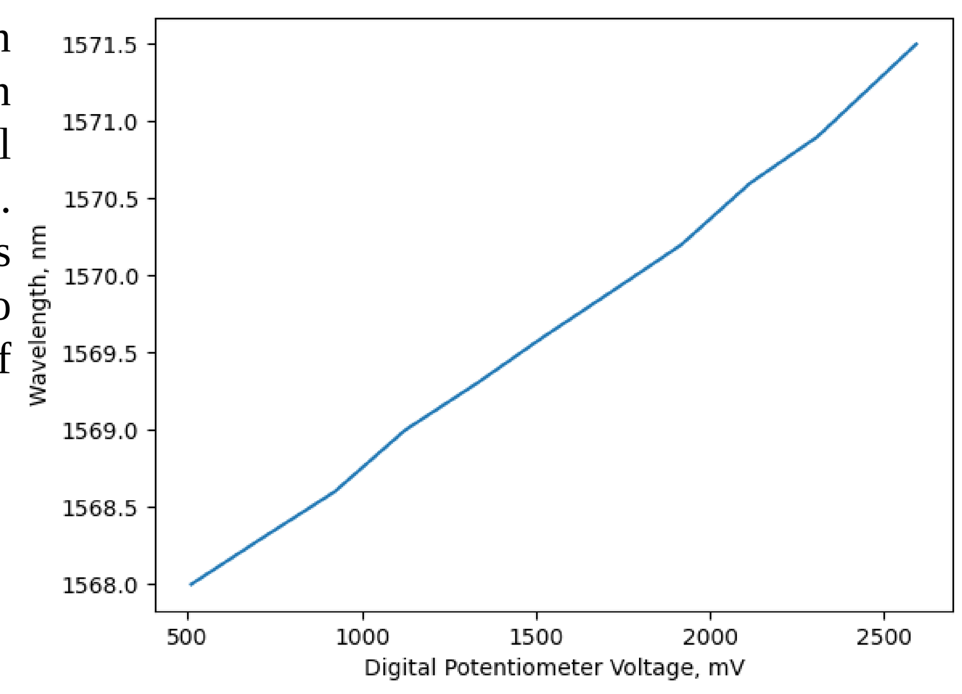

Figure 3 – The wavelength of the ML2540-1570 laser module with the use of a digital potentiometer AD5243

Detection of CO_2 absorption line

This modified laser module ML2540-1570 was used as the NIR-source in a photoacoustic spectrometer (block-scheme and photo are shown in Figure 4). The experimental spectrum of a CO_2 absorption line was performed in optical-acoustic detector (OAD) with usage of the carbon dioxide (CO_2) and nitrogen (N_2) gas mixture (CO_2 concentration of 0.99%). The Pulse-Width Modulation rate was fixed at 30 kHz. The pressure within the photoacoustic cell was atmospheric, and the temperature was 23 °C.

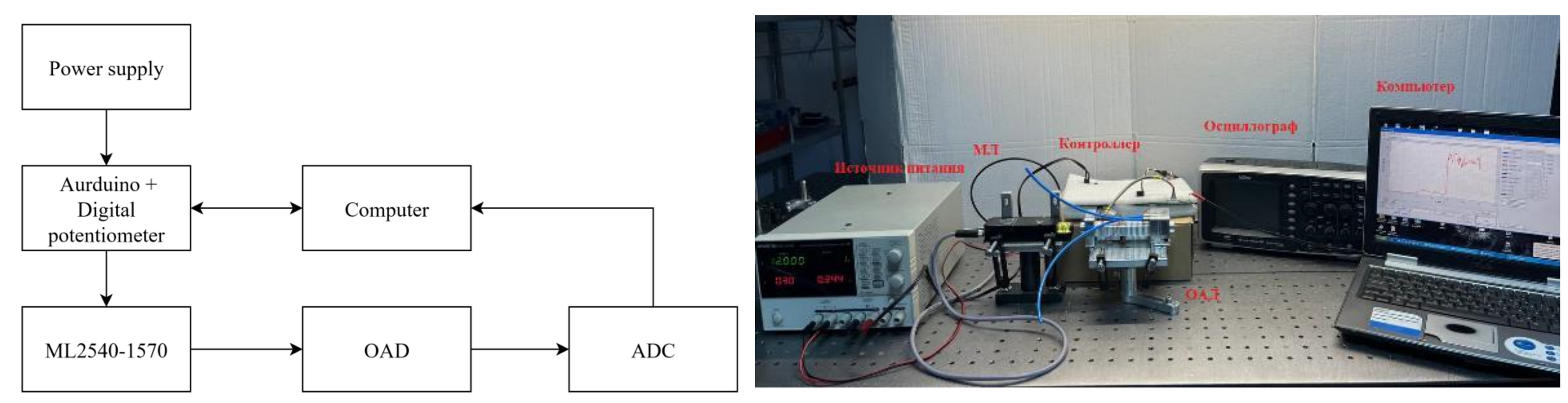

Figure 4 – The block-scheme (left) and the photo (right) of the experimental setup of TDLAS -OAD spectrometer

The spectral line was scanned by varying the voltage across the laser's thermal controller potentiometer from 400 mV to 2100 mV. The resulting spectrum was recorded as a function of time. Figure 5 depicts the spectrum of a CO_2 absorption line in a gas mixture measured within the OAD. The absorption peak exhibits a split structure. This artifact is attributed to the operational characteristics of the laser's internal temperature controller. Even when the potentiometer is set to a fixed value, instabilities in the thermal regulation process lead to "jumps," in the emission wavelength.

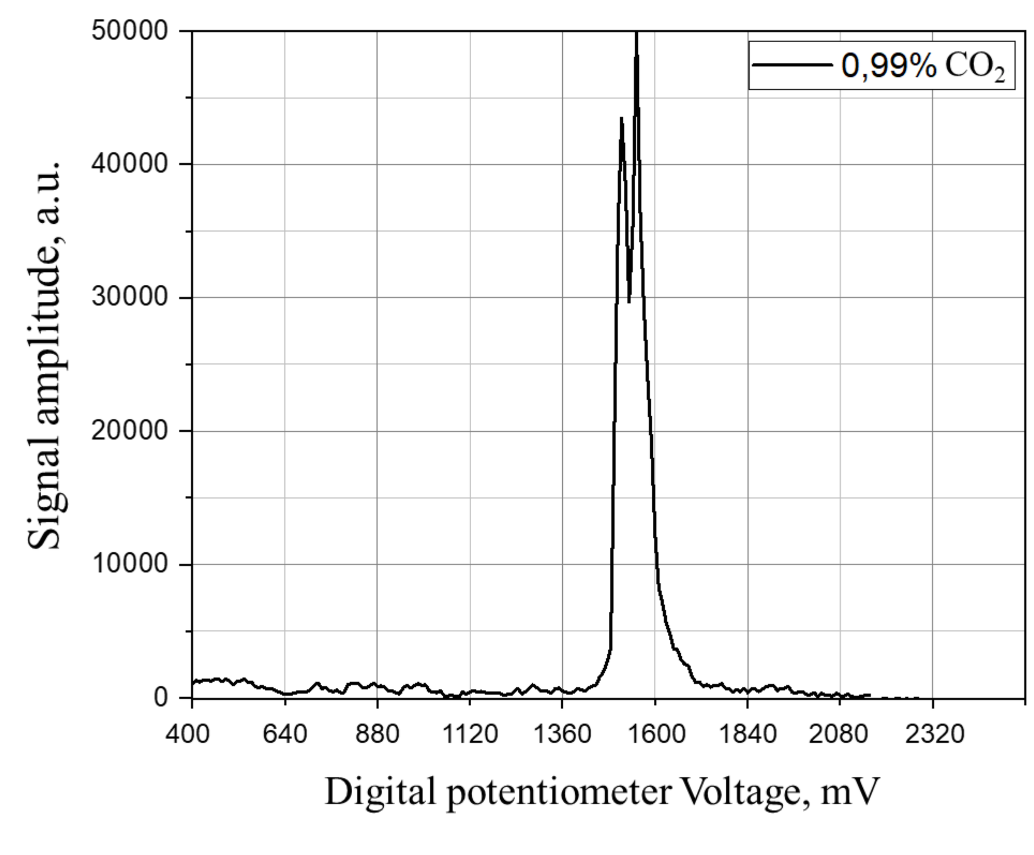

Figure 5 – Experimental absorption line of CO_2

Conclusion

The system, based on an Arduino microcontroller and a digital potentiometer, was successfully integrated with an ML2540-1570 laser module, replacing its factory-installed manual controls. The developed system demonstrated effective and repeatable control over the laser's emission wavelength, achieving a tuning range of 1568 nm to 1571.5 nm with a potential resolution of 0.014 nm. The modified laser module ML2540-1570 was implemented as the NIR-source in a photoacoustic spectrometer and used to get a CO_2 absorption line.

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