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FPGA implemented temperature controller for mid-IR methane optical detector

Streszczenie. *Powszechnie stosowane w optycznych detektorach metanu diody LED działające w zakresie od 2300 nm do 4200 nm wymagają stabilizacji termicznej warunków pracy. Związane jest to ze wyraźną zależnością emisji promieniowania od temperatury w złączach półprzewodnikowych, w tym przypadku w wykorzystywanych przez autorów strukturach w oparciu o InAsSbP. W pracy przedstawiono przykład implementacji układu stabilizacji temperatury wybranych diod LED z wykorzystaniem platformy sprzętowej Xilinx XC3S500E Spartan-3E FPGA.* ***(Kontroler temperatury dla optycznego układu detekcji metanu realizowany w układzie FPGA).***

Abstract*. Commonly used in methane optical detection LEDs operating in 2300 – 4200 nm range need specific temperature control. It is related to strict dependence of the emission of radiation on temperature in semiconductor junctions, in this case the heterostructures based on InAsSbP. The authors present the examplary implementation of temperature controller for mid-IR methane optical detector. The Xilinx XC3S500E Spartan-3E FPGA platform was used.*

Słowa kluczowe: optyczna detekcja, fotodiody IR , optopary IR, Xilinx XC3S500E Spartan-3E FPGA
Keywords: Detector, mid-IR photodiodes, IR optopair, Xilinx XC3S500E Spartan-3E FPGA platform

Introduction

Methane is one of the most important representatives of organic substances in the atmosphere and its concentration is much higher than other organic compounds [1]. It is well known that methane even at very low concentrations could be very dangerous for human safety and environment [2]. Due to this fact, the detection and analysis of methane is important in a very wide range of applications, e.g. leak detection, natural gas identification or lower-explosion-limit (LEL) measurements. During last two decades several measuring techniques were developed for methane detection, using metal oxide semiconductor gas sensors [3], catalytic gas sensors [4,5], carbon nanotube gas sensors [6] or microsystems with preconcentrators [7].

The authors propose the optical methane detector based on a pair of mid-IR LEDs and a photodiode. Both these elements contain a thermistor and a thermoelectric cooling (TEC) module. The authors present temperature controller of TEC module realized on Xilinx XC3S500E Spartan-3E FPGA platform.

Mid-IR pair for methane detection

The methane has the main absorption band in the range 3200 - 3400 nm. The other bands that can be used for detection are located around 1650 nm and 2300 nm (Fig.1.).

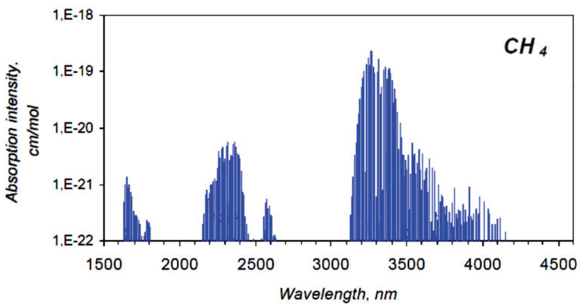

Fig.1. Absorption spectrum of methane in 1500 – 4500 nm wavelength range (according to HITRAN database)

A schematic view of methane detector system based on two LEDs and one photodiode proposed by the authors is shown in Figure 2. Diode LED1 (34TEC-PR supplied by Ioffe Physico-Technical Institute, Russia) has the maximum emission in the main absorption band of methane (3400 nm) and diode LED2 (21TEC-PR) has maximum emission in an absence of absorption of methane (2100 nm) and it is used as a reference source. The detector part of the system is based on a photodiode PD (PD36TEC-PR). The photodiode detects signals from both LEDs, and these signals are analyzed in a detection module implemented in FPGA. The reference diode LED2 is mainly used to compensate the changes in light intensity in the measuring chamber originated from humidity.

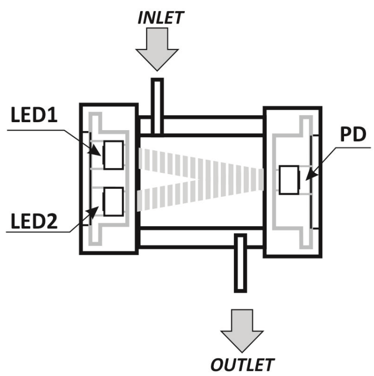

Fig.2. The measurement system for methane optical detection based on two LED diodes and one photodiode (PD)

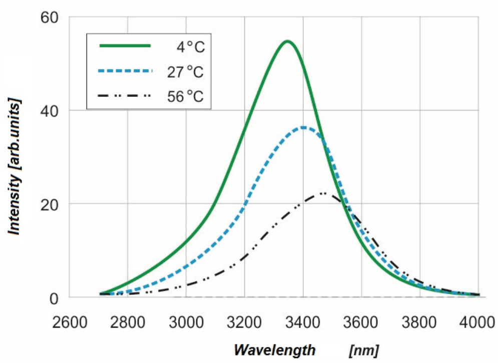

Fig.3. Typical emission spectra at different temperatures of LED 34TEC-PR

The LEDs suffer from a high sensitivity to temperature variations. Emission intensity decreases and the wavelength corresponding to intensity maximum shifts with increasing temperature (fig.3.), therefore it is necessary to control the LED operating temperature. Temperature drift of the emitted radiation is 1.5 nm/K for LED 21TEC-PR and 3 nm/K for LED 34TEC-PR [8]. One of the limitations of using photodiode (PD) in methane optical detection, is the spectral response dependence on the temperature [9]. The photodiode has lower sensitivity to temperature changes than LEDs, but it's temperature also have to be controlled.

Implementation of temperature controllers in FPGA

To control the temperature of both LEDs and PD element, the authors implemented two independent PID regulators on Xilinx XC3S500E Spartan-3E FPGA platform. The response time for PID regulators was lower than 20 μs. The Spartan 3E platform was programmed using LabView FPGA 2010 (National Instruments) tool. The diagram code prepared in LabVIEW was translated to VHDL and then to bitfile. The flowchart of the temperature controller is presented in Figure 4.

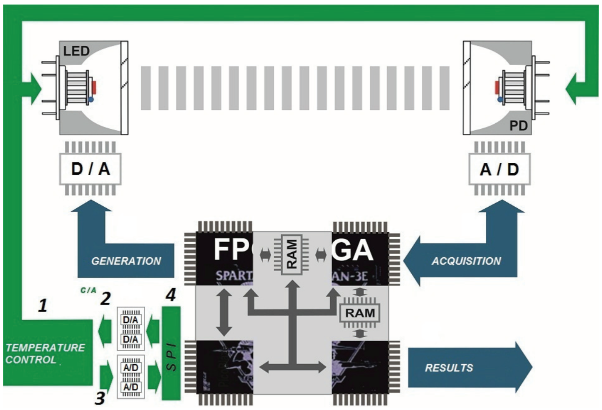

Fig.4. The flowchart of temperature controller in FPGA

The proposed solution uses for temperature control one of two analog to digital converters (ADC) and one of four digital to analog converters (DAC) available in Spartan-3E. The second ADC is used for LEDs signal generation. The other DAC is used for signal detection from photodiode PD. Due to this, a synchronization (between all the modules implemented in FPGA) during the transmission is necessary. The Spartan-3E FPGA provides over 10,000 logic cells. Only 20% of resources present in a chip were used: PID regulators used 15% and subcode (synchronization) another 5%. The uncertainty of temperature stability was about 0.1°C. To reduce the consumption of FPGA resources, the PicoBlaze microcontroller was used. Its allows for independent work of the temperature control module and other implemented modules. In this solution, synchronization is not necessary. Therefore, only 15% of the resources were used: PID regulators used 10% and subcode 5%.

The authors tested also the FPGA platform and two ADN8830 microcontrollers supplied by Analog Devices (fig.5), dedicated to temperature control in laser diodes. For such solution lower requirements for analog to digital and digital to analog converters in FPGA platform are needed. Use of ADN8830 reduced the consumption of resources to 5%. In Figure 6 the microcontroller module is presented.

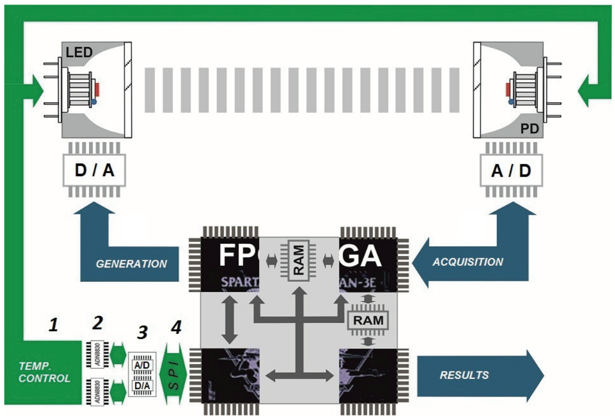

Fig.5. The flowchart of temperature control in FPGA with two ADN8830 microcontrollers

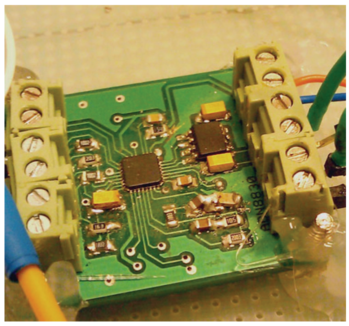

Fig.6. The ADN8830 microcontroller in a temperature control setup

During all tests the National Instrument PCI-6229 multifunction data acquisition card was used. The authors measured power consumption in TEC with changing LEDs' currents at a constant temperature 4°C. The results are presented in Table 1. The working temperature for LEDs was set to 4.5°C and for photodiode was set to 5.1°C.

Table 1. Power consumption in TEC @ 4°C

LED [mA]	50	80	100	120
TEC [W]	0.52	0.79	1.03	1.29

On Figure 7 the photodiode response in function to the methane concentration in 0 – 100% range was presented.

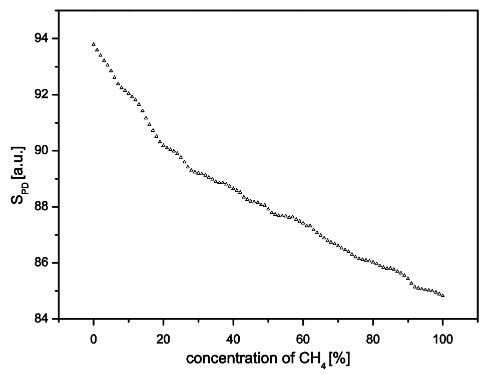

Fig.7. The photodiode response vs. the methane concentration in 0-100% range

Conclusions

The use of temperature control module (TCM) is necessary for stable work of the optopair. The authors presented three solutions including FPGA platform, internal (PicoBlaze) and external (ADN8830) microcontrollers. The lowest resources consumption was for the solution using ADN8830 elements. The authors propose FPGA platform for the whole measurement system. It could provide a fast analysis with complete signal processing. In the application, the results of methane concentration measurements are send to LabVIEW application. In this paper, the discussion is restricted only to the temperature controllers on Xilinx XC3S550E Spartan-3E FPGA for proposed optopair in view of methane detection.

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