TEMPERATURE STABILIZATION OF SEMICONDUCTOR LASERS FOR DIRECT MEASUREMENT OF INDEX OF REFRACTION OF AIR

Vít Matoušek, Doctoral Degree Programme
Institute of Scientific Instruments, Academy of Science of the Czech Republic
Department of Microelectronics, FEEC, BUT

Supervised by: Dr. Ondřej Číp

ABSTRACT

Laser interferometers are even more precise distance measurement devices with resolution in nanometer or sub-nanometer region. If interferometeric measurements carry out under atmospheric conditions (usual situation in an industry), they measure optical path length of an unknown distance instead of its true geometrical value. It is caused by an index of refraction of air that introduces a multiplicative constant to measured results. If we would like to obtain correct values the knowledge of the index of refraction is necessary.

Generally, the index of refraction can be measured by two ways: indirectly or directly. The first of them is based on parametric analysis of atmospheric properties as: relative humidity, pressure, temperature, concentration of CO_2 etc. Values of these parameters are processed then by Edlén formulas with 10^{-7} order [1]. The direct methods are more precise than Edlén formulas (more than 10^{-7}) but their practical implementation is more difficult. Devices that directly measure the index of refraction are called refractometers.

In the work, we present design of the direct method where two coupled glass cells (one evacuated and the other filled by atmospheric air) are inserted to plan-parallel Fabry-Perot resonator (F.-P. resonator). Two tunable single-frequency lasers pass laser beams through the evacuated and aired cell simultaneously. So that, two F.-P. resonators are built up: one of them in evacuated cell and the other in the open air cell. If both lasers are tuned along the resonant modes of F.-P. resonators, an optical frequency difference between two adjacent modes can be identified for each resonator. Naturally, the evacuated one will have another mode-to-mode difference than the aired resonator. With knowledge of these values we can determine index of refraction very simply.

In the refractometer design, we decided to use semiconductor lasers. Then lasing wavelength can be controlled by means of value of the injection current and the operating temperature of the laser chip. Therefore, in the work we spend a large effort to solve problems with temperature stabilization of these lasers.

1 INTRODUCTION

Nowadays very precise distance measurement is provided by laser interferometers. Results measured by interferometers are distorted by index of refraction of air, because the wavelength of used laser is different in vacuum and in atmospheric air. If we know the index of refraction, we may determine the wavelength:

$$\lambda_{air} = \lambda_{vacuum} / n ,$$

where λ_{air} is wavelength of light of laser in air, λ_{vacuum} is wavelength of light of laser in vacuum and n is index of refraction of air.

Value of the index of refraction depends on more parameters. Main parameters are temperature, pressure, relative humidity, concentration of gasses etc. In the twentieth century there was discovered method, which can to measure the index of refraction indirectly. This method is called Edlén formulas. If we will use this method, then we need to measure instantaneous values of these quantities by means of electronic weather station. It leads to very precise calibration of probes, electronic devices etc., what is much expensive. The other possibility is to use an evacuating glass cell that is placed in measurement arm in Michelson interferometer. If we will start evacuating process, optical path change caused by the evacuating will change the interference phase in the output of the interferometer. If we know size of the cell and interference phase change, then we can calculate the index of refraction very simply. Disadvantage of the apparatus is necessity of the huge pumping device that is used at each measurement period.

2 MEASUREMENT OF INDEX OF REFRACTION OF AIR

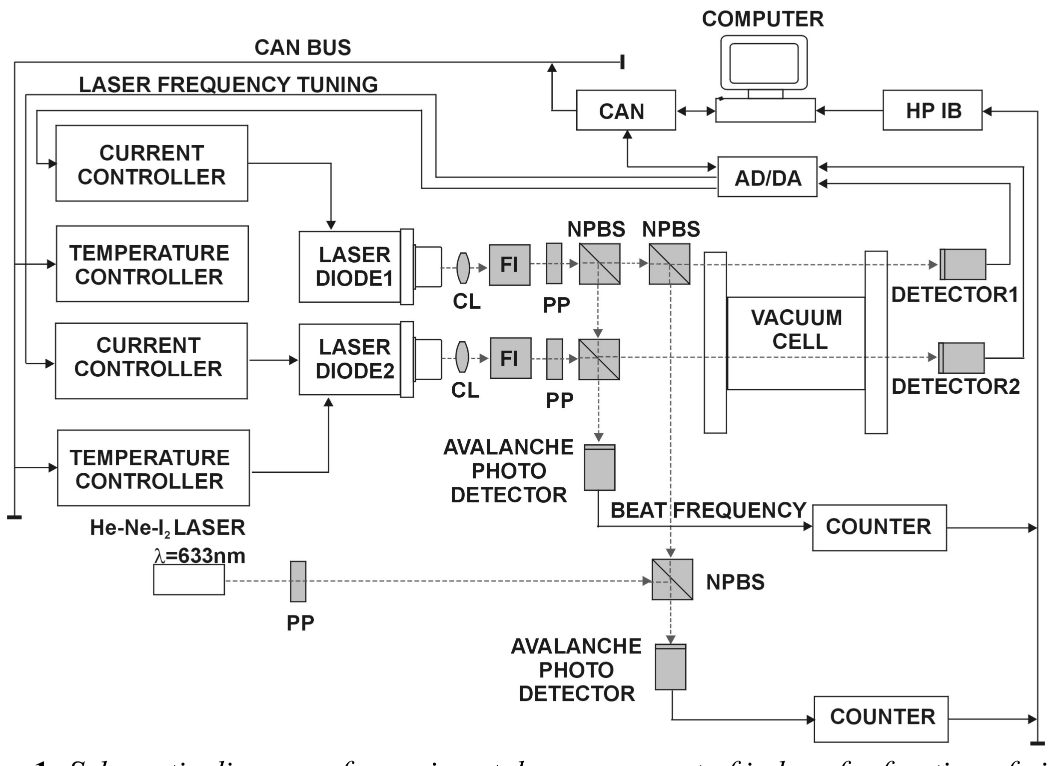

Fig. 1: *Schematic diagram of experimental measurement of index of refraction of air: FI is the Faraday optical isolator, CL is the laser diode-collimating lens, PPs are polarization plates, NPBS is the non-polarizing beam splitter.*

Our method works on principle of the frequency compression of two lasers as is shown in figure 1. If we know laser wavelength and length of resonator we may count index of refraction of air with formula:

$$\Delta\lambda = \lambda^2 / 2\, n\, L,$$

where *Δλ* is change of laser wavelength, *λ* is laser wavelength, *n* is index of air and *L* is length of resonator.

3 TEMPERATURE CONTROL OF SEMICONDUCTOR LASER

Temperature controller is one of the very important parts of the work because we need very good temperature stability of lasers for measurement index of refraction of air. Digital self-learning temperature controller regulate temperature of laser in range from 0 °C to 30 °C. We need temperature control because wavelength is sensitive to temperature changes, so that temperature must be controlled with stability below 1 mK. When we started design temperature controller we specified electronic circuits of the controller:

- Adjustment of PID components of the servo-loop controller in large range because of thermal and time parameters of the laser mounting block and heat sink can be large different.
- Self-learning algorithm for fast automatic system identification of thermal parameters.
- Digital communication interface for data interchange with a personal computer.

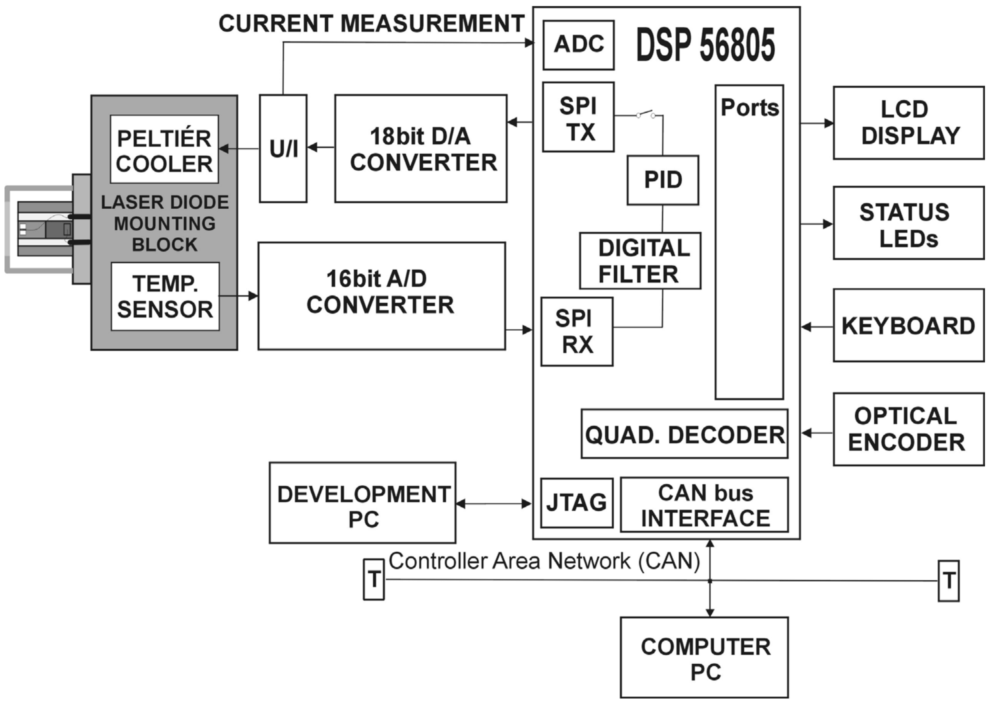

Fig. 2: *Schema of temperature stabilization of semiconductor laser*

In practice, temperature controllers are realised often with analog circuits, because such a circuit has low-noise operation than digital electronics. Because the design of the self-learning algorithm or the digital communication with personal computer is not possible to realise effectively only by means of analog circuits, we employed digital circuits and digital signal processing technology also.

We designed the controller with a schematic diagram shown in figure 2. The Peltier element is used as a temperature actuator that is mechanically connected to laser heat sink and the temperature sensor at the same time. A value and polarity of the direct current of the Peliter element control transfer of heat between both sides of the thermal system. Like the temperature sensor we used integrated circuit AD2210 (produced by Analog Devices) with linear dependency of output voltage to measured temperature. A sixteen-bit sigma delta analog-to-digital converter AD7715 (Analog Devices) samples the output voltage of the temperature sensor with 50 Hz sampling frequency. Digital samples produced by the converter AD7715 are processed with the Digital Signal Processor DSP56F805 (Motorola). In this processor we implemented PID controller, digital filters, advanced Ziegler-Nichols algorithm for system self-learning identification, and communication with other peripherals, like as the alphanumerical display module or keyboard. The processor DSP56F805 also provides regulation process on basis of knowledge of the instantaneous temperature of laser and required value of the temperature preset entered by user. The differential form of the digital PID controller calculates a relevant action value of the Peltier current. Firstly, the digital form of the value is converted to voltage representation through serial peripheral interface and eighteen-bit digital-to-analog converter AD1861 (Analog Devices). Then the output voltage of AD1861 is converted to Peltier current by means of a voltage-to-current operation amplifier. We designed the voltage-to-current amplifier with output range ±1 A. We used an industrial serial bus CAN (Controller Area Network) for multi-master communication with the personal computer. Due to higher electromagnetic noise generation coming from digital parts of the controller, we housed whole electronics into aluminum enclosure situated to 19” industrial rack, that we generally use for our self-made scientific devices developed in the institute. Figure 3 and figure 4 represent side and top view of the temperature controller.

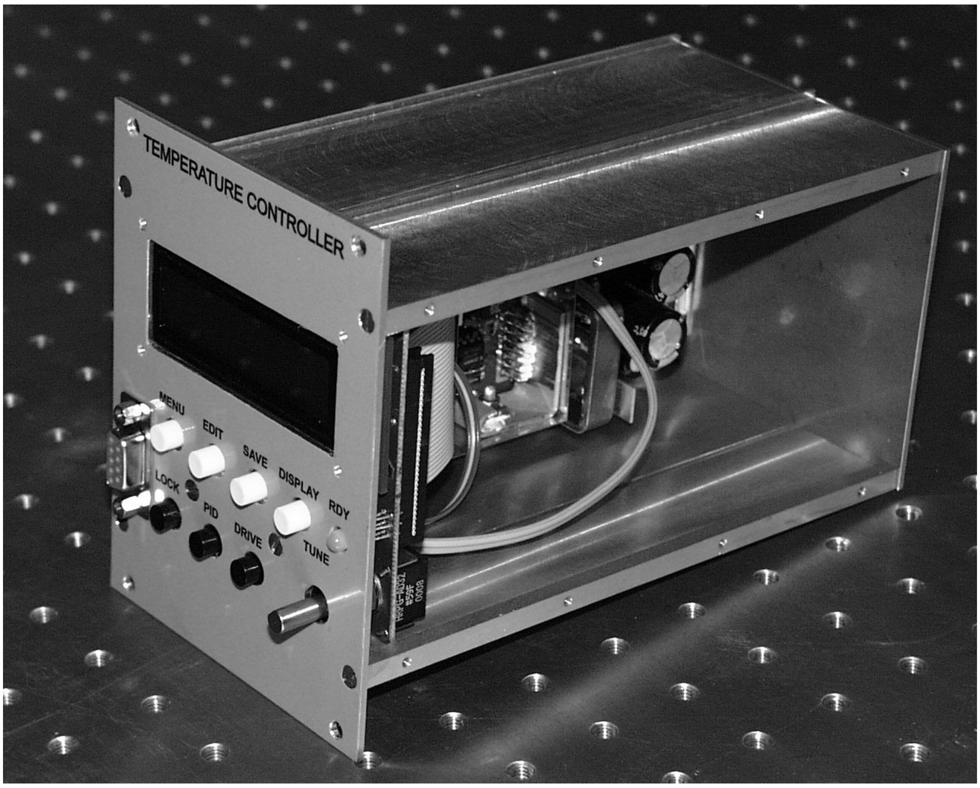

Fig. 3: *Side view of temperature controller.*

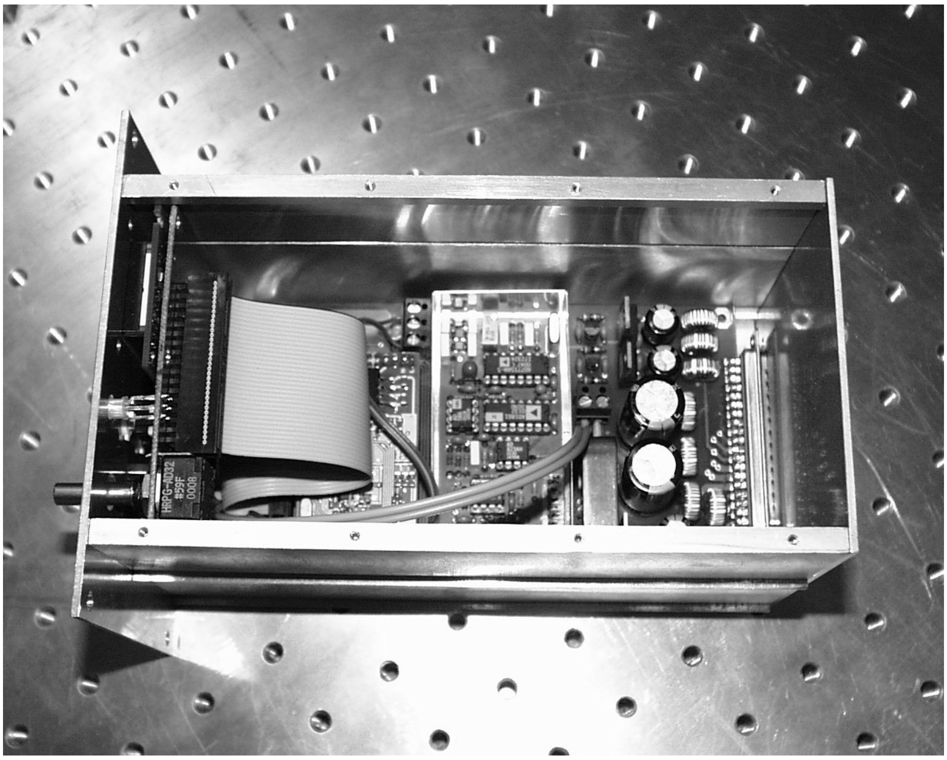

Fig. 4: *Top view of temperature controller.*

4 CONCLUSION

We presented a description of the new method of measurement of index of refraction of air with using highly temperature-stabilized semiconductor lasers. We demonstrated temperature stability of the laser diode below 1mK for two hours measurement repeatedly. The experimental setup for measurement of the index of refraction is still under development. Preliminary results will be presented.

ACKNOWLEDGEMENT

This research has been supported by Grant Agency of the Czech Republic under contracts 102/02/1318 and 102/02/P122, Grant Agency of Academy of Sciences of the Czech Republic under contract A2065202, and by the Czech Ministry of Education in the frame of Research Plan MSM 262200022 MIKROSYT Microelectronic Systems and Technologies.

REFERENCES

[1] Edlén,B.: The refractive index of air. Metrologia 1966.

[2] Číp,O.: Frequency stabilization of laser diodes and high precision laser interferometry, UPT VUT Brno, 2001

[3] Matsumoto,H., Honda,T.:High-accuracy length-measuring interferometer using the two-color method of compensating for the refractive index of air. Meas.Sci.Technol 1992.