COMPARISON OF THE METHODS FOR MEASUREMENT OF REFRACTION INDEX OF AIR WITH EVACUATABLE CELL AND WITH OPTICAL RESONATOR

Ing. Vít MATOUŠEK, Doctoral Degree Programme (3)
Dept. of Microelectronics, FEEC, BUT
E-mail: matousv@feec.vutbr.cz

Supervised by: Dr. Ondřej Číp

ABSTRACT

Laser interferometers are even more precise distance measurement devices with resolution in nanometer or sub-nanometer region. If interferometric 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. In the work, is presented design of new method with optical resonator and the obtained results are compared with other method. The new method consists of a differential setup of two F.-P interferometers equipped by a permanently evacuated cell and the other method employs an evacuatable cell inserted into the mirrors of the F.-P. interferometer.

1 INTRODUCTION

Economics with highly developed industrial states relies on manufacturing of highly advanced products. A fast progress in new microelectronic components with large-scale integration allows rapid advances in broadband high-dense optic communications, information technologies, automobile industry and the other fields of microtechnology and nanotechnology. For the microelectronics industry, laser interferometers are useful high-precise measurement devices that provide an accurate and convenient way of measuring lengths or displacements in the scale of the wavelength of the light. A Michelson interferometer controlling the displacement of 2-D micro positioning stage of lithographic systems is a typical example of this type of application. With this laser technology and servo-loop control systems, the controlled stage of the lithograph can be positioned with the reproducibility and precision to within a few nanometers in the environment of air, but fluctuations of the refraction index of air limits the achievable accuracy and reproducibility. In this case the surrounding environment in the beam path, close to the axes of measurement of position of the stage or the positioning system must be monitored with respect to the variations of the refraction index. Otherwise the fluctuations of the environment would be a source of bad reproducibility and lower production efficiency.

2 COMPARISON OF THE METHODS

The main part of the configuration for measurement of the refraction index of air is the Fabry-Perot resonator. The resonator is divided into two parts, a permanently evacuate cell and a part which is in the atmosphere. Inside the permanently evacuated part is a vacuum with pressure cca 10^{-3} Pa. For the permanently trimmed pressure inside the evacuated part was to the cell welded the special material which is called Barium Getter.

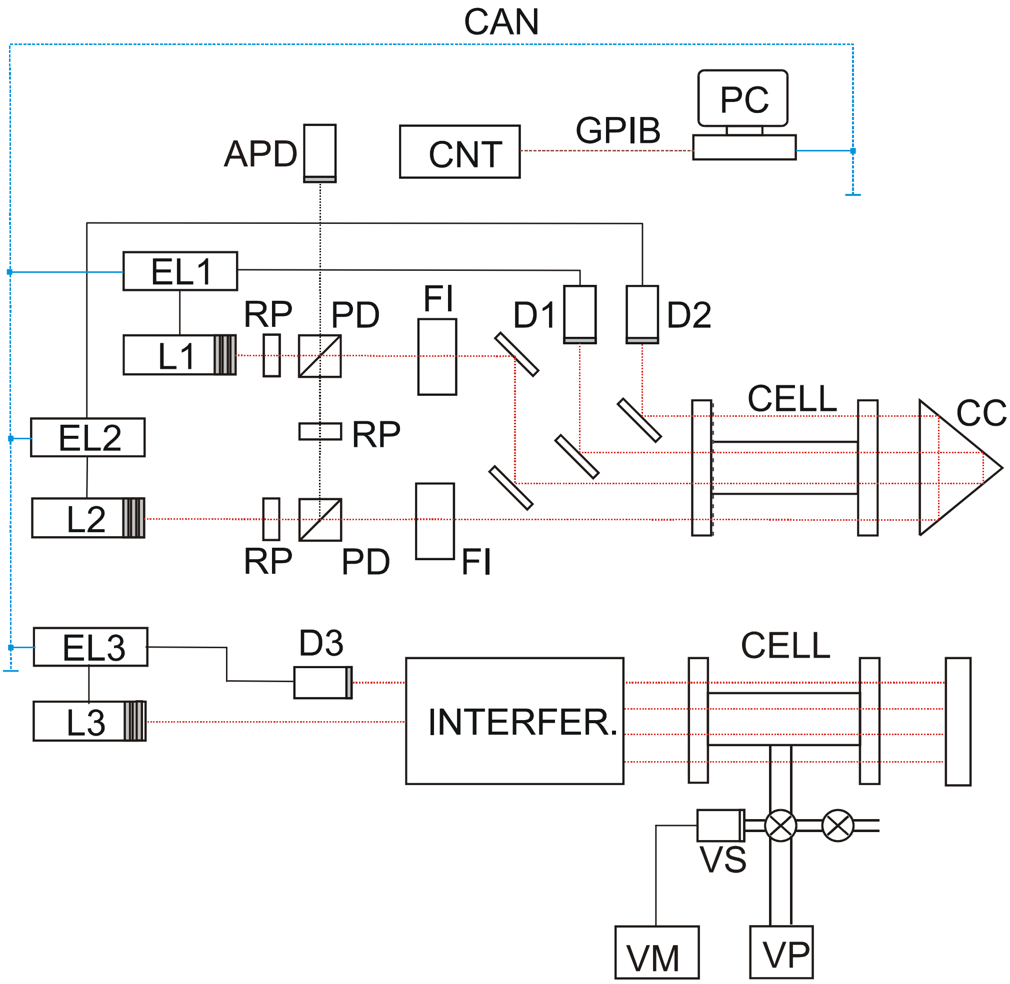

Fig. 1: *The block schema of the both methods, with evacuatable cell and with permanently evacuatable cell*

The first method uses two *He-Ne* lasers with the possibility for tuning resonation of modes. Both laser beams are in the polarization divider *PD* divided into two parts. The first part directly goes into the laser's detector with an avalanche photo diode *APD*. The second part goes through the Fabry-Perot resonator and is detected in detectors *D1* and *D2*. The suitable direction of the vector polarization of the laser beam is the half-wavelength board *RP*. The Faraday isolators *FI* are used as filters for the backward bounce of the elements of optical composition. The electronics configuration for the driving of lasers *L1* and *L2* are very important. The whole measurement is totally automatically controlled. The frequencies of the laser beams are tuned by a personal computer *PC* and digitized electronics *EL1* and *EL2*, which are connected to the *PC* through bus *CAN* (Controller Area Network). The signals from the photo detectors *D1* and *D2* are also sent to the *PC*. It works as a feedback. Signal from the photodetector *APD* (radiofrequency signal) is the difference between the signals of lasers *L1* and *L2*. Signal is sent to the counter and then via a *GPIB* bus to the *PC*. This then produces a text composed of the frequency values. These values are used to calculate the refraction index of air. For the reason of unsatisfactory retuned of He-Ne lasers more than 1 GHz is the refraction index of air calculated with atmospheric values with an accuracy of 10^{-6}. For this calculation it uses the Edlen formula [1, 2]. The Edlen formula calculated the refraction index of air with measured values of temperature, pressure and relative humidity.

For the verifications of the new method with optical resonator was constructed the other refractometer. Its accuracy is in order 10^{-8}. The purpose of construction of this method is useful for comparison with the new method. This method is working upon different principle. The method is not depending upon atmospherics sensors as temperature, pressure and humidity as the new method with optical resonator. The main disadvantages of this method lie in use of vacuum pumping equipment.

The principle of this method is the same as principle of Michelson interferometer. The laser, *L3* (*He-Ne*, 633nm) shining to the special Michelson interferometer with four passage. The interferometer is very critical on adjusted. Hence it is strongly fixt to optical table. The reflective mirror M is used for main adjust of optical path. The laser *L3* is not stabilised because it is not so critical on the result of refraction index of air. Stability of this laser has influence in order 10^{-9} and accuracy of this method is 10^{-8}. In variable branch lies the glass cell, which shows change of the length as a change of the environment. The change is detected in detector as a change of interference line. The change of the environment is drove by vacuum machine. The whole configuration of both methods is depicted in figure 1. The measurement values are compared in figure 2.

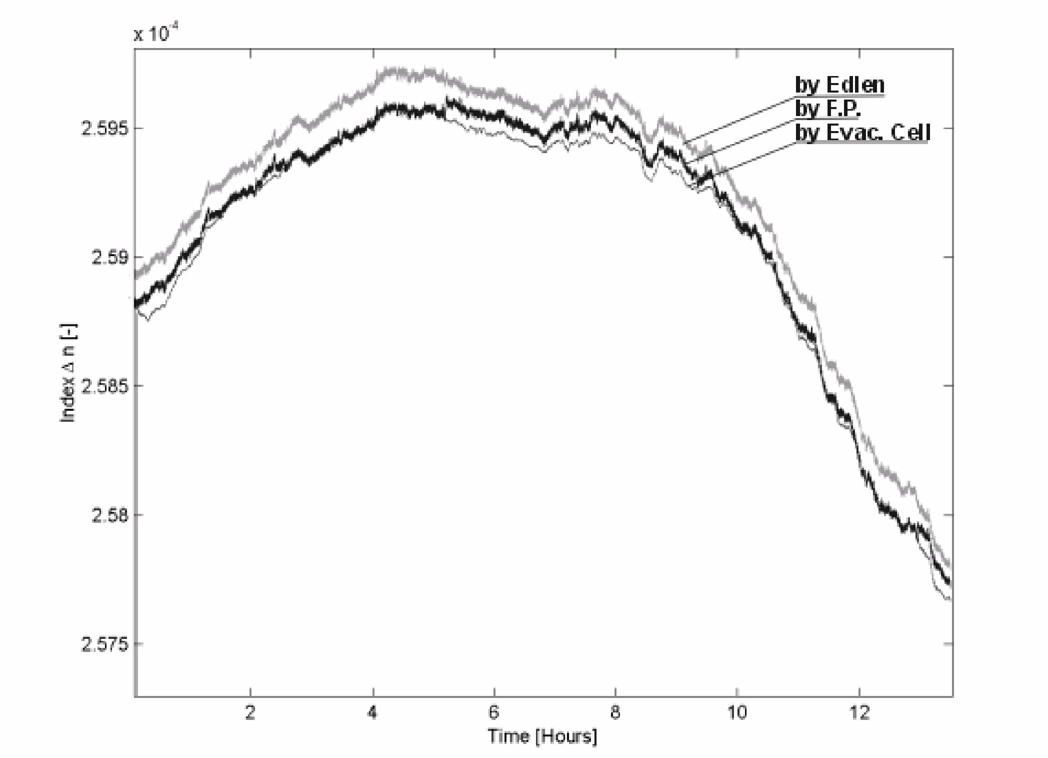

Fig. 2: *The refraction index of air measured by Edlen, Fabry-Perot and by method with evacuatable cell.*

3 CONCLUSION

The main object of the work is the experimental verification of method for measurement of the refraction index of air with a Fabry-Perot interferometer. From the long-term measurement the value of refraction index of air was obtained $n = 1.00025890$. The value of the refraction index of air is an average of the thirteen hours of experimental work.

The accuracy of the direct method of measurement of the refraction index of air is measured by using the Fabry-Perot interferometer. The distance of the mirrors has to be determined with high accuracy. In this case it is $d = 121.0149\ mm$. For the first experiment standard steel with thermal expansivity $11.5 \cdot 10^{-6}\ m/K$ was chosen. The construction of the interferometer has to be constructed with minimal thermal expansivity. Hence in the future we would like to try change standard steel per invar with thermal expasivity $2 \cdot 10^{-6}\ m/K$. We will expect better thermal expansivity of whole resonator. The material for cell inside the resonator, covar with thermal expasivity $4.6 \cdot 10^{-6}\ m/K$ was chosen. The choice of the mirrors for the interferometer is also very important. The width of the resonance line directly depends on the reflectance of the mirrors. Hence if the width of the resonance line is small the accuracy of the fraction order of the resonance (e_1, e_2) is higher. In our case we used mirrors with reflectivity of 98.5%. It corresponds to a width of resonance line of an interferometer of $4.75\ MHz$. Inside the resonator's cell Barium Getter was installed. The Barium Getter works as absorber for no noble gases. That is to save that inside the cell is permanent pressure $10^{-3}\ Pa$.

ACKNOWLEDGEMENTS

The paper has been prepared as a part of the solution of Grant Agency of the Academy of Sciences of the Czech Republic, project No. IAA206/5202 and with the support of the research plan MSM 262200022 MIKROSYT Microelectronic System and Technologies.

REFERENCES

[1] Edlén, B.: The refractive index of air. Metrologia 2, pp. 71-80, 1966

[2] Birch, K. P., Downs, M. J.: An updated Edlén equation for the refractive index of air. Metrologia 30, pp. 155-162, 1993