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Inexpensive linear scanning of the Fabry–Perot interferometer

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The solution presented here can be useful in optical measurements where scanning in the Fabry–Perot interferometer spectral range is needed. The key to the idea is the use of a pressure sensor equipped with stainless steel diaphragm giving voltage signal proportional to pressure in a chamber where the Fabry–Perot etalon is mounted. The method should find new fields of application, in a simple and cost effective way, in university laboratories as well as in other research institutions. The previous solution is updated here by introducing silicon membrane pressure sensor.

1. Introduction

The scanning of the Fabry–Perot interferometer is applied in different areas of spectroscopic research, especially in Brillouin light scattering. Brillouin scattering measures changes of photon frequencies inelastically scattered in the annihilation (anti-Stokes) or creation (Stokes) processes by acoustic phonons. Experimentally observed optical signals have a characteristic pattern, where we see strong lines from elastic scattering, the Rayleigh lines, and very weak inelastic peaks. In Brillouin experiments it is necessary to evaluate the shape of spectral lines as well as their frequencies. This can be achieved by optical path changes for optical rays trapped in an interferometer cavity. In this way an interference pattern moves with respect to a sensor positioned at a fixed point in space. In such situations we deal with the scanning of the Fabry–Perot interferometer. There are two main methods of scanning. The first one utilizes an index of refraction changes of the gas surrounding the interferometer cavity [1], and the second one applies space-distance changes between interferometer mirrors, as in the piezoelectrically controlled Sandercock setup [2] – [3]. The first solution takes advantage of the fact that the refractive index of an ideal gas, to a very good approximation, is a linear function of pressure. Here, we present pressure scanning, utilizing membrane pressure sensors, which is cost effective and easy to perform.

2. Pressure scanning

It is not difficult to show that the relationship between the refractive index of an ideal gas and pressure can be expressed as the following linear dependence between interference orders and a pressure [1], for the Fabry–Perot interferometer scanned from the arbitrary order m_1 to the order m_1+m

$$m = \frac{2d}{\lambda}\frac{n_0-1}{p_0}p \tag{1}$$

where: d is the distance between interferometer mirrors, λ is the light wavelength applied, and n_0 is the refractive index at normal pressure p_0. The periodic interference pattern characteristic for the Fabry–Perot interferometer, seen as a set of concentric rings, can be described mathematically by the transmission function [4], [5]. Neglecting the factor responsible for losses in mirrors, the function can be expressed as a function of pressure

$$t(p) = \frac{1}{1+\frac{4R}{(1-R)^2}\sin^2\left(\frac{2d}{\lambda}\frac{n_0-1}{p_0}p\pi+\varphi\right)} \tag{2}$$

where R is the reflection coefficient of the interferometer mirrors, and φ stands for the resultant phase difference between recombining wave fronts of an optical signal passing through the interferometer, in a vacuum, when pressure is equal to zero.

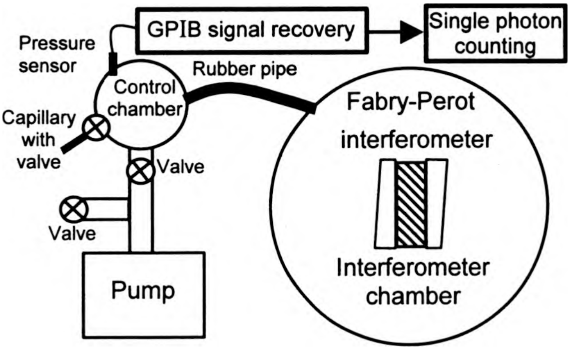

Fig. 1. Schematic of the pressure scanned Fabry–Perot interferometer.

The laboratory tested pressure scanning system consisted of two pressure chambers. In the first one an interferometer was placed. In the second chamber the valves, pressure sensor, and adjustable capillary were mounted. The setup is schematically shown in Fig. 1. The chambers were connected by 1.5 m long rubber pipe of a relatively large diameter of 2 cm. Such connections do not cause impedance effects during gas flow. The capacities of the control and etalon chambers were

$1.23 \cdot 10^{-2}$ m^{-3}, and $7.06 \cdot 10^{-2}$ m^{-3}, respectively. The equipment used in measurements included also a single-mode argon ion laser, and a unit, produced by the Photon Inc., for the low-level intensity light detection by the photon counting method. The signals from the photomultiplier along with pressure were detected at one second intervals. The typical duration of measurement was one or more hours depending on adjustable capillary diameter. As a sensor the EPO W11 7B industrial pressure sensor, Entran Inc., was applied. The stainless steel membrane exposed directly to measured air pressure warranted long time of experimental work, which cannot be said about previously used silicon-membrane sensors. The life time of silicone sensors was equal to about 100 measurement cycles.

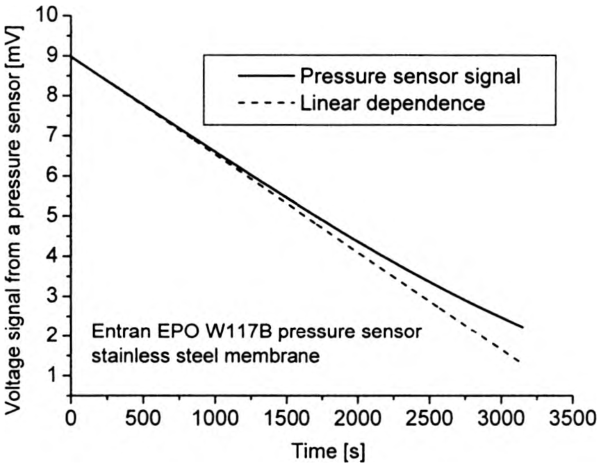

Fig. 2. Signal from pressure sensor as a function of time. Dashed straight line was added for convenience. The amount of non-linearity depends on capillary diameter applied.

It is easy to measure the output voltage from pressure sensors automatically by the GPIB standard electronics. The accuracy of the output signal was equal to 1%, which included the non-linearity between output voltage from the sensor and the pressure transformed to this voltage signal, and temperature drift of the signal. Temperature compensation of the output signal, in the range of 0–55 °C, is guaranteed by the manufacturer. Figure 2 shows the voltage signal from a pressure sensor as a function of time. Examples of Brillouin spectrum as a function of time and pressure are shown in Fig. 3. The time interval for one measurement equal to 1 s generates a frequency error equal to about 0.04 GHz, in the full spectral range (FSR) equal to 37.50 GHz scanned during 20 min. Etalons for experiments were manufactured many years ago from invar or quartz with 10^{-6} m accuracy, which is a source of the small error of 0.01 GHz. The last reason for an experimental uncertainty is non-uniform scan rate, however the rate changes slowly during measurements. For example, in Brillouin spectrum with the two 37.5 GHz full spectral ranges observed, the shape of Brillouin peak has been evaluated

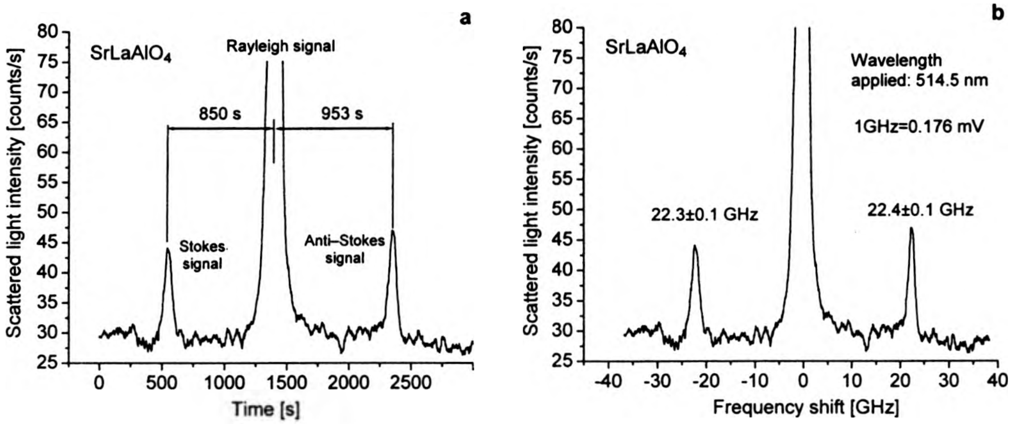

Fig. 3. Brillouin spectrum in the $SrLaAlO_4$ crystal as a function of time (**a**) where peaks are not equally spaced, and as a function of the voltage signal from sensor (**b**). The full spectral range of the interferometer is equal to 37.50 GHz.

from about 180 data points in the first FSR, and from 200 points in the second FSR. This gives a very good accuracy, which can be additionally improved by increasing the time of measurements depending on a diameter of capillary applied.

3. Summary

Provided results showed applicability of cost-effective solution for the Fabry –Perot interferometer scanning – the interferometer being of the highest available resolution power. It is hoped that the solution proposed by the author, as being competetive to more expensive installations, find significant position among other Brillouin spectrometers.

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