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Abstract. The paper describes an optical interferometer realized at INRiM, which works as pressure standard based on a well-known phenomenon of light-matter interaction: the dependence of refractive index with pressure (density) of a gas. The realization of a pressure standard via optical method requires a combined approach of high accurate refractive index measurements (sub-nanometer and sub-millikelvin metrology) with ab-initio quantum calculation of molar refractivity, paving the way for a quantum-based standard.
The paper reports recent development concerning a new layout of the system, currently focused to improve the temperature measurement and stability.
The developed system is a preliminary achievement towards a quantum-based pressure standard in the range between 100 Pa and 150 kPa.

1. Introduction

The pressure and vacuum standard developed in the last decades are based on different methods depending on the working pressure range. For pressure below 10^2 Pa, the primary standard are realized by means of systems based on static or dynamic expansion of a pure gas [1-3]. Above 100 Pa standard pressure is generally obtained by different types of pressure balances [4-6] or mercury manometers [7]: these last have the advantage to cover the pressure interval between 100 Pa and 120 kPa, but, in perspective, are not in line with recent Word Health Organization resolutions recommending the progressive reduction of human exposure to mercury.
The present paper regards a recent optical realization of a pressure standard which works in the pressure interval between 100 Pa and 150 kPa. The optical device is a homodyne Michelson interferometer having one arm folded by a multi reflection mirror assembly so to realize an unbalance between the arms of the interferometer of about 1.5 m in a compact set-up.

2. Description of the system and method of measurement

The measurement system is based on the determination of the refractive index of a gas exploiting an optical layout which is alternative to the recent realizations which use Fabry-Pérot cavities [8,9].
Figure 1 shows the schematic of the main part of the apparatus [10,11]. The phase change measured by the interferometer in the transition between vacuum and a pressure p at a given temperature, is proportional to the unbalance between the arms of the interferometer and to the refractive index of the gas.
The light source is a frequency stabilized He-Ne laser (wavelength $\lambda \approx 633$ nm), coupled to a polarization maintaining fiber ending with a collimator to launch the radiation in the interferometer.
The measurement arm of the interferometer is formed by a couple of two quasi-parallel mirrors A and B among which the laser beam is reflected several times (measurement beam), while in the reference arm the laser beam carries out one reflection on the mirror M_R (reference beam).

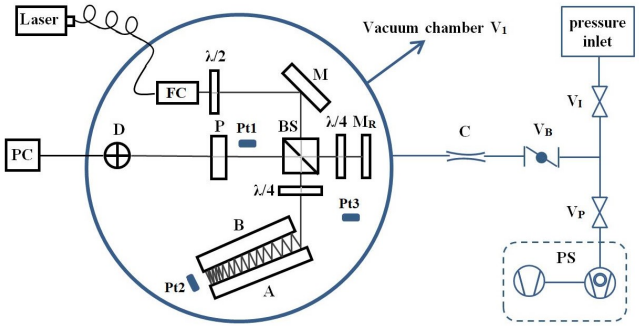

Figure 1. Schematic of the system. The unbalanced homodyne interferometer is placed inside the pressure/ vacuum chamber V_1 ; C: exchangeable conductance; FC: fiber coupler; BS: beam splitter; P: polarizer; M: mirror; M_R: reference mirror; A, B:double mirror multiplication set-up; D: double quadrant detector; Pt: temperature sensors (PT100); V_B: butterfly valve; V_P: pump valve; V_I: inlet system valve; PS: vacuum pumps

The interference between reference and measurement beams occurs by the beam splitter BS. The interference signal, after a passage through a polarizer P, is detected by the a double quadrant detector D to obtain two quadrature signal, which are eventually amplified and sent to the acquisition system PC, controlled by a software, which manages the acquisition and the analysis of data.
The interferometer is designed to be as stable as possible in temperature: the quasi-parallel mirrors A and B are made of Ultra Low Expansion ceramic glass (Clearceram®) and bonded to a Clearceram® circular plate by "hydroxide bonding" technique, practically behaving as a single glass block.
The mirrors were bonded at an angle of about 0.4° and have nominal dimensions: width = 70 mm, height = 20 mm and thickness = 10 mm. The circular plate have nominal diameter of 160 mm and height equal to 20 mm. A detailed description of double mirror beam multiplication set-up is reported in [**11**]. The figures 2 shows two pictures of the mirrors A and B.

Figure 2. Left: top view of A and B quasi-parallel mirrors; Right: laser reflections on mirrors, seen from the back side of mirror A

The initial reference condition of the system occurs at an ultimate pressure p_0 of the order of 0.1 Pa, with refraction index $n_{vac} \approx 1$. Afterwards, the gas pressure inside chamber V_1 is changed by means of gas inlet system to reach the desired nominal value p_i and after waiting a time sufficient for temperature stabilization, the refractive index n_i associated to standard pressure p_i can be calculated by:

$$n_i = n_{vac} + \frac{\varphi_i \frac{\lambda}{2}}{L} \approx 1 + \frac{\varphi_i \frac{\lambda}{2}}{L} \qquad (1)$$

where φ_i is the number of interference fringes occurred between the initial reference pressure p_0 and p_i, λ is the laser wavelength and L is the unbalance of the interferometer under vacuum, i.e. the optical path difference between reference and measurement arm of the interferometer, which was previously measured with a dedicated experiment, carried out by an independent method based on the synthetic wavelength technique in conjunction with super-heterodyne detection [12]. The current value of the unbalance length is $L = (1.4717 \pm 0.0002)$ m.

The standard pressure can be subsequently calculated, through the Lorentz-Lorenz [13, 14] equation in conjunction with equation of state for real gas, neglecting the terms higher than the second order:

$$p_i = \frac{n_i^2 - 1}{n_i^2 + 2}\frac{1}{A}RT_i\left(1 + B_i\frac{n_i^2 - 1}{n_i^2 + 2}\frac{1}{A}\right) \quad (2)$$

in which A is the molar refractivity [15], R is the universal gas constant, B_i the second order density virial coefficient [16] at temperature T_i, which is the temperature inside V_1 at pressure point p_i. T_i is measured by a set of traceable temperature sensors, as showed in figure 1.
A preliminary metrological characterization of the optical pressure standard is reported in [12].
Recently we started to revise the whole experimental set-up to improve the metrological performance of the standard: in particular we are currently working to improve the accuracy of temperature control and measurement. A new chamber V_1 was designed and realized to introduce an active temperature control to decrease the thermal gradient and stabilize the temperature inside V_1.

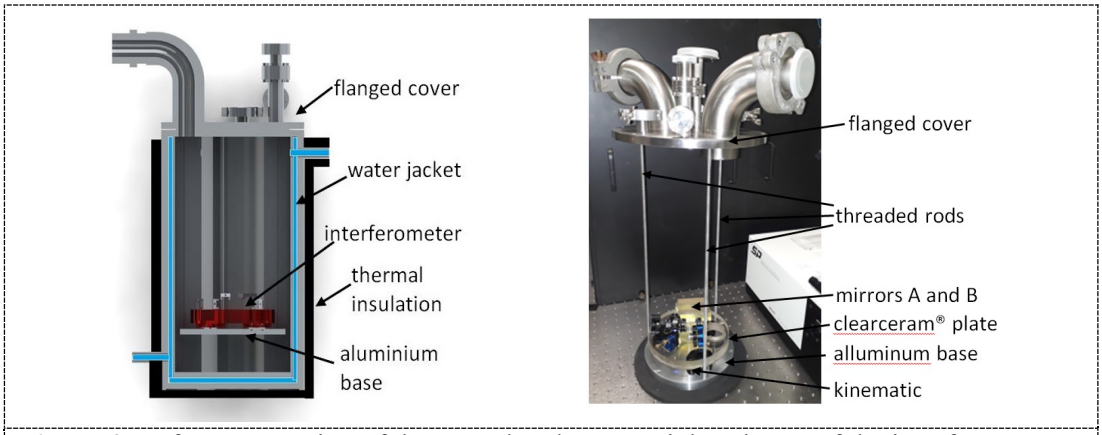

Figure 3. Left: cross section of the new chamber V_1; Right: picture of the interferometer on its support ready to be inserted in the chamber

The figure 3 on the left, shows a cross section of the new cylindrical stainless steel chamber (height 500 mm, internal diameter 200 mm), with double walls on its base and lateral surface to allow a forced circulation of water inside the interspace between the walls. The temperature of the water is controlled and maintained constant by means of an external water bath. The interferometer is placed on an aluminum plate of 180 mm nominal diameter equipped with three kinematic supports as evidenced in the picture shown in figure 3 on the right. The aluminum plate is fixed on the internal side of an ISO DN 200 closing flange by means of three threaded rods screwed onto the flange, equipped with eight vacuum ports.

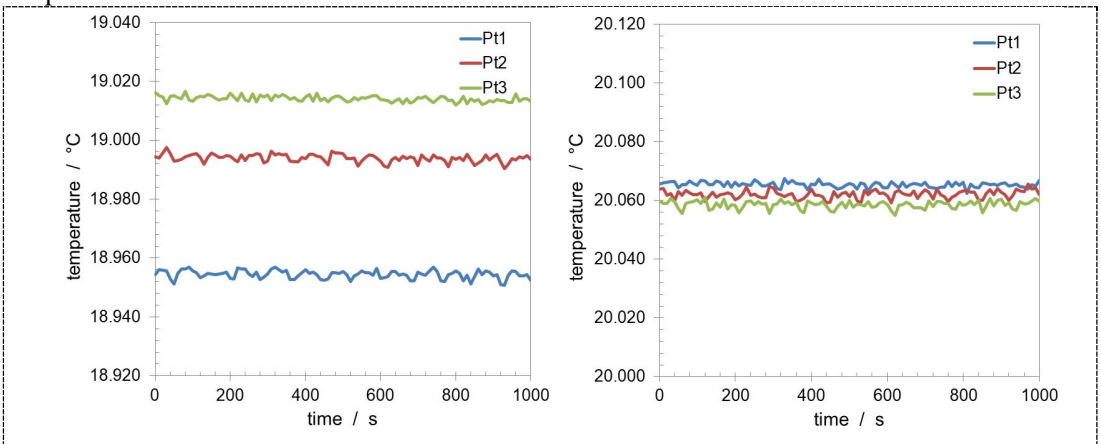

Figure 4. PT100 temperature measurements. Left: without active thermal; right: with active thermal control

The figure 4 shows recent preliminary results obtained with the novel set-up, comparing the temperature measurement carried out with or without active thermal control: the thermal gradients resulted considerable reduced with a maximum temperature difference in V_1 of about 7 mK; to further improve the temperature control of the gas, the chamber V_1 will be equipped with a copper radiation shield to uniform the temperature distribution, minimizing the thermal gradients [17].
The next months will be devoted to test the new set-up of the optical pressure standard comparing it with traditional standards.
Future development will be primary focused to introduce a more complex technique for the absolute length measurement of *L* and to improve the temperature distribution inside the chamber V_1.

3. Conclusions

A new pressure standard via optical method has been realized at INRiM. The standard is based on the measurement of the refractive index of a gas by means of a multi-reflection homodyne interferometer and is able to work between 100 Pa and 150 kPa. The experimental set-up has been recently changed to improve the accuracy of the standard. A new vacuum chamber, equipped with an active temperature control, has been designed and realized. Preliminary recent results has shown a notable improvement of the temperature gas distribution inside the chamber in which is placed the interferometer, with a maximum thermal gradient of 7 mK. In the next months the new set-up will be tested comparing the results achieved with optical method with traditional pressure standards.
Future main development will aim to adopt a more accurate technique for the absolute length measurement of the unbalance of the interferometer and to further improve the temperature stability inserting a copper radiation shield between the water jacket of the vacuum chamber and the interferometer.

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