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Refractive index measurement of compressed nitrogen using an infrared frequency-domain interferometer

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ABSTRACT

Frequency-domain interferometry is used to obtain the refractive index of compressed nitrogen in the vicinity of 1550 nm as the pressure of nitrogen increases from 0 to 40 MPa at room temperature. By referring to the equation of state of nitrogen, the relation between the refractive index and the nitrogen density is obtained and the electric polarizability of a nitrogen molecule is thereby determined to be $(1.82 \pm 0.15) \times 10^{-30}\ m^{-3}$ according to the Lorentz-Lorentz relation.

1. Introduction

Refractive index of nitrogen is an important parameter for astrophysicists to infer the distance and speed of stones falling onto the earth from outer space. For such a falling stone in the atmosphere, a pressure gradient exists in the front, which is associated with a gradient of refractive index. In order to predict accurately when and where the stone will hit the earth, the relation between the refractive index of nitrogen and its density needs to be determined for the working wavelength of interferometer.

Doppler Pin System (DPS) is one of the most popular velocity interferometer systems and is widely used in the velocity diagnostics of dynamic processes [1–7]. The working wavelength is 1550 nm, which is in the infrared range.

In the visible range, refractive index of nitrogen has been determined by interferometric measurements [8–11]. However, in the infrared range, especially in the vicinity of 1550 nm, the data are absent.

Frequency-domain interferometer has found a growing number of applications in displacement or deformation measurements [12–21]. If the distance between two reflecting interfaces along the optical path are known, frequency-domain interferometer can be inversely applied to determine the refractive index of the material between the two reflecting interfaces.

In this work, the refractive index of nitrogen in the vicinity of 1550 nm is obtained using a frequency-domain interferometer when the pressure of nitrogen increases from 0 to 40 MPa at room temperature. The refractive index measurement are detailed in the experimental section. In the results and discussion section, the relation between the refractive index of nitrogen and its pressure (density) will be given and the mean polarizability of nitrogen molecule in the vicinity of 1550 nm will be determined.

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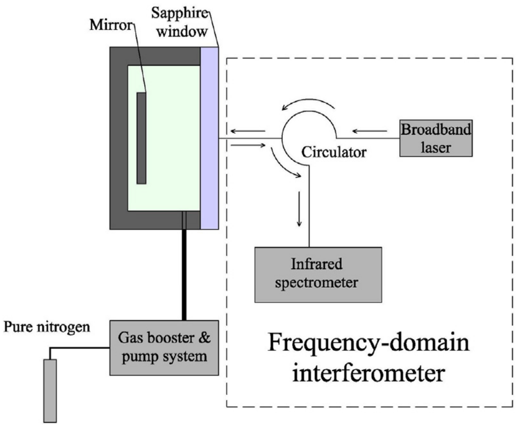

Fig. 1. A schematic diagram of the experimental setup for the measurement of the refractive index of nitrogen.

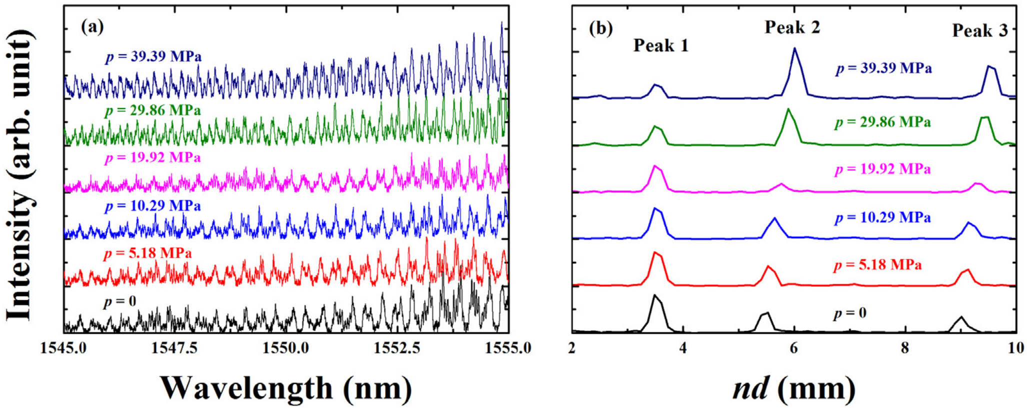

Fig. 2. (a) The interference in the frequency-domain shown from 1545 nm to 1555 nm. (b) The three most notable peaks obtained from a transformation of (a). The horizontal axis of (b) is a product of refractive index and distance.

2. Experimental

A schematic diagram of the experimental setup is shown in Fig. 1. The setup includes a gas source of nitrogen (purity > 99.999%), a gas booster and pump system, a gas cell which is enclosed by a stainless steel container and a sapphire window, and a frequency-domain interferometer which is composed of a broadband infrared laser, a circulator and an infrared spectrometer. The components of the interferometer are connected by optical fibers.

The frequency-domain interferometer uses a broadband infrared laser to provide a coherent light beam. The beam goes through the circulator in the anti-clockwise direction, and arrives at the front surface of the sapphire window, which serves as the first reflector. The second reflector is the back surface of the sapphire window, and the third one is the front surface of the mirror inside the gas cell. The distance between the front surface of the mirror and the back surface of the sapphire window is maintained by a drilled ring spacer which is not shown in Fig. 1. The reflected light beams from the three reflectors will re-enter the circulator and will finally get into the infrared spectrometer. The fringe pattern in the frequency domain will be recorded by the CCD of the spectrometer. Since we are only interested in the spectral range around 1550 nm, the spectra from 1545 nm to 1555 nm were recorded when we increased the nitrogen pressure in the gas cell from 0 to 40 MPa. The gas pressure was given by a calibrated pressure gauge with an uncertainty of 0.5%, the ambient temperature was provided by a calibrated temperature gauge with an uncertainty of 0.5 K.

3. Results and discussion

Fig. 2(a) shows the interference recorded by the frequency-domain interferometer from 1545 nm to 1555 nm. A constant offset is applied for each spectrum to show the periodic structure along the wavelength direction. The periodicity originates