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High presicion measurement of elalon optical length using optical comb pulsed interference

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Abstract
An etalon is broadly used as temperature sensors, pressure sensors, and frequency filters. We developed all-fiber etalon and absolute long distance measurement method using etalon. However, it is confirmed that etalon optical length is a key component of the distance measurement method. In this report, we propose a new method of etalon optical length measurement using optical comb pulsed interference. In this method, comparison between interference fringes of pulsed interference and etalon reduces the uncertainty of the measurement. Results of experiments showed that 50 mm optical length was measured with several nano-meter repeatability with simple optical system. Furthermore, temperature effect on etalon optical length was observed. It was indicated that this method can be applied to optical fiber temperature sensor.

Keywords: optical comb, etalon, absolute measurement

1. Introduction

Etalon (Fabry Perot interferometer) is composed of two reflecting surfaces, which works as a frequency filter. Transmission spectrum of etalon is comb-like, wherein longitudinal modes are oscillated whose interval is equal to the free spectrum range (FSR) and it can be used as frequency (length) standard. Absolute optical length of the etalon is important factor when etalon is used as standard. On the other hand, absolute distance measurement based on the etalon optucal length is proposed in the prior research [1]. Absolute measurement of etalon optical length is also important in the research.

The purpose of this research is the absolute measurement of etalon optical length with relative uncertainty of 10^{-7} to use etalon as standard in the distance measurement in the atmosphere.

2. Principal of proposed method

Fig.1 shows the interferometer using etalon multiplied reflection. Etalon is introduced to the Michelson interferometer with low coherence light source. In this system, interference fringes appear at intervals of etalon optical length (sevearal ten mm in this research) in the Mirror2 direction so that absolute distance measurement is realized with using interference fringes as standard. The problem is a method to measure etalon optical length.

We propose a high precison measurement method of etalon optical length using optical comb pusled interferometry. When optical comb is introduced in the optical system like **Fig.1**, interference fringes appear at the equal interval of etalon optical length of etalon optical length (l_{e}) and half pulse length of optical comb ($l_{\mathrm{c}}/2$) as shown in **Eq.1,**

$$\mathrm{OPD} = i_{\mathrm{e}} l_{\mathrm{e}} + \frac{i_{\mathrm{c}} l_{\mathrm{c}}}{2} \qquad Eq.(1)$$

where OPD is optical path difference between two arms, i_{e} and i_{c} are integers. With adjusting $l_{\mathrm{c}}/2$ to approximately integer multiple of l_{e}, each fringe is obserbed simultaneously. **Fig.2** shows position where optical fringes are observed. Fringes from etalon and comb (side fringes) are observed around fringes from etalon. Peak distance between side fringes (Δl_{e}) is expressed as **Eq.2**,

$$\Delta l_{\mathrm{e}} = l_{\mathrm{c}} - 2 i_0 l_{\mathrm{e}} \qquad Eq.(2)$$

$$\therefore l_{\mathrm{e}} = \frac{l_{\mathrm{c}}}{2 i_0} - \frac{\Delta l_{\mathrm{e}}}{2 i_0} \qquad Eq.(3)$$

where i_0 is

$$i_0 = \mathrm{Int}\left(\frac{l_{\mathrm{c}}}{2 l_{\mathrm{e}}}\right) \qquad Eq.(4)$$

Therefore, etalon optical lenth l_{e} can be determined by measuring Δl_{e} according to **Eq.4**. Because l_{c} is known from repetition frequency of optical comb which is highly stable (relative uncertainty is <10^{-9}), the major uncertainty source is the second term. However, Δl_{e} is divided by i_0 and the uncertainty is reduced.

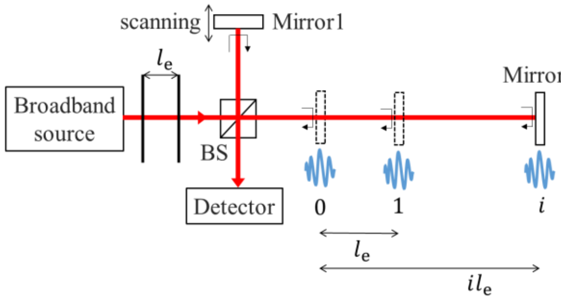

Fig.1 Michelson interferometer with ealon and broad-band source

Since Δl_e can be measured with several hundred nanometer uncertainty, l_e can be measured with several nanometer uncertainty if i_0 is over 50. This method provides high preciso etalon optical length measurement with simpler optical system than frequency domain method [2].

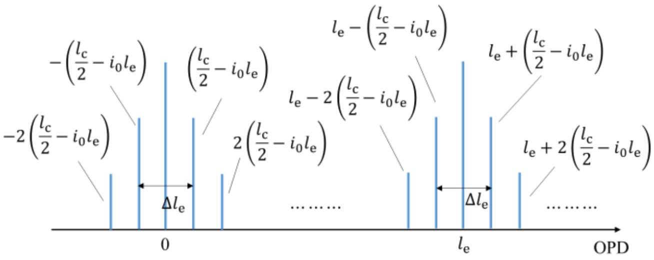

Fig.2 Inteference fringes with using etalon and optical comb

3. Experiments

The experimental setups shown in **Fig.3** was arranged to realize the measurement method in section 2. Etalon filtered comb laser went through single mode fiber and was introduced to scanning arm and reference arm. With adjusting $l_c/2$ to approximately integer multiple of l_e, etalon and optical comb fringes were observed simultaneously. Peak distance between these fringes was measured by displacement sensor (DS) and etalon optical length was calculated following **Eq.2**. All-fibered etalon shown in **Fig.4** was used in this experiment, whose end surfaces of fiber were coated with dielectric multilayer working as a reflection surface. It was cheaper than a free-space etalon and easy to introduce to optical system. Etalon reflectance was 99% in this experiment. Parameters of the experiment was set as $l_c/2 \cong 2.566\,\mathrm{m}, l_e \cong 50.28\,\mathrm{mm}$ so that $i_0 = 51$. The experiment was conducted in temperature un-controlled room for 300 seconds and temperature rise of etalon was approximatedly 0.1 K.

The result of the experiment was shown in **Fig.5**. Short-span standard deviation of measurement was several nanometers, which agreed with the expectation. Drift was observed in the result and it was considered to be from temperature change of etalon since it corresponded to temperature change. Thermal expansion coefficient of etalon optical length was estimated to be approximately 18.3×10^{-6} [/K] from the experimental result. Since sum of thermal expansion rate and thermos-optic coefficient of the fiber was approximately 6.0×10^{-6} [/K], it was larger than the expectation. It was estimated to be because of thermal expansion rate of etalon box contributing to the result.

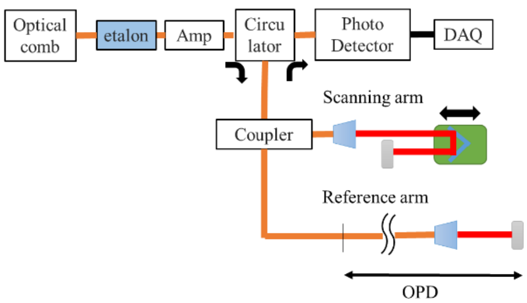

Fig.3 Experimental setups of the proposed method

4. Conclusions

In this research, we proposed the method to measure the etalon optical length with using optical comb pulsed interferometry. In the preliminary experiment, 50 mm ealon was measured with several nm accuracy so that it can be used for the ranging in the atmosphere. In addition, higher ratio of pulse interval of optical comb to etalon optical length leads to higher accuracy and sub-nm measurement. There is trade-off between the ratio and the intensity of interference fringe. It is needed to optimize it through simulations and experiments and it is our future works. Also, we will evaluate the reaction to the environment, for example temperature, pressure, etc., and consider application to sensors.

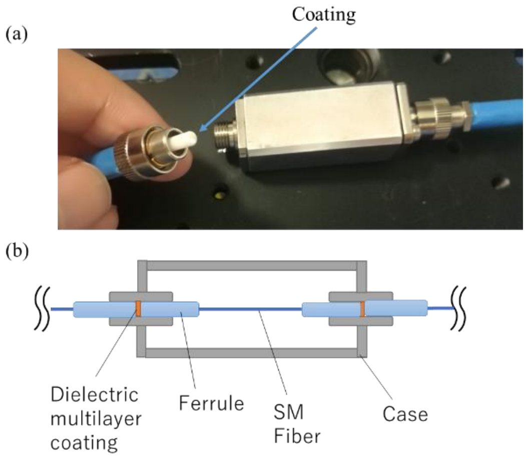

Fig.4 Fiber etalon used in the experiment

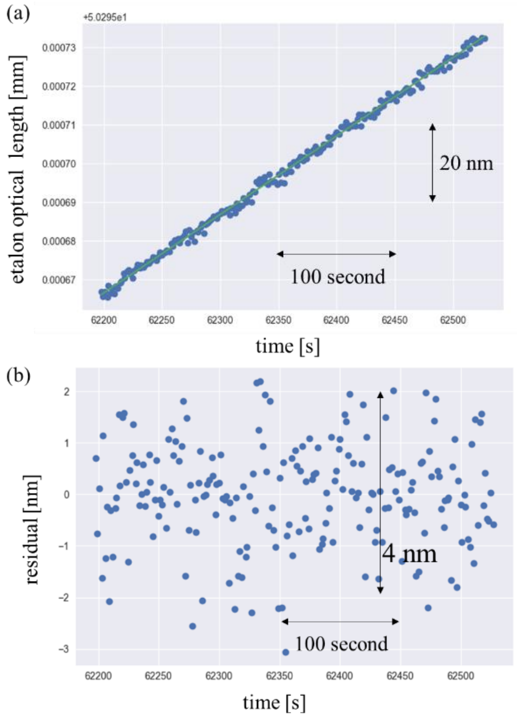

Fig.5 Experimenatal results (a) raw data (b) residual of liner fitting

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