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A high precision step height measurement system of optical fiber multiplexed interferometry

Sen Ma, Fang Xie [*], Yunzhi Wang, Liang Chen

Optical Science and Technology Laboratory, Department of Physics, School of Science, Beijing Jiaotong University, Beijing 100044, PR China

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ABSTRACT

This paper focuses on obtaining high precision of a stabilized and interleaving high coherence and low coherence interferometric optical fiber system which is capable of the measurement of step height with a symmetric peak-searching method. The interferometer performing the measurement works in both modes of low coherence interferometry and high coherence interferometry simultaneously. The range of the step height is determined by the low coherence interferometric signal while the resolution of the measurement is decided by the high coherence interferometric signal which is also used to compensate for the influences induced by the environmental disturbances through a feedback loop. High addressing precision of the peak of the low coherence interferogram, which influences the measurement precision violently, has been obtained by searching symmetrically the peak from two sides of the low coherence interferogram. The maximum step height that can be measured is 6 mm, while the measurement resolution is less than 1 nm. The standard deviation of 10 times of the measurement results of a gauge block with the height of 1 mm is 0.5 nm.

1. Introduction

With the development of microelectronics, micro-electric-mechanical system, flat panel displays, and photovoltaic cells, etc., surfaces patterned with step heights ranging from several micrometers to larger than 1 mm appear frequently. These kinds of surfaces need to be measured precisely for the purpose of products quality control. Optical interferometric profilers which is illuminated with a monochromatic light source is not capable for the measurement of step heights larger than half a wavelength because of 2π phase ambiguity [1,2]. Two-wavelength interferometric technologies [3–5] and multi-wavelength interferometric technologies [6–10] could extend the measurement range which is much larger than half a wavelength, but it is needed each wavelength working individually in sequence in the system and several steps are needed to perform the measurement. Optical low coherence interferometric measurement systems which is illuminated with a broadband light source have the advantage that the measurement range is not limited by the wavelength [11,12], and thus have the promise of being capable of measuring step heights larger than half a wavelength. Addressing the peak of the low coherence interferogram accurately is very important for the measurement precision. But the top area of the low coherence interferogram is flatten and thus it is very difficult to address precisely the position of the peak. Rao et al. [12] used two light sources with two different wavelengths to make the peak prominent, which needs two light sources working simultaneously in the system and makes the system expensive and complicated.

We develop a high precision stabilized optical fiber system interleaving high coherence interferometry and low coherence interferometry which searches the peak

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[*] Corresponding author. Tel.: +86 10 51688333; fax: +86 10 51840433.
E-mail address: fxie@bjtu.edu.cn (F. Xie).

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symmetrically from two sides of the low coherence interferogram and is capable for the measurement of step height precisely. The optical fiber interferometer performing the measurement and being stabilized by a feedback loop works in both modes of low coherence interferometry and high coherence interferometry simultaneously. The range of the measured step height that is no longer limited by the wavelength is determined by the low coherence interferometry, while the resolution of the measurement is decided by the high coherence interferometry. High precision of addressing the peak of the low coherence interferogram has been obtained by searching the peak symmetrically from two sides of the low coherence interferogram. The maximum step height that can be measured is 6 mm while the measurement resolution is less than 1 nm. The standard deviation of 10 times of the measurement results of a gauge block with the height of 1 mm is 0.5 nm.

2. The principle of the optical fiber interferometric measurement system

The principle of the optical fiber interferometric measurement system is shown in Fig. 1. By employing a broadband light source and a fiber Bragg grating (FBG) as an in-fiber reflective mirror, an optical fiber Michelson interferometer which performs the measurement task and is stabilized with an electronic feedback loop to erase the influences that are resulted from the environmental disturbances, is working in both modes of low coherence interferometry and high coherence interferometry. In order to reduce the influences resulted from the environmental disturbances, the length of the fiber in the two interfering arms of the optical fiber Michelson interferometer is made to be as short as about 11 mm, just as shown in Fig. 2.

2.1. The optical fiber interferometer measurement system

A broadband light source of amplified spontaneous emission (ASE) with flatten spectrum of C-band is used in the system. The ASE gives an output power about 200 mW with 35.8 nm spectral bandwidth. The spectrum of the light source which has flatten profile is shown in Fig. 3. The FBG used in the system has the Bragg wavelength at 1557.00 nm with 3 dB bandwidth 0.2 nm. Light emitted from the ASE passes through the isolator and the 3 dB-coupler and is split into two beams and then are collimated respectively by two grin lenses and are reflected back by the measured surface and the reference mirror, respectively. The two reflected beams are combined again at the 3 dB-coupler. The combined light from one port of the 3 dB-coupler cannot reach the light source because of the isolator. The combined light from the other port of the 3 dB-coupler goes through the circulator and reaches the FBG. The light with wavelength 1557.00 nm is reflected by the FBG while the light with the left wavelengths transmits through the FBG and is detected by PD1. As the spectrum bandwidth of the light detected by PD1 is 35.8 nm, the optical fiber interferometer is working in the mode of low coherence interferometry for this signal which can be expressed as Eq. (1)

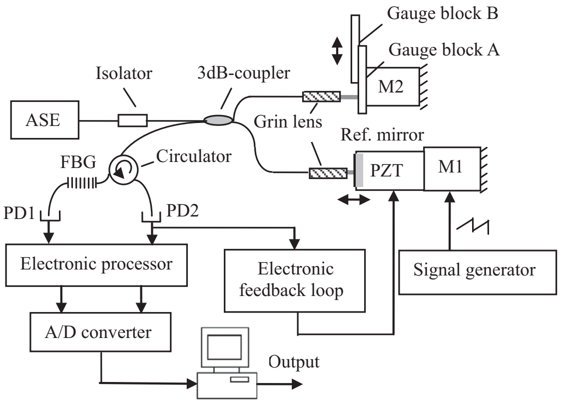

Fig. 1. The scheme of the principle of the measurement system.

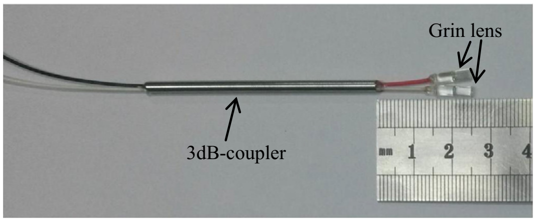

Fig. 2. The optical fiber Michelson interferometer with short interfering arms.

$$I = I_0\left\{1 + \frac{1}{2}\exp[-(2\Delta x/L_c)^2]\cos(k\Delta x)\right\} \tag{1}$$

where I_0 is the total optical power arriving at the detector, L_c is the coherence length of the light source, Δx is the optical path difference of the interferometer, k is the wave number of the light. And the low coherence interferometric signal will be the maximum when the optical path difference of the interferometer is zero.

The light reflected by the FBG is a high coherence interferometric signal which is guided by the circulator again and is detected by PD2. The optical fiber interferometer is working in the mode of high coherence interferometry for this signal which is used for both performing the measurement and stabilizing the interferometer with a feedback loop.

With the variation of the step height that is measured, the high coherence interferometric signal detected by PD2 will vary periodically and the position of the peak of the low coherence interferogram detected by PD1 will shift proportionally. During the measurement, the low coherence interferometry is used to determine the range of the step height while the high coherence interferometry is used to measure the value of the step height precisely. The value of the step height is proportional to the amount of the interferometric fringes that is detected by PD2 during the shifting range of the peak of the signal detected by PD1. And so, the measured step height can be calculated by the relationship shown in Eq. (2).