



Development of a 3-Axis Displacement Measuring Heterodyne Interferometer System Usable with a He-Ne Laser of Either 3.76 MHz or 20 MHz Split Frequency

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Abstract. We present a 3-axis displacement measuring heterodyne interferometer system developed for use with a He-Ne laser at the wavelength of 633 nm having a split frequency of either 3.76 MHz or 20 MHz. The system consists of an optical interferometer, a signal processing board, and a software.

The interferometer can simultaneously measure the displacements of three axes, from which the distance, tilt angles of a moving object can be determined in real time. A digital logic circuit which calculates the displacement values from electric signals converted from 3 optical interference signals, was developed. To demonstrate the measured results graphically, we developed a graphical-user-interface software. In addition, a feedback function through a high speed communication bus was added to the system so that it can be applied for motion control of a moving stage requiring scanning and alignment of a thin film coated substrate such as a silicon wafer. The performance of the interferometer was checked by comparing the measurement values of the displacement of a moving stage obtained simultaneously by a commercial laser interferometer and the developed interferometer.

Keywords: Laser interferometer · 3-axis · Split frequency · Optical signal processing

1 Introduction

Laser interferometers are widely used in various equipment for measuring displacement in nanometer precision. In particular, laser interferometer system is an essential part of lithographic equipment or metrology and inspection equipment used in semiconductor manufacturing processes. The equipment for fabricating or inspecting thin-film patterns on silicon wafers requires measurements of multiple degrees-of-freedom (DoF) such as height, tilts, and rotation, as well as displacements.

For a motion stage that performs 6 DoF transfer and alignment, at least 6-axis measurement is required. Also, transformation from 6-axis displacement measurement data into 6 DoF coordinate system is necessary because the optical axes are not parallel to each other and are not perpendicular to the moving object carrying a silicon wafer.

To perform displacement measurement and feedback for high-speed stage movement, the optical signal processing and the displacement computing should be performed at a high sampling frequency.

In this paper, we report on the current status of the developed 3-axis laser interferometer that can be used for 6 DoF measurements, which uses a Xilinx Zynq 7000 series board, which is suitable for a signal processing and computer board requiring large calculation and high speed communication. The performance of the 3-axis laser interferometer was evaluated by measuring motion of a moving stage, where a Renishaw's single axis laser interferometer system was also installed and used for the measured simultaneously.

2 Interferometer Design and Components

2.1 Interferometer Displacement Measurement System

Figure 1 shows the overall layout of the 3-axis laser interferometer. The developed 3-axis laser interferometer and a single axis laser interferometer from Renishaw [1] were placed side by side and the measurement object was placed on a single-axis linear motor stage. We used a Keysight 5517D He-Ne laser [2] with 3.76 MHz split frequency and a Zygo ZMI 7702 He-Ne laser [3] with 20 MHz split frequency, widely used in semiconductor equipment as the measurement light source.

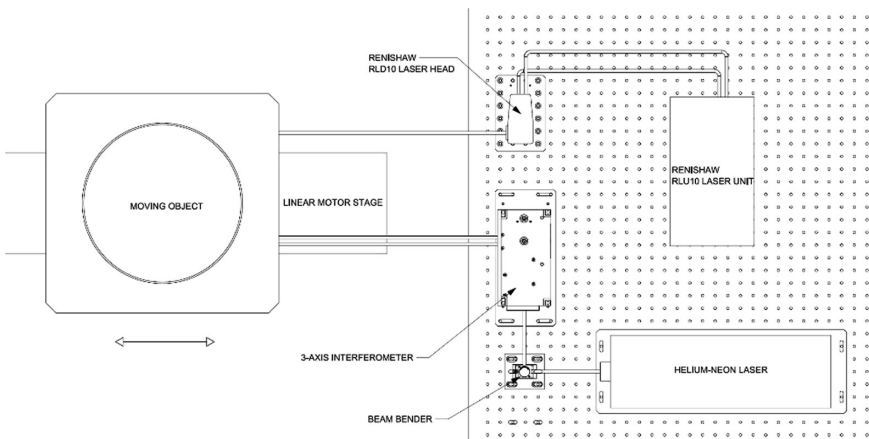


Fig. 1. Displacement measurement system for moving object using 3-axis interferometer

2.2 The 3-Axis Interferometer

Figure 2 shows the optical layout of the developed a 3-axis interferometer.

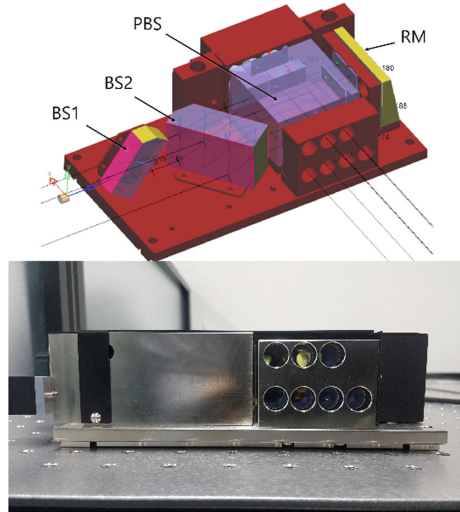


Fig. 2. Optical layout and photo of the 3-axis interferometer. BS1/BS2: beam splitter, PBS: polarizing beam splitter, RM: reference mirror

The entrance of the light source is arranged with two prisms for separating three beams of a single He-Ne laser beam. The three beams are separated into polarized vertical light and horizontal light, which are sent to the corner cube and the moving object, respectively. The measurement beams reflected from the moving object are superimposed on the reflected beams from the corner cube, respectively, and sent to the three optical connectors.

2.3 Optical Signal Processing

We developed an optical signal processing board with four photodiode receivers for 3-axis interferometer measurements. The optical signal transmitted by the optical cable is converted to a low level current through the photodiode. This current is amplified by the voltage and converted into a square wave of 3.3 V. Four square waves, one from the reference and three from measurement beams, are transmitted to the field programmable gate array (FPGA) input.

2.4 FPGA Logic Design

A digital logic circuit which calculates the displacement values from electric signals converted from 3 optical interference signals, was developed using an FPGA board of Xilinx Zynq 7000 series. To demonstrate the measured results graphically, we

developed a graphical user interface software that can run on the Linux operating system of the ARM CPU included in the Zynq chip and the remote PC. A screenshot of the software is shown in Fig. 3.

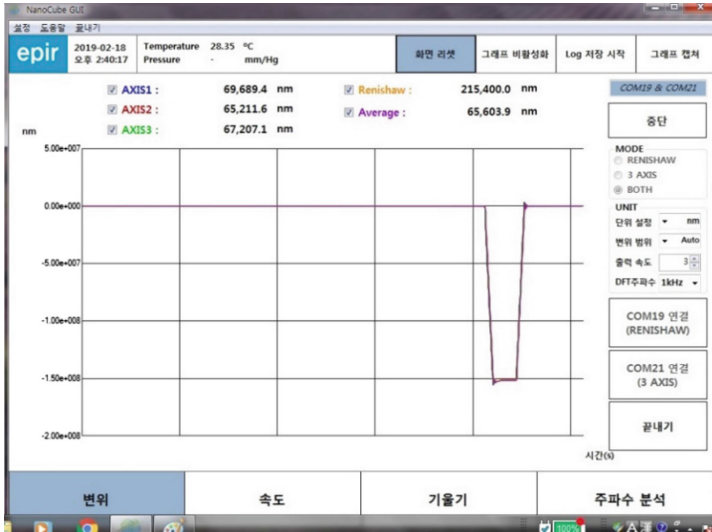


Fig. 3. Captured image of the graphical-user-interface software

In addition, a feedback function through a high speed communication bus was added to the system so that it can be applied for motion control of a moving stage requiring scanning and alignment of a thin film coated substrate such as a silicon wafer. The FPGA logic counts the number of square wave pulses and calculates rotation and tilts as well as 3-axis displacements.

3 Test Results

3.1 Optical Signal Processing for Two Split Frequencies

Split frequencies of two He-Ne lasers (Keysight 5517D and Zygo 7702) were measured using the developed optical signal processing board. The measurement results of the optical signal processing board showed correct split frequencies of 3.76 MHz and 20.0 MHz, for the Keysight and Zygo laser, respectively. Figure 4 shows the measured square waves of the reference frequencies of the two laser heads.



Fig. 4. Optical signal square wave of 3.76 MHz (left) and 20 MHz (right).

3.2 Measuring Single Axis Movement

Using the setup shown in Fig. 1, the displacements of a stage moving at 0.2 m/s were measured by the two laser interferometers. The results are shown in Fig. 5. Our 3-axis

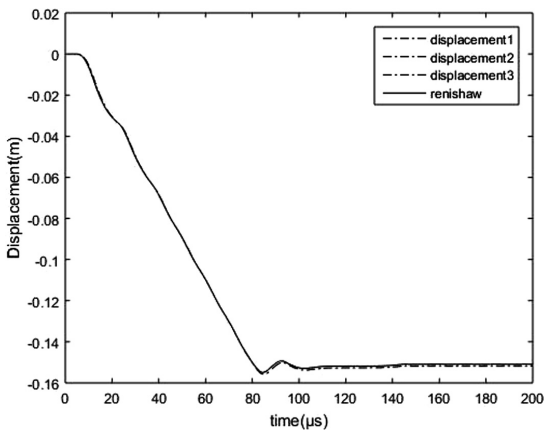


Fig. 5. Measurement results of single-axis displacement (dot lines: 3-axis interferometer, solid line: Renishaw single-axis interferometer)

laser interferometer and Renishaw's 1-axis laser interferometer both performed measurements at a 1 kHz sampling frequency. Three results measured with a 3-axis interferometer agree well with each other.

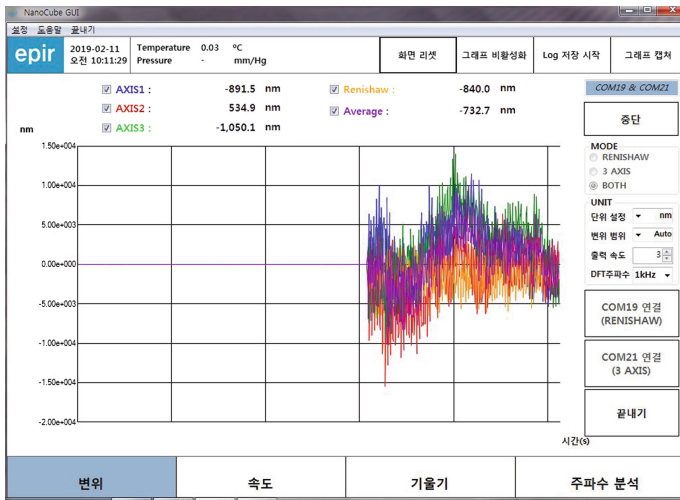


Fig. 6. Comparison of data measured by the 3-axis interferometer (blue, red, green) and the Renishaw interferometer (Orange)

Figure 6 shows the displacement data measured by the developed 3-axis interferometer and the Renishaw interferometer, when the stage is not moving. The two interferometers show slightly different values because the scaling factor is not yet calibrated as well as the wavelength of the laser not compensated. It can be seen that the four graphs are comparable and move in the same manner. The reason why the measured values fluctuate quite much is that the interferometers and the stage are installed on a different platform. So the fluctuation shows the relative vibration between the stage and the optical table where the interferometers are located.

4 Conclusion

We developed a 3-axis heterodyne laser interferometer system consisting interferometer optics module, a signal processing board, and a measurement software. It is designed for use with a He-Ne laser at the wavelength of 633 nm having a split frequency of either 3.76 MHz or 20 MHz, and is capable of 6 DoF measurements with high sampling frequency of 1 kHz. Through future works, it is expected to be applied to equipment for fabricating or inspecting thin-film patterns on silicon wafers.

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References

1. <https://www.renishaw.com/en/xl-80-laser-system-8268>
2. <https://www.keysight.com/en/pd-1000001477%3Aeapsg%3Apro-pn-5517D/laser-head?nid=-536900395.536880855&cc=US&lc=eng>
3. <https://www.zygo.com/?/met/markets/stageposition/zmi/laserheads/>