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Progress on scanning beam interference lithography tool with high environmental robustness for patterning large size grating with nanometre accuracy

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Abstract

The novel tool mainly consists of a homodyne frequency-shifting interference pattern phase locking system and a substrate stage with a grating interferometer system for XY displacement measurement. The phase locking system employs a special self-made homodyne redundant phase measuring interferometer (HRPMI) as the sensor and two acousto-opto modulators (AOM) as the actuator. By this configure, the phase locking system is very simplified and the power in several tens of micro-Watt is enough. The grating interferometer system works by combining four interferometer arrays on the fixed metrology frame and four grating rulers on the moving substrate stage. Due to the short dead optical path, the system is very environmental robust even if in a large environmental enclosure without demanding stability. The errors of the tool caused by different kinds of sources and imperfections are very complicated and can be separated into several categories. Detail error evaluation for two categories has been done for the initial experimental setup and both errors are several nanometres (3σ, $\Lambda=251.1$nm). Controlling accuracy of the initial experimental setup achieves ±4.17nm (3σ, $\Lambda=251.1$nm).

Key Words: Phase locking system, HRPMI, AOM, Frequency-shifting, Displacement measurement, Grating interferometer, Error evaluation.

1. Introduction

The scanning beam interference lithography (SBIL) tool is one of the most successful tools to pattern large size grating with high accuracy[1]. However, the tool is so sensitive to the environment fluctuation that a demanding environment control (±0.005°C for temperature, ±2.6Pa for pressure, ±0.8% for relative humidity and ±48ppm for CO2 concentration) in a large enclosure still don't satisfied with the requirement for patterning meter size or larger grating with nanometre accuracy[1]. Moreover, the tool is very complicated (optical path: 17.6m) and enormous as well as the laser utilization of the tool is very low (5%) [1]. We aim to pattern this type of grating for ultra-precision displacement measurement and pulse compression application, by means of a novel SBIL tool now under developing at Tsinghua.

2. Scheme and advantages of the novel SBIL tool

Figure 1. (a) and (b) show the scheme of novel SBIL tool. Compared with traditional SBIL tool, our tool employs a homodyne frequency-shifting interference pattern phase locking system (PLS)[2], a $xy\theta z$ substrate stage with a special grating interferometer displacement measuring system (GIDM). The PLS is a traditional interference lithography with a laser wavelength of 355nm, which also consists of a special self-made homodyne redundant phase measuring interferometer (HRPMI) as the sensor and two acousto-opto modulators as the actuator for phase locking. The PLS has been detailed in a former Letter[2]. The GIDM mainly consists of four arrays of grating interferometers (GI) and four scale gratings. The four arrays are mounted on the metrology frame, and the four scale gratings are mounted on the substrate stage correspondingly. When the stage moves, the GIs in the same array switch one by one to output the displacement measuring value all the time. The real in-plane $xy\theta z$ motions can be resolved based on the readings of the GI arrays. Due to the lack of a suitable off-the-shelf grating interferometer unit (GIU), we also proposed a heterodyne Littrow type GIU for the displacement measurement of the substrate stage, as shown in Figure 1. (c). More importantly, the metrology frame of our tool connects with the base frame by isolators to form an ultra-stable "static world". All the optics and GIs are mounted on the metrology frame. And the substrate stage is placed on the base frame. During the exposure process, both of the motion error and the drift of the interference pattern are feedback to the L-Controller simultaneously, the L-Controller orders the AOM2 to shift the interference pattern continuously to restrain the stitching error.

By use of the new scheme and design, a both compact and concise PLS with high laser utilization (≈60%) can be achieved and a small power laser head on the level of tens of microwatts of power is sufficient, which reduce the system cost compared with the heterodyne system. More importantly, as the HRPMI is very compact, the exposure and measurement point is very close. As a result, the PLS is much robust to environmental fluctuation and a high accuracy can be achieved even without demanding environmental control.

Due to the short optical dead path (several millimetres) of the GIU, the GIDM is very environmental robust even if in a large environmental enclosure without demanding stability. Another important factor to reduce the repeatability of the GIDM is the thermal expansion of the long length scale grating. As to our knowledge, the CTE (coefficient of the thermal expansion) of extremely zerodur material provided by SCOTT has reached 0.007 ppm/°C. Accordingly, when the temperature varies within ±0.01°C, the error is ±0.07 nm for a zerodur scale grating with a length of 1m. Therefore, the total error of our tool caused by environmental fluctuation and thermal expansion in a less-tight environment is rather lower than the Nanoruler in a severe environment. Moreover, the repeatability of the grating interferometer system can be calibrated to obtain high accuracy.

In addition, as the PLS and GIs are isolated from the substrate stage in the scheme, a higher stability can be got compared with the Nanoruler during patterning. We will realize the isolation scheme in our final tool in the future.

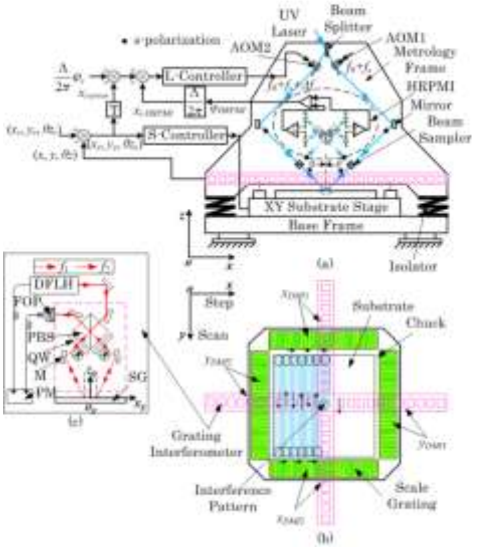

Figure 1. Scheme of the novel SBIL tool (a) front view (b) top view (c) scheme of heterodyne Littrow type grating interferometer unit

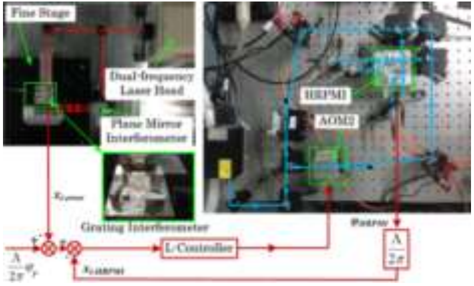

Figure 2. Initial experimental setup

We establish an initial experimental setup, as shown in Figure 2. The experimental setup mainly consists of two parts, one is the PLS and the other is the GIU comparison system. The experimental setup of the PLS has been introduced in a former Letter[2]. The experimental setup of the GIU comparison system is mainly made up of the GIU, a fine stage and a Zygo plane mirror interferometer (PMI) for comparison and a data acquisition subsystem. The data acquisition subsystem is also based on real-time VME bus so that the measurement data can be compatibly input the PLS for error motion compensation.

3. Error evaluation

The category and value of the short-time error of the primary experimental setup are listed in Table 1. The environmental stability between the measurement point and exposure point of the PLS is about ±0.01°C for temperature, ±7.5Pa for pressure, ±1.5% for relative humidity and ±50ppm for CO2 concentration. The environmental stability of the grating interferometer unit is same as the PLS. Due to the poor vacuum wavelength stability of the UV laser, the dead-path error caused by the vacuum wavelength fluctuation of the PLS is several nanometres, we will improve the wavelength stability to reduce the value to sub-nanometres in the next step.

Table 1 The short-time error of the initial experimental setup

Catagory		**Value (3σ)**
Phase locking system	Electronics noise	±0.096 nm
	Residual periodic non-linearity	±0.096 nm
	Dead path error (caused by vacuum wavelength fluctuation)	±5.986 nm (calculation value)
	Dead path error (caused by environment fluctuation)	±0.528 nm (calculation value)
	Controlling error	±1.843 nm
RSS		±6.287 nm
Grating interferoemter unit	Electronics noise	±0.41 nm
	Ploarized mixing error	±3nm
	Dead path error (caused by vacuum wavelength fluctuation)	±0.3nm (calculation value)
	Dead path error (caused by environment fluctuation)	±0.15nm (calculation value)
RSS		±3.56nm

4. Controlling result

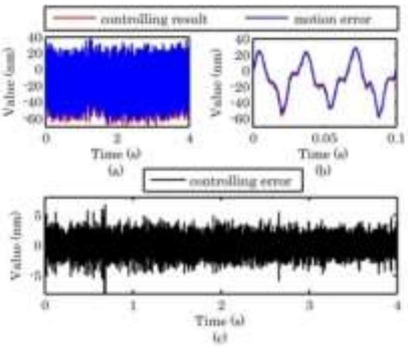

Figure 3. Experimental result: (a) controlling result (b) enlarged drawing of controlling result (c) controlling error

An experiment is operated to verify controlling performance. A sinusoidal motion with amplitude of 80nm and frequency of 30Hz is generated by the fine stage to simulate the motion error along the x direction when the substrate stage scans along the y direction. The motion error is measured by the GIU as the blue line in Figure 3. (a). An order is given to the PLS to lock the drift of the interference pattern and compensate the motion error simultaneously. The controlling result is illustrated in red line in Figure 3. (a). The experimental result shows that the interference pattern locking system not only stabilizes the interference pattern but also compensates the x_i motion error simultaneously, and the controlling accuracy achieves ±4.17nm (3σ, Λ=251.1nm), as shown in Figure 3. (c).

5. Summary

In summary, our tool with high environmental robustness has the potential to pattern meter or larger size grating with nanometre accuracy. The tool is now being developed at Tsinghua, and we will keep on reporting the progress.

References

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