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Control of an equipment for fabricating periodic nanostructure

Jing-Chung Shen *, Wen-Yuh Jywe, Chia-Hung Wu

Department of Automation Engineering, National Formosa University, Huwei, Yunlin 632, Taiwan

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ABSTRACT

This study presents the control for an equipment that is designed for fabricating periodic nanostructures. This equipment can generate the patterns required for nanostructure production using direct writing laser lithography. The equipment incorporates a direct writing laser lithography instrument, a linear motor-driven long-stroke stage (X, Y), a piezoelectric-driven two degrees of freedom (2-DOF) nano-stage (Y, θ_z), a 3-DOF laser interferometer measurement system, and a system control unit. The working stage of this equipment is combined by a long-stroke stage and a nano-stage; therefore, it can provide long-stroke and high-precision positioning. The feedback signal for this stage is obtained using a 3-DOF laser interferometer measurement system. Integral sliding-mode controllers are used to control the linear motor-driven stage and PID controllers are used to control the piezo-stage for precision positioning. This paper presents the design of the controllers and the control results. Experimental results show that satisfactory writing results can be obtained at a 100 mm/s scan speed.

1. Introduction

Light-emitting diodes (LED) are energy-saving devices with high switching speeds. They are currently used in a broad range of applications, including surface lighting, car lights, outdoor display panels, and traffic lights. Conventional LEDs have poor lighting efficiency (4% light emission area) because of their full reflecting angle. Photonic crystal nanostructures have recently been introduced to LEDs to increase the emission angle and light-extraction efficiency. This is expected to improve LED lighting efficiency significantly by up to 50–300%, thereby providing significant industrial benefits [1]. Photonic crystal LEDs are currently in the research stage. There is a shortage of cost-efficient and high-performance equipment for LED mass production. It is difficult to recruit required professionals and to acquire related techniques. Thus, it is problematic for the industry to commence mass production. Therefore, the development of cost-efficient and high-performance equipment for mass production is a valuable investment.

In 2007, the National Formosa University (NFU) of Taiwan commenced a 3-year project supported by the National Science Council of Taiwan and organized by the Department of Automation Engineering. The project integrates direct writing laser technology developed by the Electronics and Optoelectronics Research Laboratories of the Industrial Technology Research Institute (ITRI) [2] and nano-precision stage technologies developed by the NFU Department of Automation Engineering [3–7] to develop direct writing laser equipment for photonic crystal manufacturing. It is anticipated that this equipment will be used to write patterns for photonic crystals on 6-in. wafers at high speed.

Obviously, this equipment needs to achieve high precision over large strokes. Generally, two-stage precision positioning approach consisting of a coarse stage for long-range motion and a fine stage for the compensation of nanoscale motion errors is employed to achieve long-range and ultra-precise positioning. Recently, several studies about this kind of stage has been proposed [8–12]. Coarse stage can be driven by linear motors [8,9,11,12] or servo motors [10] while fine stage can be driven by piezoelectric actuators [8,10,11] or magnetic drivers [9,12]. In the literature [9], a three-DOF hybrid stage is proposed for confocal scanning microscope. In their study, the coarse stage is H-type and is driven by three linear motors while the fine stage is driven by four voice coil motors. Air bearings are used to sustain the stage. In [12], a six-DOF hybrid stage is proposed. Their stage is formed by utilizing an H-type linear motor driven coarse stage and an active magnetic bearing sustained fine stage.

This study presents the structure and control of the discussed laser direct writing equipment. A two-stage approach consisting of a coarse stage (submicron-scale) and a multi-DOF fine stage (nanoscale) for the compensation of nanoscale motion errors is employed to achieve long-range and ultra-precise positioning. In our study, the long-range stage is driven by linear motors, whereas the fine stage is driven by piezoelectric actuators. The feedback signal for each stage is obtained using a 3-DOF laser interferometer measurement system. Integral sliding-mode controllers are used

* Corresponding author. Tel.: +886 5 6315380; fax: +886 5 6314486.
E-mail address: jcshen@nfu.edu.tw (J.-C. Shen).

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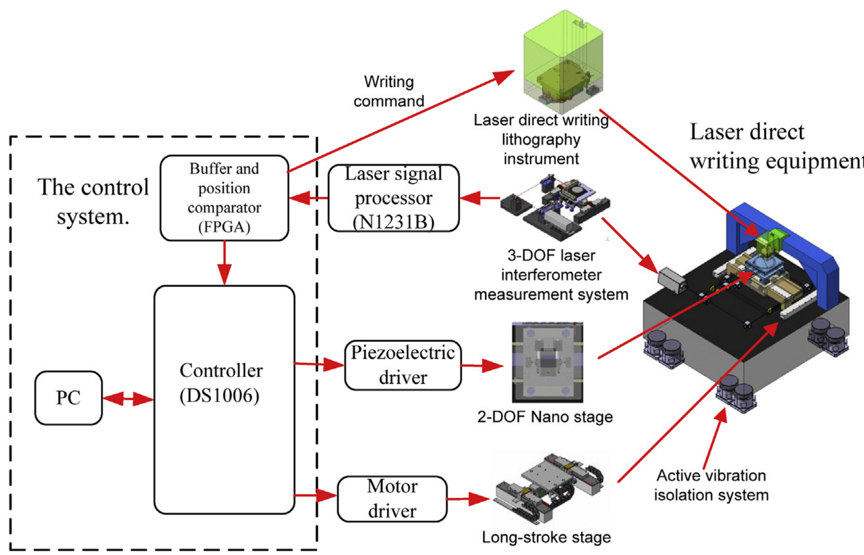

Fig. 1. Equipment block diagram.

to control the scanning motion and the step movement of the linear motor driven stage and PID controllers are used to control the piezo-stage for precision positioning.

This paper is organized as follows: Section 2 details the structure of the direct writing laser equipment, the structure of the long-stroke linear motor stage, the piezoelectric stage, and the laser interferometer measurement system. Section 3 introduces the feedback controller structure. Section 4 presents the experiment results, and Section 5 offers a conclusion.

2. Equipment structure

This section details the structure of the direct writing laser equipment. The block diagram of this equipment is shown in Fig. 1. It includes a direct writing laser lithography instrument, a linear-motor driven long-stroke stage, a piezoelectric driven 2-DOF nano-stage, a 3-DOF laser interferometer measurement system, and a system control unit.

Fig. 2 shows a photograph of the lithography instrument. It is equipped with an autofocus system and a laser power control system. By integrating a conventional blue-ray (351–413 nm wavelength) laser system with super-resolution inorganic resist thermal lithography technology, this instrument can be used to write nanostructure patterns. The inorganic resist used in this technology can be exposed by thermal effect with super-resolution.

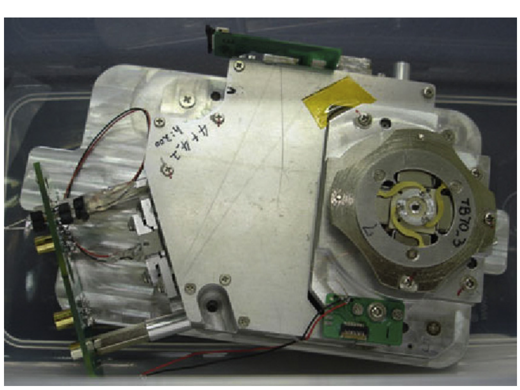

Fig. 2. Photograph of the lithography instrument.

When writing the required patterns, the laser light is focused by a focusing lens and the light intensity in the central part of the light spot is higher than that of outer part. The inorganic resist can only be reacted in the region where the light intensity is high enough. Therefore, this technology can overcome optical lithography diffraction limitations and has high potential for different areas applications, for example, generating the patterns required for gratings and encoders [2].

The long-stroke and nano-stages are combined as a hybrid precision stage to provide long-stroke (200 mm × 200 mm) and high-precision (±10 nm) positioning. A 3-DOF laser interferometer measurement system is used to measure the *X*, *Y* direction and rotational angle θ_z displacements and provide these measurements to the control system. A laser signal processor (N1231B) transforms the laser interferometer signal into 32-bit data to achieve a sub-nano resolution (0.15 nm). The refresh rate of the measured data is 20 MHz. This datum is transferred synchronously to a circuit (implemented by field-programmable gate arrays, FPGA) and down-sampled by a buffer before being fed back to the feedback controller. The feedback controller is implemented by a dSpace (DS1006) system sampled at 10 kHz.

When writing the required pattern, the stage scans the wafer at a constant speed in the *X* direction and moves synchronously step-forward in the *Y* direction. The pattern data are preloaded in the circuit implemented by the FPGA. When the writing position is reached during the scan, the circuit transmits a writing command to the lithography instrument to write on the wafer. Because the scan speed is high (100 mm/s), the response of this circuit should as fast as possible. In order to write the nanostructure correctly, the positioning of *Y*-axis must be precise and the deviation of θ_z must keep small during the scan motion. Moreover, the displacement of *X*-axis is sampled at frequency 20 MHz, for scanning at speed 100 mm/s the difference of displacement between two samples is about 5 nm. Therefore, the positioning error of *X*-axis is about 5 nm plus the error caused by the propagation delay of the circuit (about 30 nm). Fortunately, the propagation delay is known and can be compensated in advance. Thus, the requirement of the *X*-axis positioning accuracy still can be satisfied.

The equipment is situated on a granite base and equipped with an active vibration isolation system in a clean room (grade 10,000) with precise temperature control (23 ± 0.3 °C).