Prospects for the creation of an optical-mechanical unit for a high-resolution nanolithograph

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Abstract. In this paper the proposals for solution of problems related to the creation of an optical-mechanical unit of promising models of a high-resolution laser nanolithograph are considered. The approaches to the implementation of the rotation module and of the linear displacement carriage of the recording head are considered aimed at reducing the temperature distortion of the synthesized element topology including due to the observance of the principle of symmetry of the nanolithograph main elements location and the points of application of the forces of its actuators relative to the main plane of the installation. The feasibility of creating a two-channel version of a nanolithograph that makes it possible to compensate in real time (while the substrate rotates) the resulting temperature distortions of the topology generated by external and internal heat sources is discussed. It is shown that the usage in the two-channel version of a nanolithograph of the differential-type laser interferometers allows reducing the distortions of the formed element topology up to tenths of a nanometer.

1. Introduction

Currently there are two main groups of technologies for manufacturing the complex non-periodic DOE. They are the electron-beam technology and the laser technology. The potential resolution of the electron-beam technology is much higher than the resolution of the laser recording technology (tens of nanometers versus hundreds of nanometers). However, in case of the multilevel DOE production for which the use of the resist thick layers is typical, this difference is almost leveled due to the scattering of electrons in the resistor.

In a raster scan the positioning error of the beam of the electron-beam system can be as small as 0.1 nm but when jointing the synthesized elementary fields using X-Y table, the inaccuracy of topology element formation is increased to values of the order of 10-30 nm which is characteristic for the precision laser lithography systems. Apparently, the problem of jointing elementary fields in the electron-beam lithography is so fundamental that one of the leading companies in the USA which produces technological equipment for the microelectronic industry (KLA Tencor) has planned to create electron-beam image generators of a new rotary type by 2025 instead of the traditional ones which use X-Y tables [1]. According to this company specialists’ opinion, the transition to rotary type generators will allow us to increase the recording performance by times while maintaining the accuracy characteristic of
electron-beam generators with the classic two-coordinate X-Y tables.

In this paper we discuss some technical solutions concerning the creation of the basic blocks of a high-resolution circular laser nanolithograph (HCLN).

2. Optical-mechanical block of a high-resolution circular laser nanolithograph

The optical-mechanical unit of a high-resolution circular laser nanolithograph (OMU HCLN) can be divided functionally into two parts: the optical recording channel and the positioning system which includes the rotation unit and the linear movement carriage. The use of the polar coordinate system is more preferable for traditional laser lithographic systems (LLS) focused on manufacturing DOE and angular measurement structures (AMS) [2]. This is largely due to the fact that both DOE and AMS of a large diameter (100-300 mm) are in demand. Recording the topology of elements on substrates of such diameter with the help of X-Y systems requires much more time than recording in the polar coordinate system. This leads to a noticeable increase of errors associated with the thermal drift of the mechanical components, the changes of the temperature and the ambient air pressure affecting the wavelength of interferometers in the motion control systems.

As a rule, the angular coordinate modules of LLS with circular scanning are constructed on the basis of the aerostatic bearings (AB) equipped with the optical angular sensors. Modern high-speed optical angle sensors are capable of providing the accuracy up to (0.2–0.5)" [3]. However, according to KLA Tencor experts’ opinion [1], the angular sensors with a precision of about 0.01" which is provided at speeds of not less than 10 Rev/s are required for a rotary type nanolithograph. Now the sensors with a similar set of characteristics are not commercially available yet.

In its turn, the accuracy of DOE topology formation also depends on a number of reasons. For example, the imbalance caused by the placement of the large diameter heavy substrates on the spindle rotor washer distorts the original rotor balancing. As a result, the subsequent scanning of the substrate is carried out along paths that differ from circular ones. This leads to significant distortions of the synthesized topology of DOE. Therefore, when creating a HCLN with circular scanning it is necessary to reduce the specific errors introduced by the rotation unit in order to make a HCLN competitive in comparison with nanolithographs based on X-Y tables.

In this paper we will not deal with the problems of creating an optical recording channel, we will focus only on the problems of creating a rotation unit and a linear carriage of a HCLN which adequately meet the requirements of the modern nanotechnology.

2.1. The angular coordinate module of the OMB HCLN

In order to improve the accuracy of the element topology formation, it is necessary to stabilize the spatial position of the rotating rotor axis of the mechatronic module operating at low (pre-resonant) speeds. It is planned to apply several methods for this purpose. The first is the method of the rotating masses symmetrization [4]. According to it, the polar inertia moment of the lower part of a mechatronic module calculated relative to the AP rotor symmetry center should be equal to the polar inertia moment of the module upper part with the DOE blank attached to it. In the design of the module it is planned to use a new type of AP with spherical supports and porous charge limiters. Their application will allow us to increase the bearing capacity, rigidity, damping and vibration resistance of the AP. These AP have only two supporting surfaces which perceive the radial, axial and skewing axis loads. Due to these features the supports will be made with a smaller gap (4 - 5 microns) which will provide greater rigidity. The optimal operating pressure range at which the best AP characteristics are achieved is the range of 0.8 - 1.0 MPa. The rotation accuracy of these AP is 0.025 ÷ 0.05 microns. But this indicator can already be insufficient for a number of nanotechnology applications. Therefore, in order to compensate the spatial beats of the rotor axis it is planned to use the third method based on the usage of the combined optical sensors. These products provide the control of the spatial position of its rotation axis simultaneously with the measurement of the angular displacements of the spindle rotor [5]. This will allow us to take into account the spatial instability of the position of the rotor axis in the dynamics and to correct the angular coordinates of the synthesized DOE topology actively.
2.2. High-precision angular sensor of the OMB HCLN rotation module

The above-mentioned problem concerning the creation of high-precision sensors is that it is necessary to ensure the accuracy of the angle conversion at the level of 0.01” in dynamics at a rotation speed of 10 Rev/s. To solve this problem one should take into account the contributions from each of three major sources of errors: the error of the measuring raster manufacturing, the errors of discreteness (resolution) and the errors from the space position instability of the measuring raster rotation axis.

For many years in the LLS the ensuring of the required resolution of the angle sensor at a rotational speed of 10 Rev/s has been achieved by using the frequency multiplication with the help of a phase locked loop (PLL). There is every reason to rely on achieving a resolution of 0.01” at a measuring raster rotational speed of 10 revolutions per second if using this principle of frequency multiplication. This will require the usage of modern elemental base to create a pulse frequency generator controlled by the output voltage of the phase detector operating at frequencies of at least 1.296 GHz. In principle, at present this is feasible.

If annular rasters with a 14–20 μm period are used in the optical beat meters of the combined sensors, then the modern phase interpolation methods [6] on the outputs of optical beat meters will provide information on the spatial variations of the rotor axis with a resolution of 3–5 nanometers. This will allow us to reduce the error from the spatial instability of the rotor axis to 0.01” in the angle sensor if its measuring raster has a diameter of 120 mm and more. As for combined sensors which use diffraction type rasters with a period of 1 μm, this approach will reduce the angular uncertainty to 0.001” or less.

It is much more difficult with the contribution of the component from the inaccuracy when manufacturing a measuring angular raster. The problem is to calibrate the reference sensor with an accuracy of no worse than 0.01” after it has been mounted on the rotor of the spindle unit. The fact is that 0.01” is the level of uncertainty of the current State Primary Angle Standard of the Russian Federation. Therefore, calibration of angular sensors with a similar uncertainty in production conditions is a real metrological problem which has not been solved in the Russian Federation yet.

2.3. Precision linear motion carriage

At present, positioning of the carriage with uncertainty within a few units of nanometers does not cause fundamental difficulties. The main problem on creating an optical-mechanical unit for a high-resolution laser nanolithograph is to ensure the long-term temperature stability of the relative position of the spindle rotor rotation center and position of the recording head optical center and the drift absence of zero of the polar coordinate system caused by the indicated instability.

In order to eliminate this drift, it was proposed to take as a basis the observance of the principle of symmetry of the nanolithograph main elements location and the points of application of the forces of its actuators relative to the main plane of the installation (MPI) [7]. As a rule, the elements of the optical channel LLS are placed on the working surface of the massive granite slab of high accuracy class. The MPI of these systems is located orthogonal to the working plane of the granite slab and includes the longitudinal axis of symmetry of the latter, along which the carriage carrying the recording head must move. In order to improve the accuracy of the carriage linear movements in the body of the granite slab 1 (Figure 1) from the side of its working surface 3, it is proposed to assemble a longitudinal groove 2 the middle section of which is aligned with the MPI 6.

![Figure 1. The position of the MPI relative to the granite slab.](image-url)
According to the chosen concept, the rotation axis 5 of the spindle unit rotor and the thrust vector of the carriage linear motors should be located in the same plane. Then the diametrical plane of the cylindrical aperture 4 which is formed in a granite slab to place the spindle unit has also to be combined with the MPI 6. The vertical walls of the groove 2 (Figures 1 and 2) are guides for flat aerostatic bearings 7 of the motor arch 8 of the radial displacement carriage. In accordance with the chosen concept, the stators 9 of linear motors must be placed on the horizontal surface of the groove 2 orienting the axis of their symmetry in the MPI 6. Accordingly, the current coils 10 must also be placed on the radial displacement carriage motor arch 8 symmetrically with respect to the MPI. In this case the working (polished) surface 3 of the granite slab 1 is a guide for horizontal aerostatic bearings 11 of the radial displacement carriage motor arch.

![Figure 2. Cross-section of the carriage in the motor arch.](image)

With this arrangement of the linear motor current coils the point of application of the motor traction force is located in the MPI and does not cause unwanted turns of the carriage. In addition, when the ambient temperature changes, the thermal expansion of the granite slab 1 and of the vertical walls of the groove 2 occurs in different directions and symmetrically with respect to the MPI 6. In this case there is a longitudinal section of the platform 12 carrying the elements of the carriage itself and of the optical channel which lies in the MPI and does not undergo temperature drifts. The fastening points 13 of the platform 12 to the motor arch 8 are placed in this section (Figure 3).

![Figure 3. The position of the base fastening points of the carrier platform.](image)

A special instrumental arch 14 is provided for installation of the recording head on the radial movement carriage in which the offset of the recording head 15 in the transverse direction is provided with the help of the intermediate single-axis table 16. The offset should be carried out with high resolution but within small limits (Figure 4). The need for the head 15 displacements in the transverse direction is due to the fact that, as a rule, when initially assembling LRS it is not possible to align the axis of the recording head microlens with the rotation center of the spindle rotor accurately. An intermediate single-coordinate table 16 can be used to solve this problem. The use of a single-coordinate table is due to the fact that the misalignment of the axes in the radial direction can be always compensated by the displacement of the carriage itself in this direction with the help of standard drives, and the compensation of misalignments oriented orthogonally to the main plane of the installation 6 is performed with the help of the intermediate table 16. So that the table 16 during long records of large
data sets does not make additional drifts, it is blocked from unwanted displacements by a mechanism, the locking force of which is applied exactly in the MPI (or at two points located symmetrically relative to the MPI). This requirement can be met easier if linear piezoelectric motors of model U-164.01 of the German company “Physik Instrumente” are used as actuators in the intermediate table [8].

Due to the fact that the final adjustment of the recording head 15 position is carried out by shifting it in the direction orthogonal to the MPI 6, the optical radiation 17 used for the exposure of the photosensitive layer should be fed to the recording head 15 also orthogonally to the MPI, for example, with the help of a rotary mirror 18 mounted on the edge of the tool arch 14 of the linear movements carriage in the movement plane of the intermediate single-coordinate table 16.

![Figure 4. Cross-section of the carriage in the instrumental arch area.](image)

In order to suppress radically the drift of the optical center of the recording head relative to the rotation center of the rotor of a rotation unit 19 caused by changes in ambient temperature, it is offered to use a differential interferometer in the configuration proposed by Excel Precision Company (USA) as a radial displacement sensor of the carriage [7].

The position of the differential interferometer reflectors 24, 24' and 25, 25' in the linear motion carriage is shown in Figure 4.

2.4. Electronic control unit and software of the OMB HCLN

In order to provide the higher characteristics of the LLS a fundamentally new approach to the implementation of control systems for both units of the OMB HCLN is proposed. This approach underlies a significant part of all modern industrial developments. The principle involves the unification of all logical control modules on a single chip. This solution will ensure synchronous and ultra-fast interaction of all modules of the nanolithograph electron block (EB HCLN) with minimal probability of failures. In addition, this approach eliminates the use of a large number of interfaces which also has a positive effect on the speed of operation, makes the system open for updating logic modules and simplifies the mechanism of integration of new modules in a working system. Also, this approach gives us a possibility to separate the physical and logical implementation of the electronic control system which makes the system more universal and eliminates the use of a specific element base.

The usage of systems on a chip which are based on the FPGA+ARM principle seems to be the most expedient for realization of the described possibilities. A number of manufacturers offer the standard solutions based on this scheme and with different performance. All these solutions have a very long support time and, as a rule, manufacturers provide their continuity and backward compatibility, so the application of this approach to the EB HCLN will not only solve most of the described problems but will also allow us to develop the system during a long time without the need to update the hardware environment.

Nanolithograph software (SOFT HCLN) is a complex set of service applications and programs required for the calculation and recording of DOE. In addition, the SOFT includes diagnostic services, support service and HCLN settings. The key object of the SOFT is the concept of device interfaces
(CDI). The CDI allows us to combine an unlimited number of logical devices into one logical link and provides ample opportunities for their interaction to the developer.

The main problem of the current version of the SOFT is a rigid binding to the operating system and, as a consequence, to the interfaces of the used devices. Therefore, work on the SOFT development should take place in parallel with the modernization of the electronic unit (EB). In future this will allow us to integrate the SOFT into the EB partially or completely and this will reduce further development and modernization costs significantly, and in the long term it will eliminate the need to use a specific type and version of the used operating system.

3. Dual-channel version of the OMB HCLN

When recording the topology of DOE of a large diameter (such as 200 – 300 mm), it is necessary to take into account the possibility of the DOE topology distortion because of the thermal expansion of the substrate material occurring during the recording which is rather large for such diameters (up to two hours and more). If, for example, during recording the substrate temperature changes by only 0.5°C it will lead to a change in the coordinates of the DOE peripheral zones up to 500 nanometers. As the substrate rotates all the time during recording, it is not possible to measure the current temperature of the substrate. And it is not possible to take the temperature changes into account according to the classical algorithms. Monitoring methods of the substrate temperature changes by means of raster structures recorded in the selected angular sector in the test windows at different times have been proposed [9]. With regard to micron and submicron technologies the proposed methods have made it possible to compensate temperature distortions of DOE structures effectively. However, in case of nanotechnology the possibilities of such methods are insufficient. In order to ensure the accuracy of the DOE topology formation at the level of nanometer units, it is necessary to monitor the temperature changes of the DOE substrate almost continuously. This possibility can be provided by a two-channel version of the nanolithograph optical-mechanical unit. Under this option the first (main) recording channel is placed on the one side relative to the spindle module and the second (additional) channel is on the other side. The layout of such OMB HCLN is shown in Figure 5.

![Figure 5. The OMB HCLN layout option.](image)

The task of the main channel working, for example, with a source of UV radiation is to record the DOE topology, and the additional channel working with a source of visible radiation should carry out a continuous monitoring for the position of the test object such as an arc or circle formed on the periphery of the DOE working field. When using a differential laser interferometer as a feedback sensor, the position of the test object can be monitored with an accuracy of not less than 0.1 nanometer, since the resolution of interferometers with flat mirrors currently reaches 38.6 picometers [3]. In this case it is possible to form the DOE topology in accordance with the nanotechnology requirements.
4. Conclusion
The proposed approaches to the creation of the main units of the optical-mechanical block of a high-resolution circular laser nanolithograph allow us to speak about the real prospect of creating such a system which is competitive in terms of the diffraction optical elements production in comparison with the systems of the electron-beam lithography. In this case the proposed nanolithograph will provide a high performance of the recording process. It is quite possible to obtain a spatial resolution exceeding the current level of 300 nm which is typical for commercially available scanning systems of laser lithography with UV diode lasers.

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