Long Range Stage for the Metrological Atomic Force Microscope

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Abstract

We are constructing the AFM based nano-measuring machine with long measuring range for the metrological applications. In this project, our aim is to develop the measuring system with sub-nm resolution to measure three-dimensional positions of the artifacts used for semiconductor metrology. For developing the nano-measuring machine, a high precision positioning stage with a travel range of 200 mm x 200 mm x 30 μm is also fabricating. On designing the system, we mainly consider an Abbe offset free arrangement and a simple structure with low vibration and low deformation. In stead of the traditional two level stages, we adopted a single level stage using a surface plate as the reference of the stage. Therefore, it has low profile, and small pitch and roll error motion. The X-Y stage consists of a micro-stage driven by the PZTs and a global stage driven the DC geared motors and lead screws. The position and angular motion of the X-Y stage can be measured and controlled by laser interferometers. The positioning of AFM tip is achieved by 3 PZTs and capacitance type gap sensors, and the approaching AFM tip to the sample and retracting it is achieved by a inchworm motor.

Introduction

Scanning probe microscopes (SPMs) have been used frequently to observe the surface texture over past years. With the development of nanotechnology, there has been growing demand for measuring the dimension of the very small structure. For this purpose, several national metrology institutes have developed the metrological SPMs upgrading the commercial machines with precision flexure stage and displacement measuring system such as capacitance type sensor or laser interferometer [1, 2]. These metrological SPMs are used mainly for measuring critical dimensions, pitch and step-height. However, the disadvantage of these measuring systems are the small measuring range of a few μm. For measuring the image placement of the photomask and wafer, a special metrological system having long measuring range is required. National Institute of Standards and Technology is developing a STM based Molecular Measuring Machine having an accuracy of 1 nm and a measuring range of 50 mm x 50 mm x 0.1 mm [3]. PTB also developed a SEM based Electron-Optical Metrological System with a measuring range of 300 mm x 300 mm [4]. At present, we also are constructing a metrological system similar to NIST

Molecular Measuring Machine. The aim of the project is to develop a nano-measuring system presenting a resolution of about 0.1 nm with a measuring range of 200 mm x 200 mm x 30 μm.

Structure of the stages

We designed the measuring system to apply to semiconductor metrology. Fig.1 shows X-Y translation system. On designing the system, we mainly consider an Abbe offset free arrangement and a simple structure with low vibration and deformation. In stead of the traditional two level X and Y stages, we used one level X-Y stage.

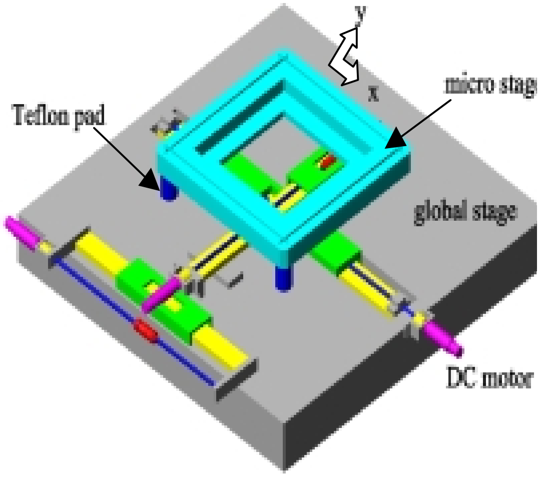

Fig. 1 Schematic diagram of 2-axis translation system.

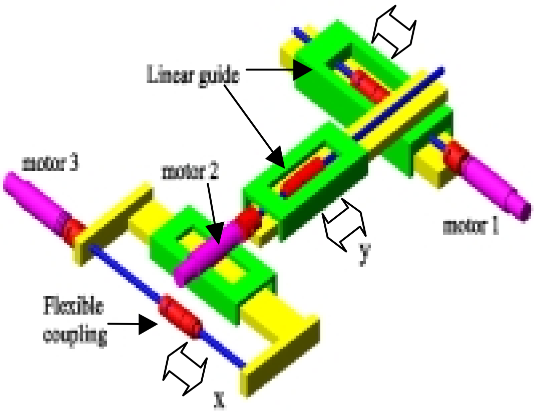

Fig. 2 Schematic diagram of the translation system for global stage.

The surface plate is used as the reference of the stage. Therefore, It has low profile, and small pitch and roll error motions. Surface plate was made of the cast iron and its flatness is below 1.5 micrometer over the size of 650 mm x 650 mm. The X-Y stage is positioned on the surface plate. It is guided horizontally by a cross structure with two precision bars rectangularly linked and vertically by the surface plate. The X-axis guide bar with a moving plate is fixed on the surface plate. The Y-axis guide bar is attached to the X-axis moving plate and moved to the X direction by motion of the X stage. Finally the y-axis guide bar guides the Y-axis moving plate on which the X-Y moving plate is fixed, so the X-Y moving plate can be moved to two directions. The sliding pads, which are made of PTFE, are used at X- and Y-axes moving plates, and also used for vertically supporting the X-Y stage on the surface plate. Each stage is driven by the lead screws with the geared DC servo motors. In this structure, by the movement of the X-axis moving plate, the position which the driving force for the Y-axis movement is applied to MAY be changed. It usually induces the yaw error. To prevent this error motion, we incorporate a special guiding system that is fixed on the surface plate parallel to the main X-axis guide. This second X-axis driving system is controlled to move at the same speed with the main X-axis driving system. And it carries a geared DC servo motor for the Y-axis driving. As a result, the driving force for Y-axis is always applied to the center of the stage (see Fig. 2). And this structure can prevent the vibration of the motor from transferring to the X-Y stage. The X-Y stage plate has the two-axis flexure stage machined by the precision wire-cutting machine. The flexure stage provides a total moving range of 30 μm x 30 μm and angular motion for adjusting yaw error motion (see Fig. 3). The stage plate and the flexure stage are made of a single aluminum block. By both of them, the stage provides the fast movement and the fine positioning. Three-axis tilt stages for adjusting the two pitch motions of the stage are fixed on the flexure stage and a square mirror for laser interferometer is positioned on the tilt stage. The Z-stage has a design based on three pairs of capacitance type gap gauges and PZTs driving a kinematic assembling of two plates. The lower plate is fixed on the tilt stage and upper one supports on the measuring target. The distance from the surface to the top of the square mirror is 55 mm. The Z stage based on inchworm mechanism is fixed on a bridge which is kinematically coupled on the surface plate. The inchworm stage is used to approach the AFM tip to the sample and retract the tip from sample. It was made of a PZT tube with large diameter, two flexures for clamping and fixed ring. It has a large through-hole to view the sample surface and tip by an optical microscope (see Fig. 4).

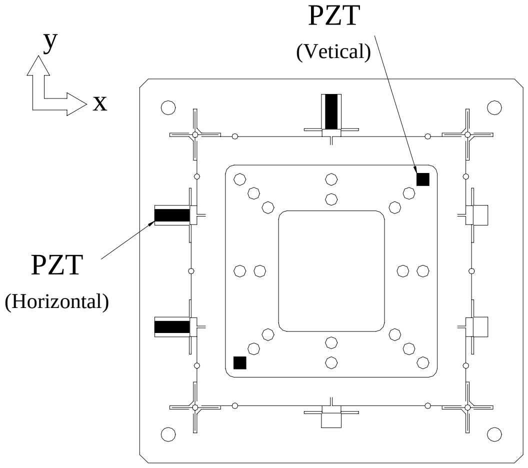

Fig. 3. Configuration of micro stage structure.

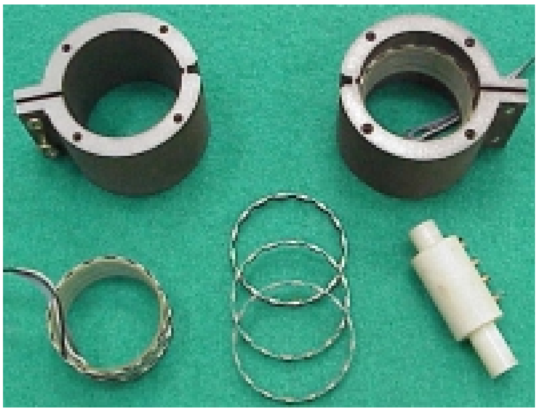

Fig. 4 Inchworm motor. In the figure, the developed inchworm motor and commercial motor are shown.

The laser interferometer measures the position of the stage and also measures the angular motions such as two pitch errors of the two axes and one yaw error. For this purpose, we also are developing the heterodyne laser interferometer having two frequencies. The transverse Zeeman stabilized laser is used as a light source of which frequency is stabilized by thermally controlling the plasma tube length. Its beat frequency is about 170 kHz. Now we are evaluating the nonlinearity compensation technique and phase encoding electronics.

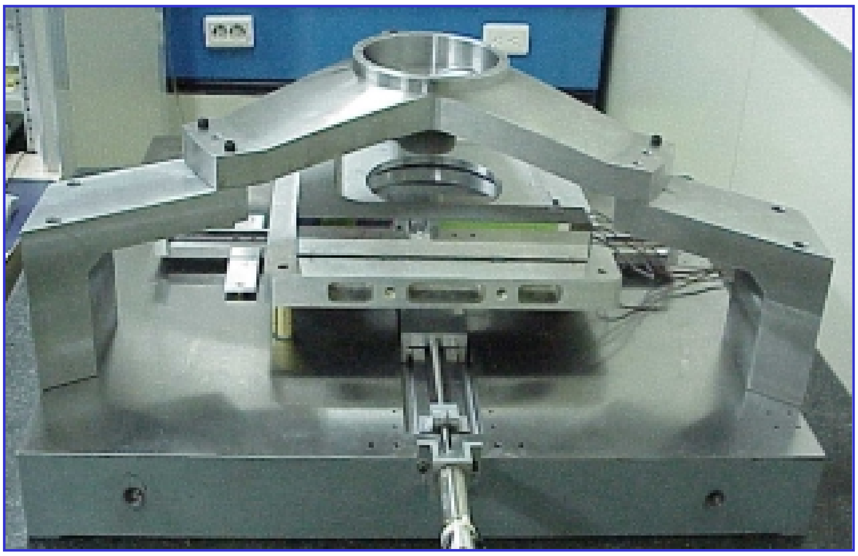

Fig. 5 prototype nano-measuring machine under developing.

Further works

Now we are constructing the prototype nano-measuring machine for semiconductor metrology applications. The preliminary test shows that the long range stage works well. Further study is to combine the stage with laser interferometer and develop the control algorithm. After that, we will design the final system.

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