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Design of a Positioning Table Using Crystalline Lattice and Surface Topography as a Reference Index

結晶格子をインデックスに用いた位置決めテーブルの設計

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ABSTRACT

This paper describes a design of a positioning table which uses crystalline lattice and minute surface topography as a reference index of positioning. Such a positioning table is to be realised by incorporating a Scanning Tuneling Microscope tuneling unit for observation of the index target. Feasibility of the system and some problems will also be discussed.

1. Introduction

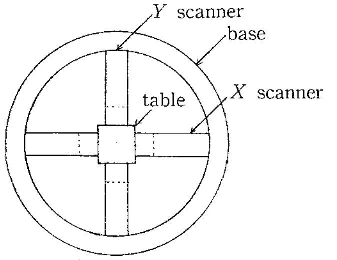
Development of a subnano to nanometer order positioning table is expected to become a strong tool in fields of scientific research and development. However, due to the very high accuracy and resolution of positioning that is required, feasibility of the system is expected to be greatly affected by the choice of methods of positioning and control.

The authors have designed a positioning mechamism using as an index of positioning, the lattice structure of a crystal or micro topography of a target. Such a system is to be realised by attatching directly under the positioning table a scanning probe of a Scanning Tunneling Microscope (STM)1). By observing the topography of the target as the table is moved and positioned, the positioning accuracy of the table can be made to reflect the high resolution and repeatability of the STM image. Due to the basic operating principle, the positioning table will be called "XPOS" for short.

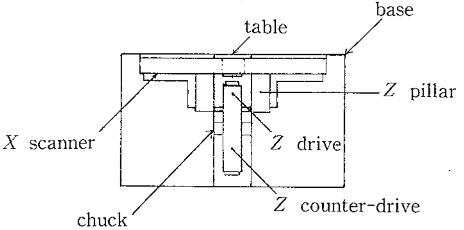
Since the resolution of the positioning table is determined by the resolution of vertical and horizontal image of the STM, insensitiveness to thermal drift and vibrations were considered for stable operation in relatively ill-defined environments.

2. Structure of XPOS

Figure 1 is a schematic diagram showing the structure of the XPOS. Figure 1.a shows the top view of *XY* scanners made of massive piezo electric ceramic beams. A table to be positioned is attatched to the central cross of the scanners. The base is a cylindrical shaped glass. The shape and material of the base were chosen to improve directional uniformity of thermal expansion and to lessen the rate of expansion. Figure 1.b shows the cross section of the base, *Z* pillar, *Z* drive with a target attatched on its top, *Z* counter-drive, and a chucking element of the *Z*



(a) Top view



(b) Cross section

Figure 1 Schematic diagram of XPOS

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drive. The Z pillar are used to increase the lowest eigen frequency of the XY scanners. Also, the length of the Z pillar is chosen to counteract the thermal expansion of the Z drive. Thus the relative position of the target and tunneling probe is relatively well-defined. Z drive and Z counter-drive are massive cantilevers secured to the base via the chucking element. Z counter-drive, which has the same length and load as the Z drive, is driven with a 180 degrees phase difference to that of the Z drive. By such a method, cancellation of vibrations can be expected. Such a mechanism was adopted to lessen the possibility of the excitation of the Z direction lowest eigen frequency of the XY scanners. Z drive and its counter-drive are roughly positioned by an inch worm from below. The chucking element is an expanding ring driven by a small laminated piezo electric ceramics. Some merits of the above structure are listed below.

a) Directional uniformity of thermal expansion, low thermal expansion, structure to cancel thermal expansion.

b) High lowest eigen frequency of the XY scanners in the Z direction.

c) Relative position of target and probe well-defined by the Z pillar.

d) High eigen frequency of the Z drive due to its very low load. The lowest eigen frequency of a 5×5×10mm massive element is approximately 26 kHz. By limiting the moving range of the Z drive to the order of a 100nm, the length of the Z drive can be made smaller, and thus the lowest eigen frequency of above 100kHz can be achieved.

e) Improvement of sound to noise ratio of the image by active vibration control using the Z counter-drive. Control of periodic outer vibrations can also be expected.

3. Positioning methods

In this chapter, various types of targets and methods of positioning will be discussed. The use of a man made grid with hot electron bands will also be discussed in section 3-3.

3-1 Positioning using crystalline lattice as an index

From the high eigen frequency of the tunneling unit of the designed XPOS, acquisition of a cryistalline lattice structure image of reasonably high quality can be expected. By constructing a servo system so that the probe tracks the arrays of atoms, use of the lattice structure as an index can be executed 'in principle'. This method apparently lacks robustness and also neglects the expected existence of defects and other cause of disturbances. Solutions to such problems will be discussed in section 3-2 and chapter 4.

3-2 Positioning using characteristic surface topography as an index

Feasibility of the positioning method of 3-1 depends highly on the preparation and maintenance of a defect free crystalline surface. As an alternative to the above positioning method, the use of pattern matching techniques will be discussed in this section. By taking in the image of a target and calibrating the XY location of the image by displacement sensors, location of topographic features will be defined. Since relatively good repeatability of images can be expected, we plan to calculate the current position of the probe from pattern matching between the calibrated image and the local image that can be obtained by local scanning of the probe. The study on positioning by this method may be applied to general STMs for finding the area of observation that has once been lost.

3-3 Positioning using stripes of hot electron bands

An index grid with a micron to submicron pitch can be produced with recent photo-etching techniques. When using such man made scales as an index, the relatively large height difference of the target surface is expected to lower the scanning speed of the tunneling unit. Also, atomic order tracking of the probe is too fine to obtain a positioning accuracy of a micron order. To improve scanning speed, and to simplify the Z direction positioning control of the probe, the authors are thinking of using the existence of hot electron bands observed on a metal-insulator-metal structure with a potential difference applied along the surface. The phenomena was reported by Muralt in 1986[2]. The existence of hot electrons will cause a large amount of current flow from the target to the probe, so easy detection of the hot electron band is made possible. Using as a target a metal-insulator-metal stripe or grid, the authors aim to position the probe without controlling the Z direction position of the probe.

4 . Problems to be solved

4 - 1 Position-lock of the probe and servo tracking of atomic arrarys

After the probe finds an atom or a topographical land mark above which it should stay, a"position-lock" control must be carried out. Since the only information that can be obtained from the tunneling unit is the tunneling current, the direction of drift after positioning can not be directly known. The authors are investigating on the effectiveness of applying a small amplitude of dizzer signal onto the XY scanners to sense and control probe drift. Also under study is the effectiveness of super position of dizzer onto the XY scanners for servo track of atomic arrays.

4 - 2 Mini tip switching, alteration of atomic array of the tip

If a mini tip switch occurs during a positioning process, the obtained image would become uncontinuous, and the relative position of of the probe and the home position atom would appear to have changed. In such a case, the probe must go back to the neibourhood of the home position, find the home position by local scanning and then recalibrate its home position. If a sudden drop of resolution occurs due to tip change, the phenomena may be detrimental to the positioning table. In situ cleaning is the only possible solution. As discussed from the early stage of STM development, a well defined stable tip is one of the factors that determines whether the STM and the XPOS is robust and practical.

4 - 3 Contamination of the target

There is a great possibility of local change of the target occuring after the XY calibrated image is taken in. If the area that underwent change is relatively small, a self diagnoses and self healing function may be given to the XPOS. By memorizing the changed topography as a new index surface, and then calibrating its XY position by charge drive of the piezoelectric elements and by comparison with the images of the unchanged areas, a reasonably good positioning accuracy should be regained.

5 . Conclusions and remarks

A design of a positioning table (XPOS) incorporating a tunneling unit was proposed. High eigen frequency and thermal insensitivity was considered upon design. The use of piezo electric element for active control of vibrations was proposed for improvement of the image. Superposition of dizzer signal onto the XY scanners was proposed for position-lock and servo tracking of the probe. Stripes of hot electron bands caused by a metal-insulator-metal structure was proposed as a man made index for scanning without fine probe-target distance control.

It should be noted that the research is still at the early stages of constructing the designed XPOS. Validity of the proposed methods and algorithms are to be confirmed and reported upon experiments.

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