研 究 速 報

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A Dual-Tunneling-Unit STM
——application as a nm order measuring machine and a positioning table——
デュアル トンネル ユニット STM
——測長器および位置決めテーブルとしての応用——

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Abstract

The authors have developped a Dual-Tunneling-Unit Scanning Tunneling Microscope for observation and measurement of a nm order surface structure. The Dual-Tunneling-Unit STM consists of two probe tips and two Z drives and a single XY scanner. The XY scanner has two target mounting surfaces for each Z drive and tip, enabling an independant simultaneous acquisition of images of two targets. Such a structure was adopted to calibrate the XY length of the acquired image. By mounting a target with a clean crystalline surface on one mount, and mounting an arbitrary target on the other, and then carrying out the process of simultaneous acquisition of images, the regularity of the crystalline lattice structure can be used for XY calibration of the acquired image.

1. Introduction

Since the development of the STM[1], acquisition of images of nm to sub nm order has been carried out. As an industrial application, for example, observation and measurement of a nm order circuit pattern or a reference grating can be pointed out. However, if the STM is to be used for measurement of length (eg. measurement of the width of a circuit pattern), the scale of an STM image in the scanning direction must be calibrated with reasonable accuracy. Although a few piezoelectric ceramics with low histerisis and good linearity are recently being developped, the common open-loop voltage drive of the scanners is not quite so satisfactory in terms of ; (1) linearity, (2) histerisis, (3) drift of displacement and characteristics, (4) different scanning characteristics between different scanners, (5) correctness of displacement etc.

In order to solve the above listed problems, the authors have developped a Dual-Tunneling-Unit STM. The STM consists of two Z scanners and probe tips and a single XY scanner. The XY scanner has two target mounts for each Z drive and tip, enabling an independent simultaneous acquisition of images of two targets.

By carrying out a simultaneous acquisition of an image of a crystalline lattice structure and an image of an arbitrary target, the regularity of crystal lattice length can be used as a reference for XY length calibration.

This paper will introduce the following;

(1) the structure of the Dual-Tunneling-Unit STM.

(2) introduction of the "Impact-Drive-Mechanism" for rough positioning of the Z drives.

(3) feed-back control of XY scanners to eliminate effects of probe drift. An application of image pattern recognition and dizzer vibration.

(4) some examples of the application of the Dual-Tunneling-Unit STM.

2. The structure of the Dual-Tunneling-Unit STM

Figure 1 is a schematic drawing of the Dual-Tunneling-Unit STM. The base is a V shaped block with a rectangular hole at the centre. The V block serves as a guide for the rough positioning mechanism: the "Impact-Drive-Mechanism" which has been developped at our laboratory[2]. The Impact-Drive-Mechanism carries the Z drive with the probe tip. The XY scanner is attatched to the rectangular hole

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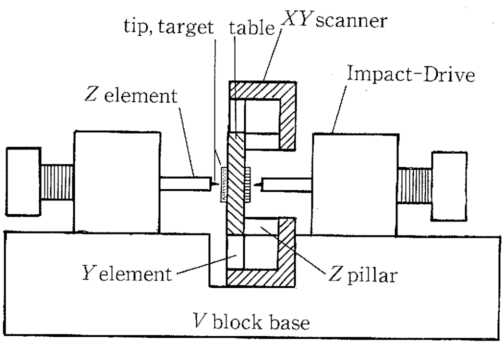
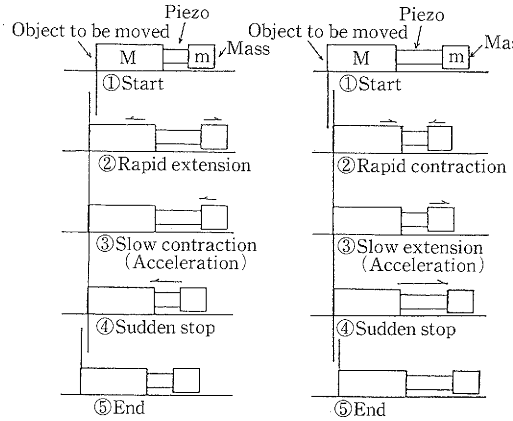


Fig. 1 The Dual-Tunneling-Unit STM



(a) leftward movement (b) rightward movement

Fig. 2 Operating Principles of the Impact-Drive-Mechanism

at the centre of the V block. We have built two types of XY scanners. One, a narrow-operating-range, high resolution type scanner with massive piezoelectric elements, and other, wide range, low resolution type; a parallel spring suspension type machined from a solid block of high stiffness invar.

By using the Impact-Drive-Mechanism, the Z elements with the probe tips are brought into the tunneling range within several seconds. After the two probe tips reach the tunneling current controlled state, the XY scanner is moved for acquisition of images.

3. The Impact-Drive-Mechanism[2)]

Figure 2 is a diagram showing the operating principles of the Impact-Drive-Mechanism. The Impact-Drive-Mechanism consists of the following elements; (1) Main mass, (2) Counter mass, (3) Laminated piezoelectric ceramics. The Main mass and Counter mass are attatched to each other via the laminated piezoelectric ceramics. The Main mass is placed on a table or a V block and is normally in a stationary state due to the friction acting between the table and itself. When sudden contraction or expansion of the laminated ceramics occurs, the acceleration of the Counter mass exerts an inertial force onto the Main mass. And if the exerted force exceeds the force of static friction, the Main mass starts to move. Slow expansion or contraction is then carried out so that the Main mass does not move back to the original position. By such a simple mechanism, a stable displacement resolution of 4nm/impact and a maximum speed of 10 mm/sec were confirmed at ambient pressure. The elimination of the chucking element and the above mentioned positioning performance proves its superiority over the conventional inch worm or louse.

However, it should be pointed out that the time duration of one impact is in the order of 10 μs. This means that if the control bandwidth of the Z element is not sufficiently high, a tip to target collision will occur during the rough positioning procedure. To avoid such problems, we have adopted the following procedures. (1) The Z element is retracted before each impact. (2) step movement approach of approximately 50nm is executed. (3) the Z element goes into the equitunneling current controlled state and is elongated to a maximum of 150 nm to search if the target is within the next step. (4) if the target is not in proximity, the Z element is fully retracted and the Impact-Drive-Mechanism is again activated.

4. The Position-Lock function

Most STMs suffer from problems of drift. For example, the drifting of the probe tip, or, an undesireable drifting of the area of observation. This is inevitable if the XY scanner is driven by a simple open-loop voltage or charge drive. To eliminate drift, the authors have pointed out the effectiveness of feed-back control of the XY scanner from the information gained from the acquired STM image[3)].

In this chapter, application of dizzer vibration will be introduced. Figure 3 shows the basic structure of the circuit for Position-Lock of a probe tip over an atom or a hillock. The following explanation will be

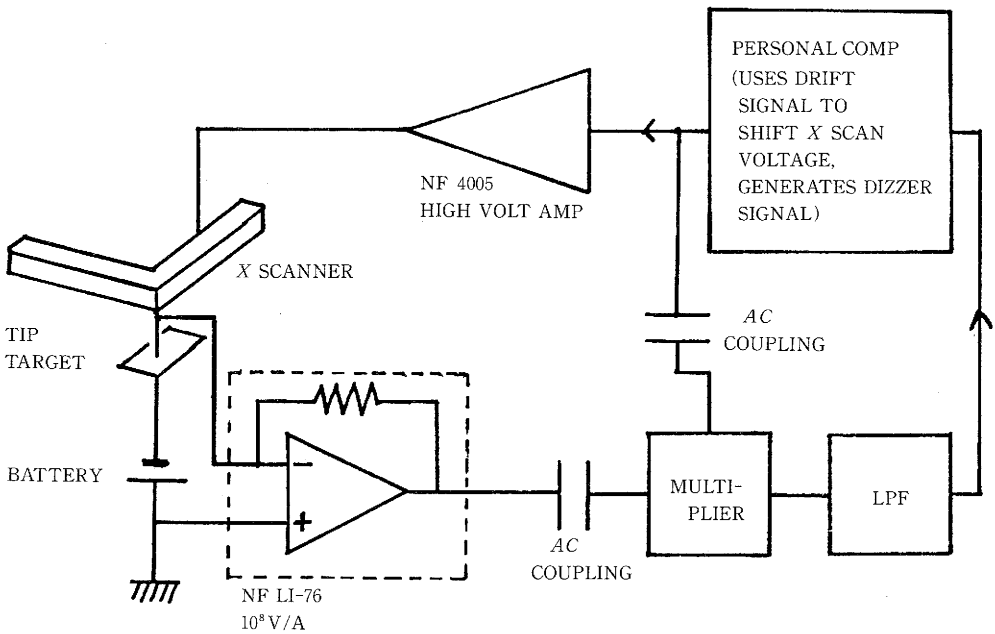


Fig. 3　Circuit for dizzer-Vibration Position-Lock Procedure

for the X degree of freedom. (1) A small amplitude of dizzer vibration is superimposed onto the X scanner. (2) the AC coupled signal of the tunneling current and the AC coupled signal of the X scanner electrode voltage are multiplyed. (3) the output of the multiplier is then connected to a low pass filter to integrate the signal around the dizzer frequency. (4) output of the low pass filter is positive when the centre of dizzer vibration moves to the negative direction of X, and vice versa. $X=0$ is defined as the position of the atom over which the Position-Lock is carried out. (5) by connecting the output of the filter to the computer, the computer generates a X scanner scanning signal that compensates the drift.

By changing the polarity of the feed-back signal, a Position-Lock control with either convex-surface-stable or concave-surface-stable characteristics can be realised.

As an interesting application of this control, a stepping action of the probe tip by an intentional feed-back polarity-switching of the drift-control signal can be pointed out. This may be regarded as a "stepping motor" that uses crystalline lattice as the "teeth" of the stator poles.

5. Examples of application

In this chapter, various examples of the expected application will be introduced in greater detail.

5-1　Calibration of the STM image

As pointed out in Chapter 1, an STM image acquired by open-loop voltage drive of the XY piezoelectric scanner is locally compressed or elongated due to the non-linearity of voltage-displacement characteristics of the scanner. One solution to this problem is the charge drive of the scanner. As another solution, the authors are presently investigating the effectiveness of using the lattice structure of a crystal as the reference of length. If this method gives satisfactory results, there is a possibility of using the crystal as the standard of length in measuring micro machined objects. The authors are planning experiments to check the effective digit of this measuring procedure.

5-2　A positioning table[3)]

The authors have introduced the basic idea of a positioning table incorporating a tunneling unit. Since it uses crystalline lattice as the reference index, it was named "XPOS" for short. "X" standing for crystal. One tunneling unit of the Dual-Tunneling-Unit STM can be used to execute the function of the XPOS. By taking in a map of the topographic features of the index target, or by counting the number of lattices, high resolution positioning and repeatability can be expected.

6. Further studies and comments

It should be here pointed out that the preparation of the apparatus has only recently been completed. Effectiveness of the various functions mentioned in this paper are to be confirmed and reported in the near future. The authors greatest interest in this research is the following;

(1) measurement of length of a certain object. Repeated measurement of an object using various reference crystalline targets composed of the same element (eg, silicone). Confirmation of the effective digit of this measuring procedure.

(2) confirmation of the positioning function and the Position-Lock function.

7. Acknowledgement

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