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New Scanning Mode of Scanning Tunneling Microscopy

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ABSTRACT

The coincidence scanning mode has been developed by analyzing feedback equations for constant-current scanning and imaging surfaces with atomic resolution with the new mode.This mode can be almost applied to the feedback control of all sorts of SPM instruments,and reduces the scanning time to 60%.

Keywords: STM, scanning mode, coincidence scanning

1. INTRODUCTION

Scanning tunneling microscopy (STM) [1] can be sorted as constant-altitude mode and constant-current mode by measuring methods. Constant-altitude mode is only used to samples with comparatively smooth surface, while constant-current mode can be used to measure samples with irregular surface. The shape of samples is unknown in factual application. In a general way, when the vertical distance from pit to heave of surface is over 10 nm, as a result of avoiding the collision between probe and heave, it cannot form tunneling current between probe and pit of the surface. This limits the application of constant-altitude mode on STM. This paper is associated with constant-current mode and discusses the function of Coincidence mode.

Present constant-current scanning modes are usually based on time, and provided with two scanning frequencies: slow scanning (usually at a frequency of 2 Hz) and fast scanning (usually at a frequency of 10 Hz). We must use slow scanning mode to reduce image distortion when the samples have some considerable changes. Current STM usually adopts slow scanning mode for the unknown pattern of sample surface. The scanning region of typical STM is from several nanometers to 100 μm with 64 to 512 data dots (some instruments up to 1024 data dots) per row and a square scanning image which has data dots from 64×64 to 512×512 (or 1024×1024), so the total data dots are summed up from 4 096 to 262 144 (or 1 048 576). The scanning time is 32 s to 256 s (or 512 s), and this has limited the application of STM. Afterwards an improved method processing at fast speed in linear scanning and slow speed in turning scanning direction has come out to overcome measuring errors when turning probe back. In present article [2] an improved method by the name of 'adaptive scanning' can automatically reduce scanning frequency to 2 Hz when the instrument detects mutation of sample surface, and increase scanning frequency to 10 Hz when scanning considerable smooth surface. From all accounts, this method can execute higher scanning frequency and gain considerable precision in measuring steep sample surface at the same time.

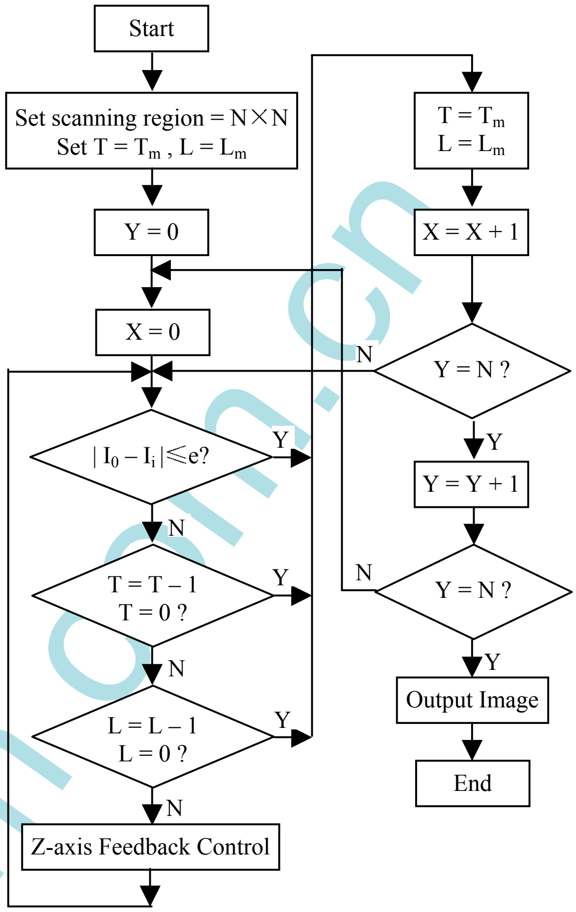
Current constant-current mode is limited with two defects. One is scanning time superabounds. When the scanner has reached a dot even if the tunneling current equals the reference current, the scanner still waits a fixed period at this dot and then moves to another dot. This is the cause of increase of scanning time. On the contrary, the other defect is lack for scanning time. If the scanner reaches a dot where tunneling current does not approach to reference current in the fixed scanning period, it goes to scan next dot in despite of the two currents are unequal and leads to a false image data as a result.

2. COINCIDENCE MODE

A new scanning mode by the name of 'coincidence mode' is stated in this paper as follows: X and Y scanners process no longer by time but by the 'coincidence flag' between tunneling current and reference current at the comparator in the circuit. Coincidence flag comes out at the dot where tunneling current equals reference current.

Coincidence mode overcomes the defects of exiting constant-current scanning mode. When the scanner reaches a dot, it goes to scan the next dot if tunneling current equals the reference, or holds scanning at this dot until these two currents equal. It reduces measuring time and assures the precision as well.

Specific adjustment flowchart is shown in fig.1. Where T_m is the upper limit of scanning time. L_m is the maximum of displacement of the probe. I_0 is reference current. I_i is tunneling current. e, as an error, will be discussed in the following text. X and Y mean coordinates of the scanning array.



3. Z-AXIS FEEDBACK ADJUSTMENT

The height adjustment of probe is controlled by control circuit. The circuit outputs a control signal according to a control algorithm and changes the voltage applied to the PZT. The height of the probe attached to the PZT changes while the sample is unmovable. It has no specific relation between the voltage and the displacement for the non-linearity of PZT. Usually we can resolve this matter by software amendment, hardware compensation and close loop control. In practice software amendment and hardware compensation are both unable to eliminate the non-linearity error while close loop control can.

Usually STM applies PID (or PI) algorithm to close loop control adjustment. PID is one of the most commonly used algorithms in automatic control. And its form can be described as equation

$$u(t) = K_p \left[e(t) + \frac{1}{T_i}\int_0^t e(t)dt + T_d de(t)/dt \right]$$

PID adjustment of PZT is shown in Fig.2.

According to the figure, PID adjustment is characterized with oscillations in the initial two or three periods before it swings to the set value. We can develop the process through adjusting the parameters. The swing can be very smooth when the sample surface is comparatively smooth but be difficult to set parameters for irregular samples.

In this paper we apply fuzzy control algorithm, a powerful tool to eliminate non-linearity, to height adjustment of the probe, and have attained good effects. Fuzzy control mainly generalizes operators' experience as fuzzy control rules and input computer after being processed with fuzzy mathematics. On the other hand, fuzzy control simulates ratiocination of brains and establishes fuzzy ratiocination rules in computer. It processes with fuzzy control rules and fuzzy ratiocination rules, outputs fuzzy control signals, and controls movement at last.

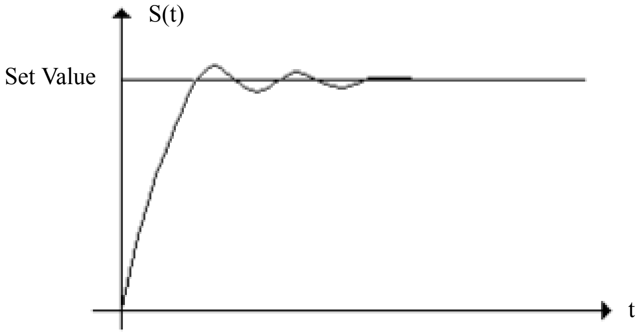


Fig.2 PID control

By setting fuzzy control parameters and control table step by step, the adjustment will get to set value in one (or two) period. It has obviously improved the adjustment speed as well as adjustment precision.

Fuzzy control adjustment curve is given in follow curve.

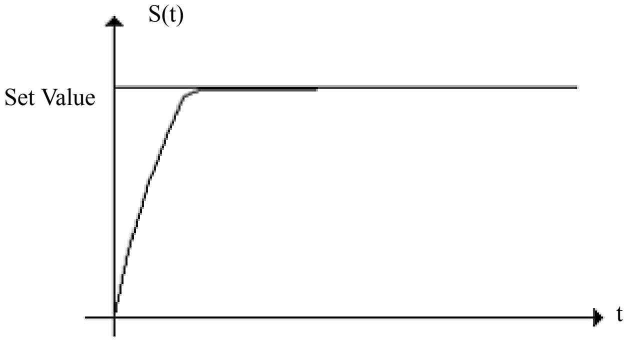


Fig.3 Fuzzy control

4. EXPERIMENTS

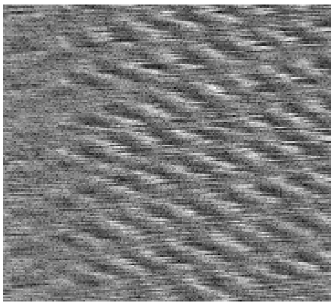
Experiments have been carried out on CSTM-9000 type STM using coincidence mode. Adjustment period are set with 100 µs (A/D conversion time is 2µs, D/A conversion time is 1µs) considering the drive power and response time of PZT. An experimental study of the scanning on the same region of the surface of a plumbago sample with the two sorts of mode presents a different result. The images are shown in fig. 4.

The experiment shows that the scanning speed of new mode is about two times faster than old mode's. And the image quality has been improved. Two practical considerations have been solved in the experiment.

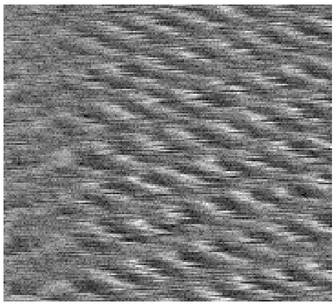
One case is samples have fatal defects. In such case the tunneling current maybe can't get to the reference current (or disappears), and the scanner can't work normally. We can add two diagnose signals. One signal is interval time. The scanner steps over the dot (tagged as defect) to the next dot if the tunneling current is not equal with reference in prearranged time T_m. The other signal is displacement of Z-axis. The scanner also steps over the dot if scanner has moved over a prearranged distance L_m and that the tunneling current is not equal with reference.

The other one is the degree of coincidence of signals. It will take a considerable period to make tunneling current equal with reference. In this paper an error band ($e > 0$) is set up in the experiment. When the absolute value of the difference between tunneling current and reference is less than e, we call it coincidence and amend the image with the difference.

5. CONCLUSION



(a) original mode
scanning area 1 μm×1 μm
resolution 180×180
average time 40.6 s



(b) new mode
scanning area 1 μm×1 μm
resolution 180×180
average time 15.1 s

Fig.4 scanning experiment images

The 'coincidence mode' stated in this paper can be applied not only to STM, but also AFM (atomic force microscope) and almost all other SPMs (scanning probe microscopes) to control Z-axis feedback adjustment. It provides great support in improving measurement precision and speed of STM. Especially it has latent significance in transition from 'observation STM' to 'metrology STM'.

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REFERENCES

[1] Kuk Y, Silverman P J. Scanning tunneling microscope instrumentation [J]. Review of Science Instruments, 1989, (2): 120-125.
[2] Technique & Technologies for Scanning Probe Microscopy [Z]. Park Scientific Instruments, 1997.

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