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ADVANCES IN STM DESIGN AND INSTRUMENTATION

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In the past, scanning tunneling microscopy (STM) [1] and related scanning techniques have led to a remarkable progress in understanding the structure of surfaces. This progress was mainly initiated by improvements in instruments' design and reliability of operation. A few years ago, experimentalists were proud to show the atomic resolution capability of their instruments in all kinds of environments, such as in air, in inert gas atmospheres, in liquids, in ultrahigh vacuum (UHV) and at low temperatures. Today, effort is being made to construct scanning tunneling microscopes (STM's) which work under extreme conditions, e.g. at the lowest possible background pressure, at the lowest possible temperatures and at the highest possible magnetic fields. For instance, A.P. Fein et al. [2] have designed a STM which can be operated at temperatures down to 400 mK and in magnetic fields up to 8 T. In the authors' laboratory, a UHV compatible STM has been built up, working in the 10^{-12} mbar range (fig. 1). Combinations of STM with other microscopical or analytical techniques have been realized, such as with optical, electron

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or field ion microscopes as well as with almost all known conventional surface analytical techniques. Finally, by changing the probing mechanism between the tip and the sample surface, several STM-related scanning probe microscopes have been invented, offering the chance to measure various kinds of surface properties with a spatial resolution in the nanometer range.

The design criteria for scanning tunneling microscopes have been previously summarized [4-6]. However, depending on the environment in which the STM has to be operated, additional constraints may exist. To achieve the goal of the highest possible tunneling gap stability, it is necessary to construct the STM as rigidly as possible. This is particularly important for environments where only minimal vibration isolation can be added, e.g. for a STM working in a liquid helium cryostat. On the other hand, operating a STM in UHV requires at least an in-situ sample exchange mechanism and preferably an in-situ tip exchange mechanism. This demand automatically leads to an increase in the size and a more open construction of the STM unit, thereby decreasing its rigidity. Therefore, an efficient vibration isolation system has to be added. In UHV, the best choice may still be a two stage spring system combined with eddy current damping (fig. 1), as originally used by G. Binnig, H. Rohrer and coworkers for the second generation STM. Additionally or as an alternative, a stack of metal plates separated by Viton damping elements may be used as was first successfully demonstrated for the "pocket-size" STM [7]. Commercially available vibration isolation systems consisting of pneumatic damping elements are used in conjunction with STM's working in all kinds of environments.

For the coarse approach of the sample towards the probing tip, a piezoelectric walker (the "louse") was used in the early days of STM. Today, piezoelectric driving elements such as "inchworms" or electromagnetic walkers (fig. 1) are implemented. To further increase the rigidity of the STM unit, differential screws driving either a reduction lever or a differential spring system have also proven to be successful in many STM designs (fig. 2). Finally, replacing the piezoelectric tripod scanning unit by a tube scanner [9] afforded the opportunity to construct even smaller and more compact STM's with higher resonance frequencies. However, piezoelectric hysteresis, creep and crosstalk between the three possible directions of movement still remain a problem, particularly for large area scans (several square micrometers).

Advances in the mechanical part of the STM design have been accompanied by advances in the STM electronics and computer automation. A standard STM electronics and data acquisition system nowadays consist of a computer controlled approach circuit, a sample bias voltage supply (either by a battery or a computer controlled DAC), a preamplifier with a gain of 10^6-10^9 V/A, a logarithmic amplifier, a feedback loop realized either by an analog integrator and a proportional amplifier or by a digital feedback, a scan generator provided either by synchronized ramp generators or computer controlled DAC's, high voltage amplifiers for the amplification of the scan- and feedback signals applied to the x-, y- and z-piezoelectric drivers respectively, and several ADC's for digitizing the desired signals (feedback signal, current etc.). A sample and hold circuit is desirable for the implementation of all kinds of spectroscopic capabilities. A minimal electronic noise level is as important as a minimal electrical pickup of disturbances from external sources such as switches.

The most important progress in STM required for the future might be a better control of the probing tip on the atomic scale. Producing STM tips by simply cutting a Pt-Ir wire or by electrochemical etching of a W wire, sometimes combined with an additional in-situ treatment such as electron bombardment, field emission or voltage pulses, undoubtedly yields satisfactory images of atomic surface structures. However, particularly for the interpretation of spectroscopic information, a better knowledge of the front tip cluster and its electronic states, which support the tunneling current, is desired. Well defined single atom tips [10] used for STM investigations might help to solve this problem.

Besides the progress in STM instrumentation, many novel related scanning probe microscopies have been invented during the past years [11]. Their development has greatly profited from the experience which has already been gathered with STM.

These novel scanning probe microscopies offer the chance for studying surfaces of materials not accessible by STM (e.g. surfaces of bulk insulators). They also provide additional information, such as magnetic stray field distributions, charge distributions, frictional properties, thermal profiles, to mention only a few. The whole family of scanning probe microscopies has already led to a novel perception of nanometer scale properties of matter. Future progress in design and instrumentation of scanning probe microscopes will at least partly arise from miniaturization, such as the construction of "STM's on a chip" [12], leading to micrometer or at best nanometer probes for nanometer scale properties.

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REFERENCES

[1] G. Binnig and H. Rohrer, Helv. Phys. Acta 55, 726, (1982).
A. Baratoff, Europhys. News 17, 141, (1986).

[2] A.P. Fein, J.R. Kirtley, and R.M. Feenstra, Rev. Sci. Instrum. 58, 1806, (1987).

[3] R. Wiesendanger, G. Tarrach, D. Bürgler, T. Jung, L. Eng, and H.-J. Güntherodt, Proc. IVC-11/ICSS-7, Cologne, Sept. '89, Vacuum (in press).

[4] D.W. Pohl, IBM J. Res. Dev. 30, 353, (1986).

[5] Sang-il Park and C.F. Quate, Rev. Sci. Instrum. 58, 2004, (1987).

[6] Y. Kuk and P.J. Silverman, Rev. Sci. Instrum. 60, 165, (1989).

[7] Ch. Gerber, G. Binnig, H. Fuchs, O. Marti, and H. Rohrer, Rev. Sci. Instrum. 57, 221, (1986).

[8] D. Anselmetti, R. Wiesendanger, V. Geiser, H.R. Hidber, and H.-J. Güntherodt, J. Microsc. 152, 509, (1988).

[9] G. Binnig and D.P.E. Smith, Rev. Sci. Instrum. 57, 1688, (1986).

[10] H.-W. Fink, Phys. Scripta 38, 260, (1988).

[11] For a recent review see: H.K. Wickramasinghe, Sci. Am., Oct. 1989, p. 74.

[12] T.R. Albrecht, Ph.D. Thesis, Stanford University, 1989.

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Figure Captions

Figure 1:

a) Schematic drawing of a STM unit used in the authors' laboratory for surface studies of metals and semiconductors in UHV. An electromagnetically driven wedge transforms its horizontal movement into the vertical movement of a sample stage which carries the clamped sample holder with the horizontally mounted sample. The scanhead rests on three ballbearings and can be flipped backwards, giving easy access to the sample and tip.

b) The STM unit described in a) is mounted on top of a stack of five stainless steel plates separated by Viton rubber elements. This stack itself is supported from the inner platform of a two stage spring system combined with eddy current damping. The whole unit (STM plus vibration isolation system) can be mounted into a UHV chamber through the bottom flange by using an elevator.

c) Schematic drawing (top view) of the entire UHV surface analysis system ("NANOLAB") consisting of a surface analysis chamber, a transfer, a preparation and a separate chamber containing the STM (from right to left). Preparation facilities include resistive and electron beam heating, ion etching, evaporation, gas inlet and high pressure gas reaction. Conventional surface analysis techniques such as LEED, SEM/SAM, XPS and UPS are used for additional characterization of the surfaces and for getting complementary information. The whole UHV system is mounted on sixteen air pads for further vibration isolation (see also ref. 3).

Figure 2:

a) Photograph and b) schematic drawing of a rigid STM unit used in the authors' laboratory for surface studies in air, in inert gas atmospheres and at low temperatures. The approach mechanism is based on a differential lever system consisting of two levers with different spring constants. The sample, which is mounted on the lever with the higher spring constant, can be moved towards the tip by reducing the tension of this lever with the coarse approach screw. By bending the lever with the lower spring constant with the fine approach screw, a high reduction of the sample movement can be achieved. A single piezoelectric tube scanner with the tip holder is fixed to a rotatable scanning head. After rotating the scanning unit by 90°, the tip and sample can easily be exchanged. The microscope is rigid enough to be operated at low temperatures without additional damping system but can also be mounted on top of a stack of five stainless steel plates separated by Viton rubber elements or supported by a commercially available antivibration table (see also ref. 8).

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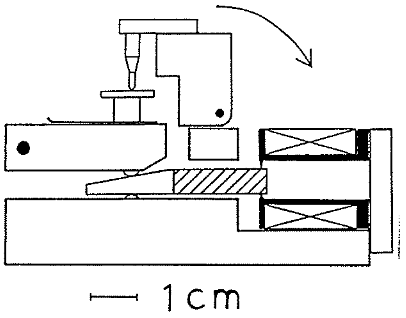

Fig. 1a

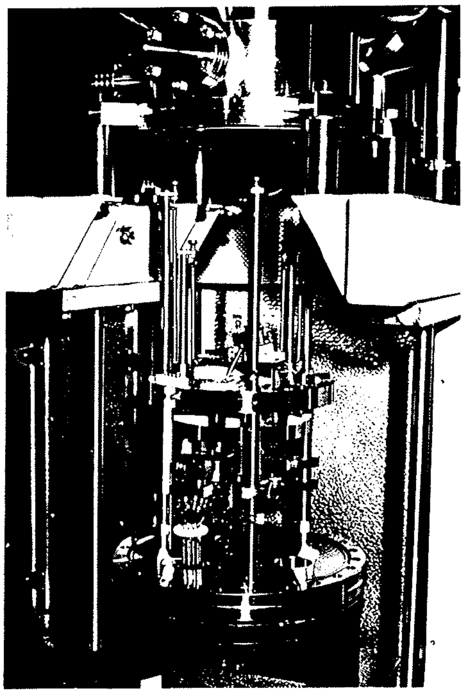

Fig. 1b

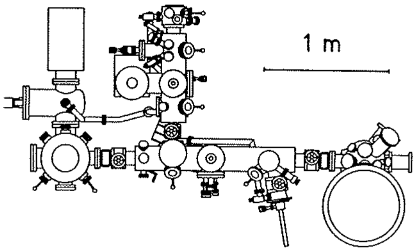

Fig. 1c

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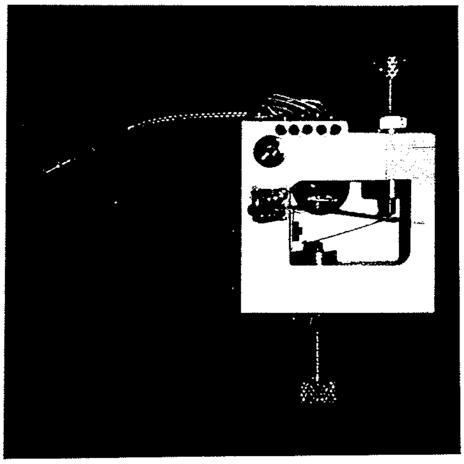

Fig. 2a

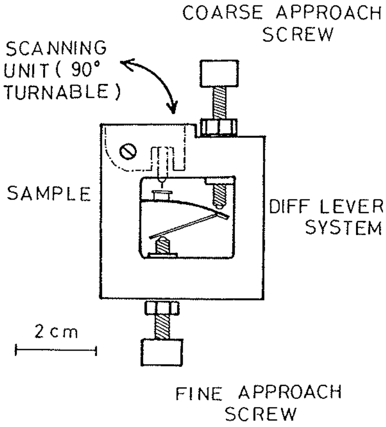

Fig. 2b

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