ULTRAHIGH VACUUM SCANNING TUNNELING MICROSCOPE

STM *GPI-300*

GPI SPM is a line of ultrahigh vacuum scanning probe microscopes designed for surface investigations with atomic resolution. The following principles are in a basis of a design of devices:

- *It should work in a combination to standard methods of the surface analysis and preparation in ultrahigh vacuum*

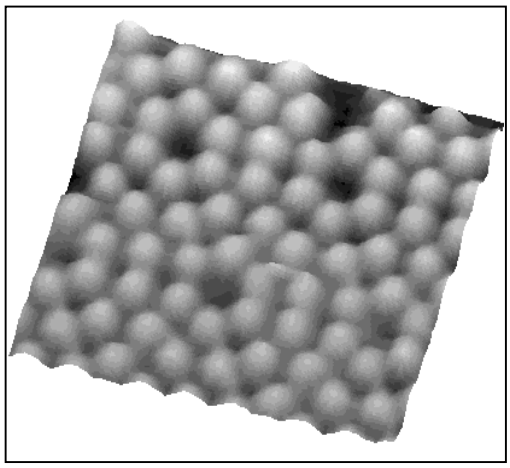
- *The open access to a surface of a sample for influence by electrons, ions, photons, atoms and molecules should be provided while scanning.*

- *Control electronics, vacuum module, sample/tip transfer system, arrester and other components of the scanner should, if possible, stay the same for any type of the scanning head: atomic-force, spin-polarized etc. even for variable sample temperature option.*

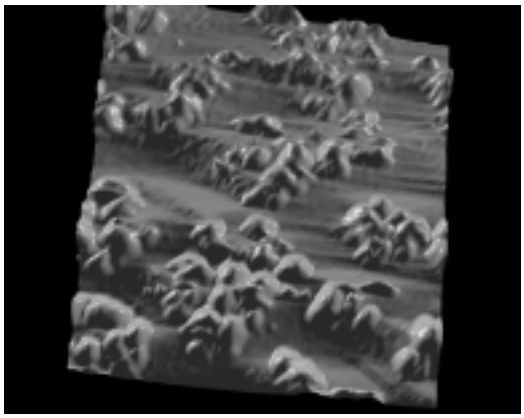
GPI-300 is a ultrahigh vacuum scanning tunneling microscope, designed for *in situ* surface processes study with atomic resolution at room temperature. It can be used for study of any surface processes *in vivo*. Areas of application:

- chemical and photochemical reactions,
- heterogeneous catalysis
- coating and epitaxy
- semiconductor technologies
- adsorption
- modification of a surface by ions, electrons and other particles
- nanotechnology, single-atom manipulations

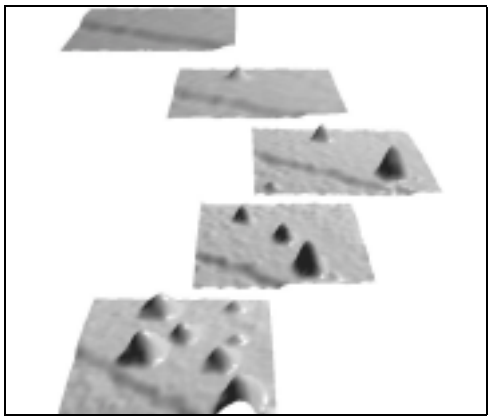
GPI-300 was developed in General Physics Institute (**GPI**) of the Russian Academy of Sciences in 1994 and since that time it has been successfully employed in the Surface Phenomena Laboratory at GPI. The main objects of studies are the reaction of halogens with metals and semiconductors, carbon nanotubes material and radiation defect behaviour on a surface of graphite.



Si(111)(7x7) surface.



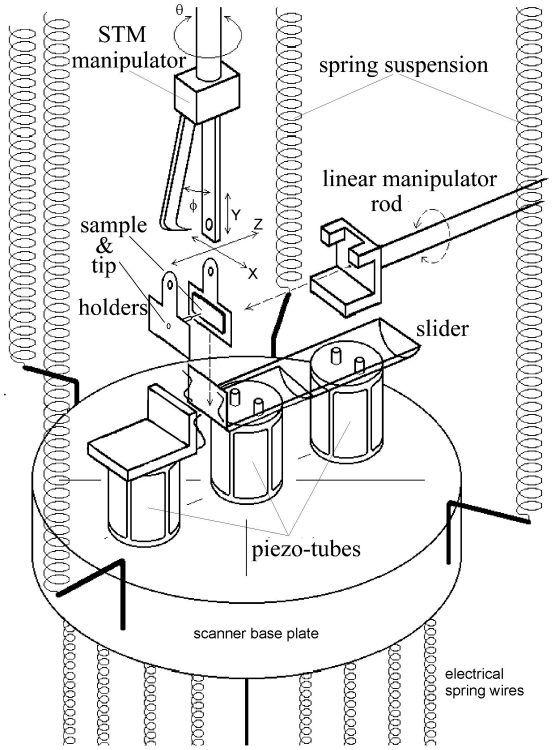
Copper choride islands.

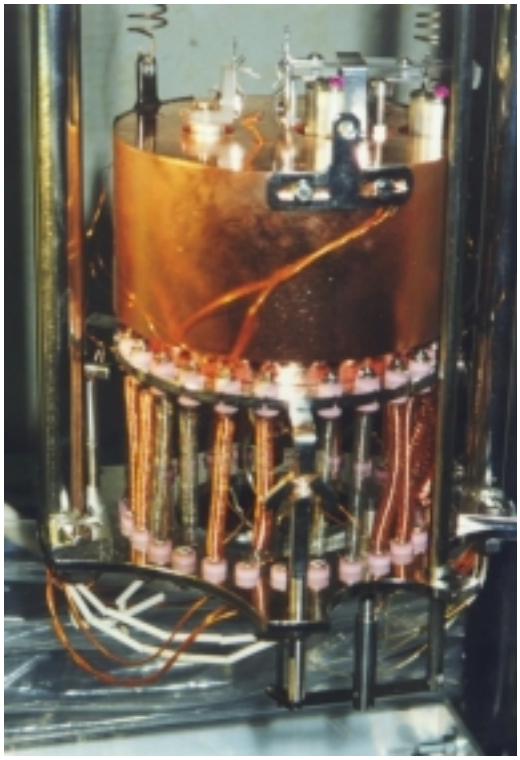


Sequence of five images illustrates a process of nanoobjects creation.

The most significant scientific results, obtained with the help of such STM:

1. B.V.Andryushechkin, K.N.Eltsov, V.M.Shevlyuga, “Commensurate-incommensurate structural transition in chlorine monolayer on Cu(111)”. Phys. Rev. Letter, submitted.
2. B.V.Andryushechkin, K.N.Eltsov, V.M.Shevlyuga, V.Yu.Yurov. “Direct STM observation of surface modification and growth of AgCl islands on Ag(111) upon chlorination at room temperatures”. Surface Science, 431 (1999) 96-108.
3. B.V.Andryushechkin, K.N.Eltsov, V.M.Shevlyuga. “Atomic structure of silver chloride formed on Ag(111) surface upon low temperature chlorination”. Surface Science, 433-435 (1999) 109-113.
4. B.V.Andryushechkin, K.N.Eltsov, V.M.Shevlyuga, V.Yu.Yurov, “Fourier analysis of STM images to measure structural parameters of adsorbed layers”. Poverkhnost (Russian), 7 (1999) 35.
5. B.V.Andryushechkin, K.N.Eltsov, V.M.Shevlyuga, V.Yu.Yurov. “Atomic structure of saturated monolayer on Ag(111) surface”. Surface Science, 407 (1998) L633-L639.
6. K.N. Eltsov, “Surface chemical reactions and their application for nanotechnology”. Review paper in “Izvestiia Akademii Nauk” (in Russian), 67 (1997) 985. Presentation on the Presidium of Russian Academy of Sciences, December, 1996.
7. K.N.Eltsov, A.N.Klimov, V.Yu.Yurov, U.Bardi, M.Galeotti, V.M.Shevlyuga and A.M.Prokhorov, “Surface atomic structure at Cu(100) chlorination observed with scanning tunneling microscopy”. JETP Lett. 62 (1995) N5, 444-450.
8. E.Obraztsova, V.Yy.Yurov, R.E. Baranovsky. V.M. Shevlyuga, V.A. Nalimova, V.L. Kuznetsov, V.I. Zaikovskii, “Structural Investigation of close-packed single-wall carbon nanotube material”. Nanostructured Materials, 11 (1999) 295.





The original STM design described in [K.N.Eltsov, A.N.Klimov, S.L.Priadrin, V.M.Shevlyuga, V.Yu. Yurov, Phys. Low-Dim. Struct. 7/8 (1996) 115] was taken as a basis for the commercial device ***GPI-300***. The scanner consists of three piezo-ceramics tubes, fixed in one line on a surface of a massive copper platform. Every tube has four outside and one internal metal electrodes, that allows to carry out positioning of the free end of the tube in three coordinates X, Y, Z. The tip holder is mounted on the left piezo-tube, and the sample holder is fixed to a special slider that lies on four sapphire balls on the top of two others tubes. The sample and the tip transfer from a linear manipulator into the STM is carried out by the XYZ-manipulator. After positioning to a distance of 2-3 mm the tip and the sample could be easily closed in to a distance of a tunnel gap (5-10 Å) by piezo-inertial movement realized by means of two piezo-tubes: quartz slider with a sample slips on sapphire balls. Direction and the speed of movement is adjusted by the special generator, controlled by a computer. Such a movement is in Z- and X- directions with speed up to 2 mm/min with accuracy of positioning up to 5 nm.

The platform with the scanner is suspended by means of long springs as the main step of vibroisolation system, the other step is small viton columns, separating suspending system and a case of the vacuum chamber. Electrical feed-throughs for input/output signals are mounted on DN40-CF flanges of the nipple. The control and signal wires, that pass separately through metal tubes of a support frame, are distributed on a circle of the bottom motionless ring and then, are connected to the scanner by springs. Samples and tips transfer occurs at an arrested position of the scanner on motionless support on the bottom ring. For this purpose the arresting system, including standard rotary feed-through (DN40-CF or DN16-CF) is used.

In ***GPI-300*** the digital electronics unit for the control and data acquisition was developed on the basis of the digital signal processor (DSP) ADSP-2181. It consists of control logic, RAM and SRAM, ADCs and DACs of a high word length (up to 20 bits), high-voltage amplifiers (HVA ±150V) and generators (see the diagram below). The software allows to carry out structural and spectral measurements of any degree of complexity. Flexible architecture of the unit and software can be adjusted easily the for various types of scanners.

The Control System structure
for UHV/STM Room Temperature

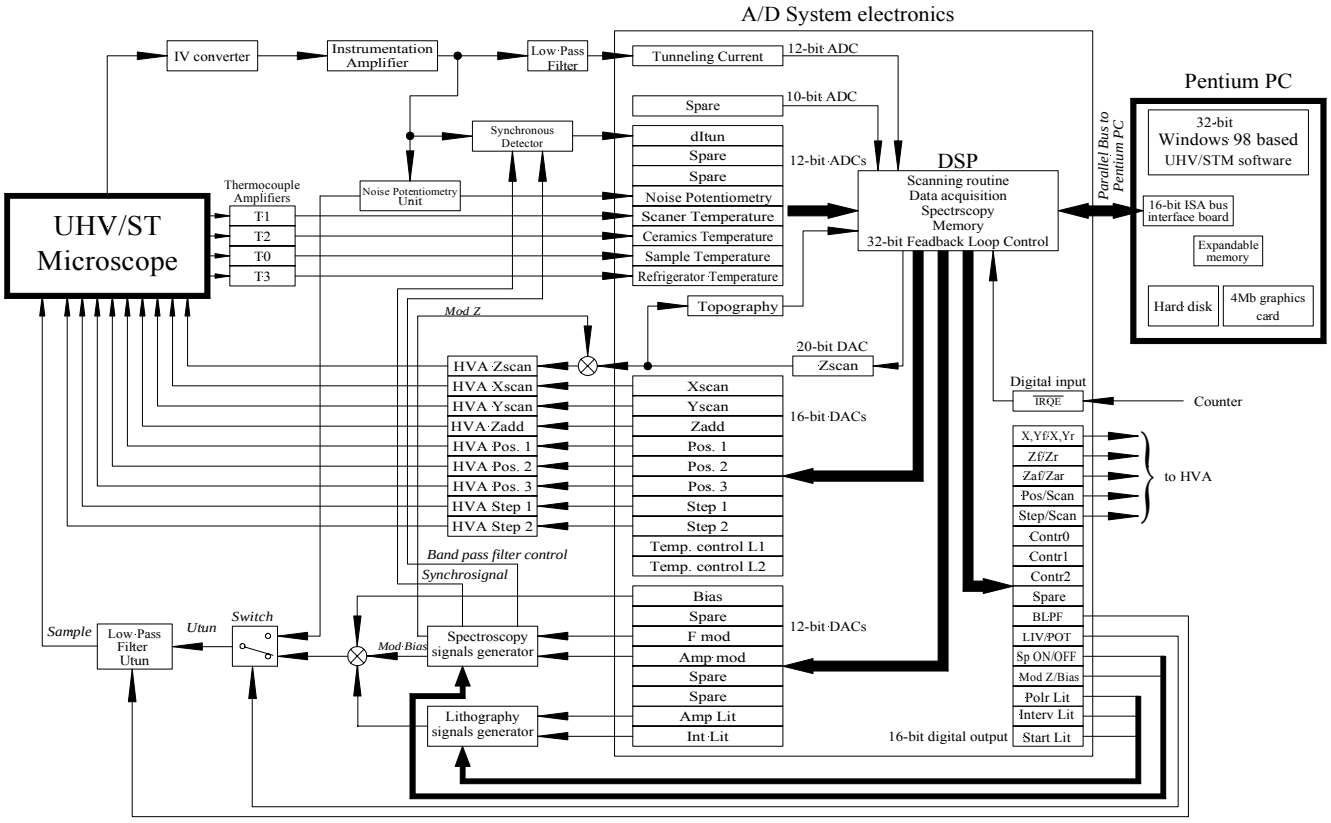


Fig. 1

The control system consists of:

- The digital electronics unit;
- Low-noise I-V converter in UHV design mounted directly on the scanner;
- Preamplifier and filters connected to electrical feed-throughs of the vacuum module;
- Two levels of the software (the low one - the program loaded in DSP and the top one - the program, running on the host-computer). The software performs various types of scanning: a mode of a constant tunnel current, a mode of constant height, a mode of work-function mapping, a special mode of measurement and elimination of both drift and slope distortions of an image (and for initial piezo-ceramics calibration as well) [V.Yu. Yurov, A.N.Klimov, Rev. Sci. Instrum.65 (1994) 1551]. Besides there is a mode of V-I or Z-I spectroscopy in any point of the image and lithography mode as well.

Specification

Working temperature	Room temperature	
Max. Scanning area With high voltage amplifiers (HVA) Without HVA	(X,Y,Z) 1.8x1.6x1.8 μ^3 140x130x140 nm^3	
Max. Positioning area	(X,Z) 5x11 mm^2	
Resolution With HVA Without HVA	(X,Y) 0,3 Å 0.02 Å	(Z) 0.02 Å 0.0014 Å
Verified resolution	Atomic resolution on metals	
Approaching and positioning method	Piezo-inertional	
Tunnel current range	0,01÷12 nA	
Bias voltage range	±10 V	
Stationary drift	0.1 nm/min	
Resonant frequency of the scanner	2.5 kHz	
Feedback loop type	Digital	
Sample size	(X,Y,Z) 10x6x2 mm^3	
Resonant frequency of the suspension	1.2 Hz	
Vacuum module size	200x200x630 mm^3	
Vacuum module flange	200 mm (DN160-CF)	
Baking temperature	150 C	
Base pressure	$1x10^{-10}$ Torr	
Compatibility with other methods of influence and analysis of a surface while scanning	Ions, laser irradiation, electrons, molecules, optical spectroscopy	

GPI-300 *has several distinctive features allowing to use it easily in a combination with other methods of the analysis or technology in ultrahigh vacuum.*

In particular,

- The application of piezo-inertial system for a tip to sample approach has allowed to create the scanner with " open architecture ". It, in turn, gives a basic opportunity to influence on a surface by molecular, laser, electron or ion beams and to analyse the appropriate characteristics of a surface simultaneously with STM images obtaining.
- The uniform standard of the tip and sample holders allows to use a uniform way for their transportation inside vacuum set-up. The system of transportation uses only standard, commercially available XYZ- and linear manipulators. It allows easily to build STM in existing technological and analytical ultrahigh vacuum chambers. Small STM chamber also can be attached to any vacuum set-up, in which transport of samples is made, as a rule, by means of linear manipulators.
- The verified technology of cleaning and sharpening of STM probes by ion bombardment in vacuum, guarantees to deliver sharp, atomically-clean probes to the scanner. The restoration of a probe, spoiled during scanning, can be made *in situ* as well.
- Besides analytical opportunities, such as actually microscopy and spectroscopy, the ***GPI-300*** has function of local modification of a surface with the help of the STM-probe.

The *GPI-300* set-up consists of:

- Ultrahigh vacuum STM module including scanner, internal vibroisolation system, and arrester mounted on DN160-CF nipple with eight DN40-CF flanges;
- Control system including the digital electronics unit, low-noise I-V converter in UHV design mounted directly on the scanner, preamplifier and filters with connectors to electrical feedthroughs of the vacuum module;
- The software;
- The end-piece on the linear manipulator for tip and sample holders transportation
- The appliance for the tip and sample holders capture by XYZ - manipulator

GPI-300 can be delivered together with technology of preparation of tungsten tips with an angle of sharpening ~ 20^{o} and apex radius 2-4 nm, [K.N.Eltsov, V.M.Shevlyuga, V.Yu. Yurov, A.V.Kvit, and M.S.Kogan, Phys. Low-Dim. Struct. 9/10 (1996) 7]. As the first stage of tip preparation the standard procedure of a tungsten wire etching in an electrochemical cell mounted on a vibroisolated table is used. The oxide removal and final sharpening of tips is made by an ion bombardment directly in the vacuum chamber. The delivery consists of an electronic unit for the wire etching process control, electrochemical cell and complete technological card including a stage of tips sharpening by ion etching.

Service:

1. Adjustment of the STM into UHV chamber of the customer
2. Installation of the technology for tungsten tips preparation
3. Experimental research in a field of customer's interests with training of the local personnel.

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