The advantages of using the scanning tunneling microscope for accurate measurements when solving problems in nanotechnology are considered. The results of noise measurements made using the scanning tunneling microscope are presented and it is shown that the fundamental limitation on the spatial resolution along the normal to the surface of the sample being investigated is due to low-frequency fluctuations of the tunnel current. The limit sensitivity of the microscope is determined.

The scanning tunneling microscope is an instrument which enables one to measure the geometrical relief and physical properties of conducting surfaces with atomic resolution [1]. It enables the electron properties of a surface and their role in the formation of surface structures to be investigated. Below we describe the physical principles of the operation of the scanning tunneling microscope, we present some experimental results of measurements of the relief of the surface structure of certain materials, and we consider the noise of the scanning tunneling microscope, on which its limit sensitivity depends. The results of measurements of the internal and external sources of noise of the microscope, which determine the limit sensitivity of the electronic apparatus, are given.

The operating principle of the microscope is based on the high sensitivity of the tunnel current to the distance between the conductors which form the tunnel contact. In the simplest model, namely, vacuum tunneling, metal electrodes, and a one-dimensional potential barrier, the tunnel current density is given by the formula [2]

$$j_t = \frac{2e^2}{4\pi\hbar} U_t \exp(-2k_0 s),$$

where $e$ is the electron charge, $\hbar$ is Planck's constant, $s$ is the probe-sample distance, $U_t$ is the potential difference across the tunnel contact, $k_0$ is the attenuation constant of the wave functions of the electrons in the contact, $k_0 = \sqrt{2\mu\varphi}^{-2}$, $\mu$ is the electron mass, and $\varphi$ is the effective height of the potential barrier; usually $k_0 = 0.2-1.0$ Å⁻¹.

It follows from (1) that when the distance $s$ changes by 1 Å, the tunnel current $I_t$ changes by an order of magnitude. Hence, the high-resolving power of the microscope is due to the exponential dependence of $I_t$ on the distance. This enables the tunnel current in the feedback of the controlling voltage $U_z$ to be controlled and, by setting $I_t = \text{const}$, enables the tunnel gap $s$ to be maintained practically constant.

When the microscope operates under constant-current conditions, the piezoelectric manipulator system displaces the needle over the surface of the sample in a horizontal plane, while the feedback keeps the tunnel current of the variation of the vertical position of the needle constant. By recording the feedback signal one can obtain the two-dimensional function $Z(x, y)$, which represents the geometrical profile of the surface. Under constant height conditions, the vertical position of the needle remains unchanged and the tunnel-current function $I_t(x, y)$ is recorded.

Translated from Izmeritel'naya Tekhnika, No. 4, pp. 58-61, April, 1998.
The two-dimensional functions obtained can be processed mathematically by computer, and then displayed graphically in the form of three-dimensional images on the monitor screen or printed out on a printer. In this case the voltage on the piezoelectric manipulators is converted into distance using the known coefficient characterizing the piezoelectric ceramic. For precise calibration of the piezoelectric manipulator one can use test objects with a known spatial structure: the surfaces of different crystals, artificially manufactured nanometric structures with specified topographical features, for example, the surface of highly oriented pyrolitic graphite with a unit cell period of 2.45 Å, according to x-ray analysis data (Fig. 1), and diffraction gratings with a spatial period in the thousands of angstroms range. The use of test objects with such different characteristic dimensions is desirable in order to carry out the most suitable calibration, which takes into account possible nonlinear effects of the piezoelectric transducer. The calibrated instrument can be successfully employed for a quantitative estimate of the dimen-