Low thermal power electron beam annealing of scanning tunneling microscope tips

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An add-on unit was developed that allows the cleaning of scanning tunneling microscope tips by electron beam annealing even if they cannot be disconnected from the piezo scanner *in situ*. The whole scanner tip combination, which is attached to a linear motion stage, is subjected to a pulsed annealing treatment. The heat impact is focused on the outermost tip by sticking the tip through a hole in a grounded Mo screening plate with the cathode mounted on the opposite side. Tungsten tips attached to the scanner of the Omicron ultrahigh vacuum Multiscan Lab were annealed to achieve atomic resolution of ultrahigh vacuum cleaved GaAs (110) faces. A highly doped superlattice package grown on semi-insulating GaAs was also able to be investigated on the cleaved (110) face due to the ability of exact tip positioning with a scanning electron microscope. © *1997 American Institute of Physics.* [S0034-6748(97)04008-2]

Scanning tunneling microscope (STM) measurements under ultrahigh vacuum (UHV) conditions require well-cleaned tips. It is known in particular that the investigation of UHV-cleaved (110) faces of GaAs and related crystals, e.g., those containing superlattices, by cross-sectional STM (XSTM)[1,2] is only possible if the tips are carefully cleaned. For cleaning they are usually disconnected from the scanner and *in situ* cleaned by electron beam annealing. Thereby, a constant heating power is applied until the desired cleaning effect is achieved.

In the Omicron UHV Multiscan Lab[3] a STM and a scanning electron microscope (SEM) are combined; this promises to be most useful for performing XSTM investigations. This combination allows the exact positioning of the tip, e.g., on a superlattice layer, with an accuracy of approximately 100 nm. In this system the tip is connected to the tube scanner as an exchangeable unit in order to have good access to the tip position via the SEM. The tip cannot, therefore, be disconnected from the scanner *in situ* as is possible in other systems. Since the piezoelectric material of the scanner depolarizes at 450 K, a special low thermal power tip annealing procedure has to be applied to avoid an overheating of the scanner.

Two basic measures are taken to reduce the heat budget to the scanner: First, pulsed heating is used instead of stationary heating and, second, a grounded Mo screening plate is mounted to restrict the electron beam heating to the outermost tip region. For pulsed heating, the maximum possible temperature of the scanner (neglecting the cooling by heat radiation and heat conduction across the scanner tube) is given by the thermal pulse energy divided by the heat capacitance of the tip including its metallic mount, which is glued to the scanner tube. In our case an energy of about 1 W s increases the temperature by 10 K; therefore about 13 W s are tolerable.

The Omicron UHV Multiscan Lab consists of a sample preparation chamber and an analysis chamber, the working pressure of both is below 1×10^{-10} mbar. The tip cleaning unit is mounted in the sample preparation chamber. Figure 1 illustrates the tip cleaning setup, including a scanner mount that accepts the scanner/tip combination from the transport rod. Via a linear motion stage, this mount, holding the scanner, can be lowered until the tip reaches through a hole in the grounded Mo screening plate. All electrical connections of the scanner including the tip potential are attached to the scanner holder, which is biased to $+1200$ V. If the dc-grounded cathode filament on the other side of the Mo plate is electrically heated, the emitted electrons are attracted solely by the outermost STM tip. The Mo plate screens the residual tip holder and the scanner from the electrons as well as from the heat irradiation of the cathode. Thus, a pulsed emission current of only 1.2–1.4 mA at an acceleration voltage of 1200 V, corresponding to a heating power below 2 W, is sufficient to clean the tip. Usually, 5–10 annealing cycles of 3 s each are applied with a waiting period of 20–30 s after each cycle. With each pulse the deposited energy is below 6 W s, entailing a maximum possible temperature increase of below 60 K of the scanner tube. The thermal resistance across the scanner can be estimated to be 140 K/W. Since the average heating power is below 0.2 W, the expected average temperature increase of the scanner should be below 30 K. The pressure in the preparation chamber usually rises to 1×10^{-8} mbar during the first annealing step. The procedure is finished when the pressure rise during the pulse is below 5×10^{-9} mbar.

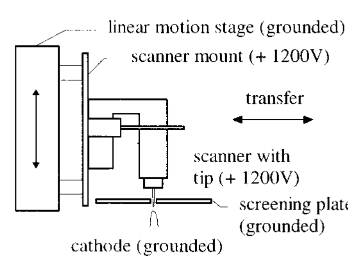

FIG. 1. Schematic of the electron beam annealing setup.

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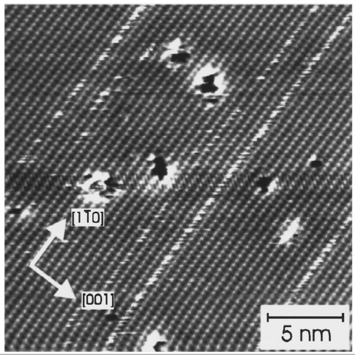

FIG. 2. STM image of a (110)-cleaved 1×10^{18} cm^{-3} Si-doped GaAs surface. The As surface is measured using a gap voltage of -2.9 V and a tunneling current of 0.6 nA.

This procedure was applied to STM tips prepared from a 0.35 mm tungsten wire that was electrochemically etched in a 5% NaOH solution. After etching, the tips were only rinsed in distilled water and then attached to the scanner and transferred into the UHV system. Using these cleaned tips yielded atomic resolution of UHV-cleaved (110) GaAs:Si, as shown in Fig. 2. The typical atomic rows of As in the [110] direction are clearly seen. Furthermore, some point defects and defect clusters are visible, similar to those discussed in Ref. 4. Figure 3 shows the *in situ* UHV-cleaved (110) cross section of a Si-doped superlattice package grown on a semi-insulating GaAs substrate. This investigation was only possible by positioning the STM tip exactly above the 700-nm-thick superlattice during the tip approach, as only this layer is electrically conductive.

For the first time it is shown that cleaning STM tips by electron beam annealing is possible and effective even if the tip is mounted on a STM scanner. This technique improves the experimental possibilities of a system like the Omicron UHV Multiscan Lab to achieve atomic resolution in XSTM investigations of cleaved (110) faces of GaAs and related materials.

FIG. 3. STM image of a (110)-cleaved 5×10^{18} cm^{-3}, Si-doped $GaAs/GaAs_{0.7}P_{0.3}$ superlattice package on a semi-insulating GaAs substrate. The image was taken with a gap voltage of -3 V and a tunneling current of 0.5 nA.

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