Designation: E 1813 – 96 (Reapproved 2007)

# Standard Practice for Measuring and Reporting Probe Tip Shape in Scanning Probe Microscopy[1]

This standard is issued under the fixed designation E 1813; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

## INTRODUCTION

An image produced by a stylus scanning in close proximity to a surface is usually not an exact replica of the surface. The data are subject to a type of distortion called dilation. The amount of dilation depends on the shape and the orientation of the probe as well as the surface topography (**1**).[2] Analysis of the scanned probe images thus requires knowledge of the probe shape and orientation.

## 1. Scope

1.1 This practice covers scanning probe microscopy and describes the parameters needed for probe shape and orientation.

1.2 This practice also describes a method for measuring the shape and size of a probe tip to be used in scanning probe microscopy. The method employs special sample shapes, known as probe characterizers, which can be scanned with a probe microscope to determine the dimensions of the probe. Mathematical techniques to extract the probe shape from the scans of the characterizers have been published (**2-5**).

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

2.1 *ASTM Standards:* [3]

F 1438 Test Method for Determination of Surface Roughness by Scanning Tunneling Microscopy for Gas Distribution System Components

## 3. Terminology

3.1 *Definitions:*

3.1.1 *active length*—length of the region of the probe tip that could come into contact with the sample during a scan, and is set by the height of the tallest feature encountered, and it should be less than the probe length (see Fig. 1).

3.1.2 *characterized length*—the region of the probe whose shape has been measured with a probe characterizer (see Fig. 1).

3.1.3 *concave probe*—a probe that is not convex.

3.1.4 *convex probe*—the probe is convex if for any two points in the probe, the straight line between the points lies in the probe.

3.1.4.1 *Discussion*—Conical and cylindrical probes are convex, while flared probes are not. Minor imperfections in the probe, caused for instance by roughness of the probe surface, should not be considered in determining whether a probe is convex.

3.1.5 *dilation*—the dilation of a set *A* by a set *B* is defined as follows:

$$A + B = \bigcup_{b \in B}(A + b) \quad (1)$$

The image *I* produced by a probe tip *T* scanning a surface *S* is $I = S + (-T)$ (**6**). This is the surface obtained if an inverted image of the tip is placed at all points on the surface. The envelope produced by these inverted tip images is the image of the surface (**3**).

3.1.6 *erosion*—the erosion of a set *A* by a set *B* is defined as follows:

$$A - B = \bigcap_{b \in B} (A - b). \quad (2)$$

An upper bound for the surface *S* is $I - (-T)$, where *I* is the image and $-T$ is an inverted image of the probe tip (**5**).

3.1.7 *feedback-induced distortion*—distortion of a scan trace arising from the inability of the probe microscope feedback to maintain close proximity between the tip and

[1] This practice is under the jurisdiction of ASTM Committee E42 on Surface Analysis and is the direct responsibility of Subcommittee E42.14 on STM/AFM.

Current edition approved June 1, 2007. Published June 2007. Originally approved in 1996. Last previous edition approved in 2002 as E 1813 – 96 (2002).

[2] The boldface numbers in parentheses refer to the list of references at the end of this document.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

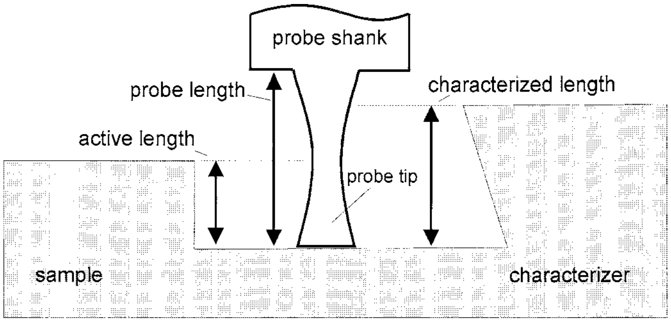

FIG. 1 Probe Tip Characterization

surface, which can be caused by scanning too quickly and changes with scan speed and scan direction.

3.1.8 *flexing-induced distortion*—distortion of a scan trace arising from flexing of the probe or shank during scanning.

3.1.9 *probe apex*—end of the probe tip, which is farthest from the shank.

3.1.9.1 *Discussion*—For some shapes, the position of the apex is somewhat arbitrary. The apex position coincides with the origin of the coordinate system used to describe the probe.

3.1.10 *probe characterizer*—a structure designed to allow extraction of the probe tip shape from a scan of the characterizer.

3.1.11 *probe flank*—side of the probe in the region between the apex and the shank.

3.1.12 *probe length* $L_t$—distance between the apex and the shank (see Fig. 1).

3.1.13 *probe shank*—stiff structure supporting the probe tip.

3.1.14 *probe stiffness*—resistance of the probe from flexing caused by lateral forces, expressed as a force constant (N/m) describing the lateral flexing of the probe under an impressed force.

3.1.15 *reconstruction*—an estimate of the surface topography determined by eroding the image with the probe tip shape.

3.1.15.1 *Discussion*—The closeness of the approximation depends on both probe shape and surface topography. Regions in which the estimate is not close are known as unreconstructable regions or dead zones.

## 4. Coordinate System

4.1 The coordinate system used to describe the probe shape is shown in Fig. 2 and Fig. 3. It is a three-dimensional, right-handed, Cartesian system with mutually orthogonal axes $x$, $y$ and $z$. Distance along the axes is measured in nanometers (nm) or micrometres (µm). In many cases, these axes will be parallel to the corresponding axes used for the sample. The $z$ axis is chosen to be parallel to the axis of the probe. If the probe is mounted on a cantilever, the orientation of the $x$ and $y$ axes relative to the cantilever may be relevant because these cantilevers are often tilted.

4.2 If the probe axis is tilted relative to the sample, Eulerian angles should be used to express the orientation of the probe. These angles are shown in Fig. 4. They may be expressed in degrees. The order in which the rotations are applied is important. The first is about the $z$ axis through the angle $\phi$. The second is about the $x'$ axis through the angle $\theta$. The final rotation is about the $z''$ axis through the angle $\psi$. The positive sense of each rotation is determined by the right-hand screw rule. Example: In a typical scanning force microscope, the cantilever is tilted 10°. If the cantilever is oriented parallel to the $y$ axis before being tilted, then the orientation would be $\theta = -10°$, $\phi = 0°$ and $\psi = 0°$.

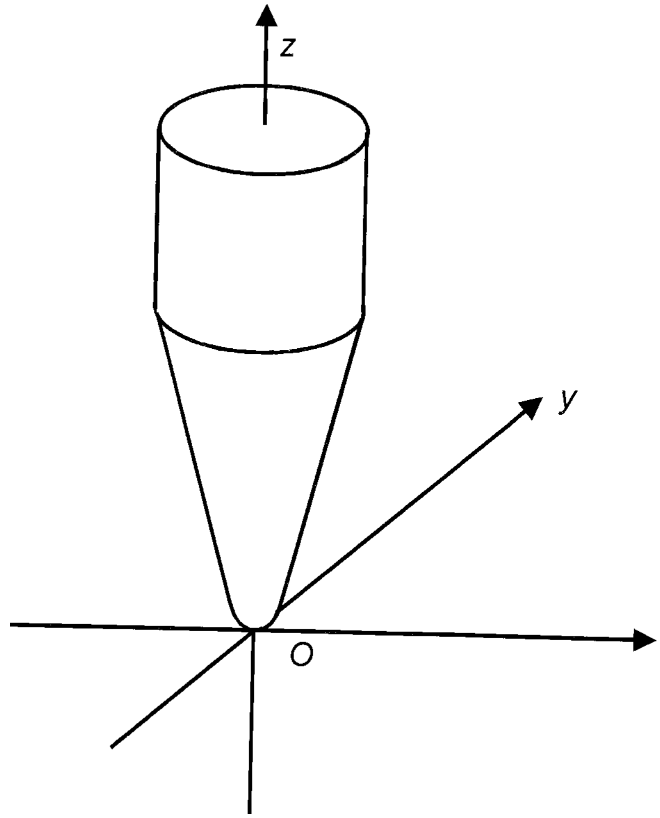

FIG. 2 Probe Tip Coordinates

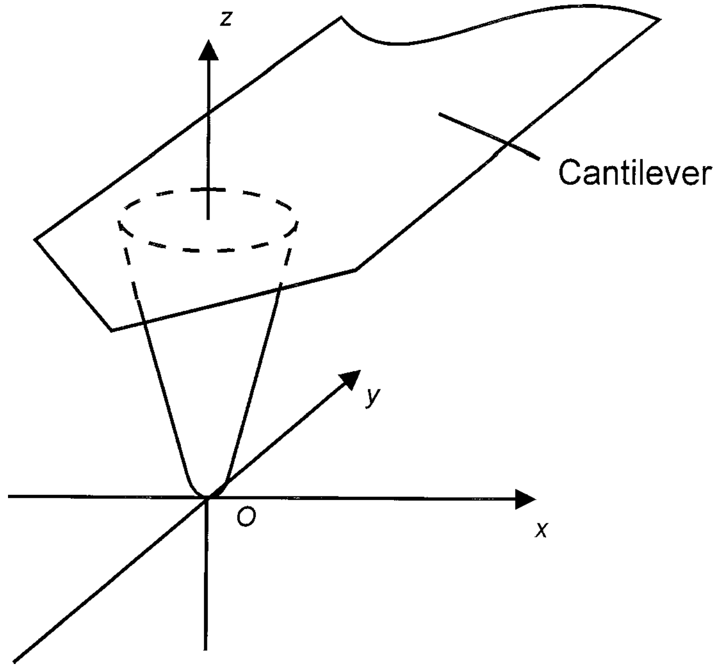

FIG. 3 Coordinates Relative to Cantilever Orientation

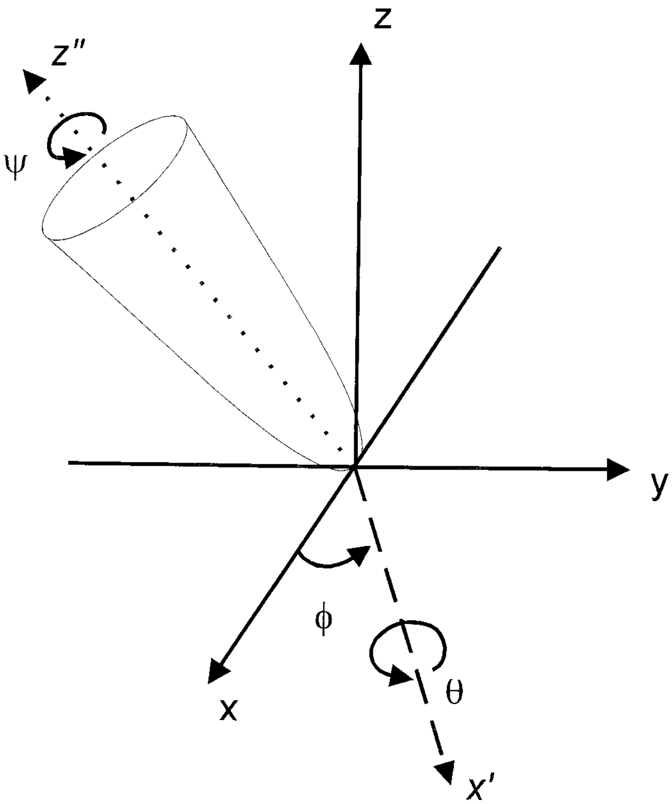


FIG. 4 Tip Rotations

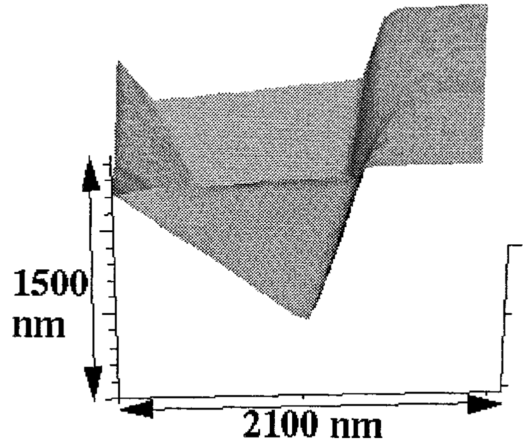


FIG. 5 Probe Tip Shape Reconstructed from a Scan of a Probe Characterizer (Reprinted with permission: G.S. Pingali and the Reagents of the University of Michigan, Ref (4))

## 5. Description of Probe Shapes

5.1 Probe tips usually have shapes that approximate regular geometrical solids, such as cones or cylinders. Because of imperfections in manufacture or erosion during use, however, data are often collected with probes that are somewhat irregular. The most precise way to describe a probe is the method described in 5.2. In many cases, such a thorough description is not needed or is not practical. Consequently, a more economical method for describing good-quality probes that closely conform to a regular geometrical shape is presented in 5.3 and in Appendix X1.

5.2 *General Shapes*—The surface of a probe tip can be presented in precisely the same ways that a sample surface can. An example of such a presentation is shown in Fig. 5, an image of a probe tip generated with software designed to interpret scans from a probe tip characterizer (**4**). In such a presentation, the axis of the probe is defined to be parallel with the $z$ axis. Eulerian angles are not required to express the orientation of the probe. The surface is defined by an array of data points on a rectangular grid lying in the $x–y$ plane. Alternatively a pair of line cuts through the probe surface can be used to represent the probe shape along orthogonal directions. The appropriate orientation of the line cuts will depend on the probe shape and the sample scanned. The probe surface extracted from a scan of a characterizer automatically determines the characterized length. If the probe is slender, the total length should also be given.

5.3 *Analytical Shapes*—If the probe is sufficiently regular, the shape can be expressed with a few parameters corresponding to a given geometrical shape. Though this mode of description is not as complete as that of the previous section, it may be preferred for several reasons. First, the complete, general shape may not be available. Second, the measurement performed with the tip may not demand the general description. Finally, a few analytical parameters are a much more economical way to express one or more figures of merit for the probe. The most commonly encountered shapes are listed in Appendix X1. The relevant analytical parameters appear in parentheses at the beginning of each description. Through the shape name and the analytical parameters, anyone analyzing the data presentation will be able to determine the effect of the probe on the data.

## 6. Description of Probe Characterizer Shapes

6.1 *Probe Characterizer Types*—Just Just as there is no probe tip appropriate for all surfaces, there exists no probe tip characterizer suitable for all probes. These characterizers generally fall into two classes, those for measuring probe apex radius and those for measuring the shape of the probe flanks. Most available characterizers fall into the first class.

6.2 *Apex Radius Measurement*—In instances, such as surface roughness measurement of smooth surfaces, where only the radii of curvature of the probe apex is needed, a small object with known radius of curvature may be used as a probe characterizer. Possible shapes are shown in Fig. 6. The left-hand shape is simply a small sphere of known radius. The right-hand shape may be either a feature with a sharp tip or it may be a linear feature with a sharp edge. Spheres such as colloidal metal particles or latex are described below. Sharp

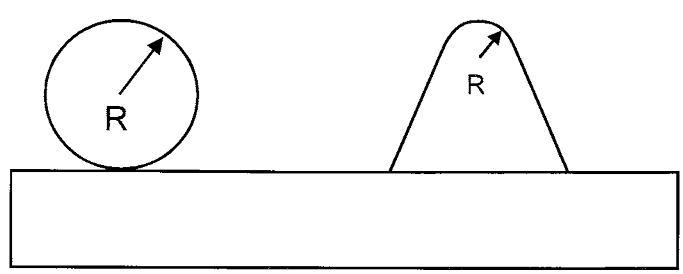


FIG. 6 Point and Edge Characterizers