less case, the error is reduced by an order of magnitude. Within the Gaussian optics frame, which covers the experimental conditions here, the error is linear in P. Based on these, the maximum scanning range using a moving probe can be larger than 100×100 μm^2.

In order to move the cantilever, it is attached at the end of the scanning piezoceramic tube, which is controlled by the high voltages applied to the electrodes located at the side walls of the tube. When the PZT is bent by these voltages, it is accompanied by a tilt of the bottom surface as described by Carr, R. G. "Finite element analysis of PZT tube scanner motion for scanning tunneling microscopy", *Journal of Microscopy,* 152, pp. 379–385, 1988. This results in a large change in the probe height during scanning. The tilt is removed to less than experimental tolerances by using the special S-shaped scanner of this invention. Experiments demonstrate that this design and method yields excellent images in AFM. See Jung and Yaniv, *Electronics Letters,* 29, No. 3, pp. 264–265.

In the prior art, which makes the PZT tube bend in an L-shape, one of the electrodes is controlled by a scanning voltage, say, in the X direction (Vx+), and the opposite electrode is controlled by another voltage (Vx–) in the X direction. The tube bends by an amount proportional to the difference in the two high voltages in the X direction. In the orthogonal direction (Y), each of the two electrodes facing each other has another controlling voltage in the Y direction in a similar fashion. One is Vy+ and the other is Vy–. Therefore, the tube will bend in the Y direction in response to the difference between Vy+ and Vy–. In addition, the inner surface of the tubes is covered with a separate cylindrical metallic electrode. A separate voltage to control the amount of the extension of the tube is applied to that electrode (Vz). The amount of the voltage difference between the Vz and the average values of the Vx+, Vx–, Vy+ and Vy– determines the amount of the extension, which is used to adjust the height.

The S-shaped scanner **19**, as shown in FIGS. **3**, **4** and **5**, is composed of two identical PZT scanners implemented one on the top of the other. Both parts have four independent electrodes around the side walls of the tube, thus the total number of independent electrodes in the S-shaped scanner of the current invention is eight. Each electrode occupies one quadrant and tracks on the side wall outer surface as shown in FIGS. **3** and **4** where "A" represents applied voltage Vx+, "B" represents Vx– voltage, "C" represents Vy– voltage, and "D" represents Vy+ applied voltage.

In the current invention, two of the tubes with the same electrode configuration as the prior art are used. The improvement is to make one body scanner by placing one on top of the other. This is achieved either by gluing two separately made PZT tubes together or separating the four quadrant electrodes by half, at the midway along the length of the scanner tube, thus realizing eight different electrodes. Then the top and bottom half electrodes are connected to the opposite polarities of the control voltages, such that if one of the top electrodes has Vx+, the bottom electrode at the same side has Vx– connected, and vice versa. At the orthogonal direction, Vy+ is at the top, the Vy– is at the bottom, and vice versa. Therefore, although four additional electrodes are added, the number of necessary control voltages are the same, including the Vz which is connected at the inside electrode, to control the height as shown in FIG. **3**.

When the top section of the S-shaped scanner bends to one side, the tilt is created at the end of the section, which is the exact mid-point of the tube. At the same time, the bottom part bends to the opposite direction, with exactly the same amount of the tilt but, in the opposite direction, because the relative polarities of the voltages are opposite. Therefore, the net tilt at the bottom of the overall tube is virtually eliminated, as long as the sections are of the identical property.

In fact, the two sections bend to the opposite directions. However, the direction of the tilt of the top part is to the same direction of the bend, which makes the bottom part displaced to the same direction as the bending. The bottom part is bending toward the opposite direction. The top surface of the tube is a fixed flat surface, and the bottom part bends from the tilt angle caused by the top section of the PZT tube toward the direction of the displacement. The bending of the bottom part always leaves the overall net displacement to the direction of the bending of the top part. This result is obtained because the direction of the tilt is the same as the direction of the bending; the amount of the tilt is proportional to the amount of the bending; and the two sections are exactly identical to each other.

Therefore, the tilt angles are eliminated, while achieving the net scanning motion of the PZT tube. When the bending occurs, the overall shape looks like as alphabet "S". The extension action in the Z-direction is not affected by such electrode configuration. FIG. **5** shows the S-shaped bending of the present invention.

Mathematically, two same sections of arcs taken from one circle connected tangentially at the one end to the opposite direction will always yield a net displacement between the two end points, so long as the arcs are less than one-half of the circle.

The displacement of the prior art L-shaped bending is given by:

$$d_L=\tfrac{1}{2}(L/R)^2$$

where R is the radius of the arc and L is the length of the overall tube, if R>>L. The S-shape yields:

$$d_s=2*\tfrac{1}{2}(L/R)^2=\tfrac{1}{4}(L/R)^2$$

Therefore, the displacement is reduced by ½, which is compensated for by increasing the length of the PZT tube by 1.4 times.

While illustrative embodiments and applications of this invention have been shown and described, it would be apparent to those skilled in the art that many more modifications than have been mentioned above are possible without departing from the inventive concepts set forth herein. The invention, therefore, is not to be limited except in the spirit of the appended claims.

What is claimed is:

1. An atomic force microscope for examining surface properties of a sample surface, said atomic force microscope comprising:

a frame;

a sample stage;

a scanner element having a scanner end capable of motion relative to said frame in response to signals applied to said scanner element;

a cantilever having a reflective surface, a first cantilever end and a second cantilever end, said first cantilever end having a sharp probe tip extending therefrom toward said sample stage, said second cantilever end attached to said scanner;

at least one beam tracking element held in a fixed relationship to a portion of said scanner element;

a source of a collimated light beam, said source arranged to project said collimated light beam to said at least one