US 20130088585A1

(19) United States

(12) Patent Application Publication

Mulay

(10) Pub. No.: US 2013/0088585 A1

(43) Pub. Date: Apr. 11, 2013

(54) **SURFACE IMAGING WITH MATERIALS IDENTIFIED BY COLOR**

(75) Inventor: **Apekshit Pradeep Mulay**, Richardson, TX (US)

(73) Assignee: **TEXAS INSTRUMENTS INCORPORATED**, Dallas, TX (US)

(21) Appl. No.: **13/269,031**

(22) Filed: **Oct. 7, 2011**

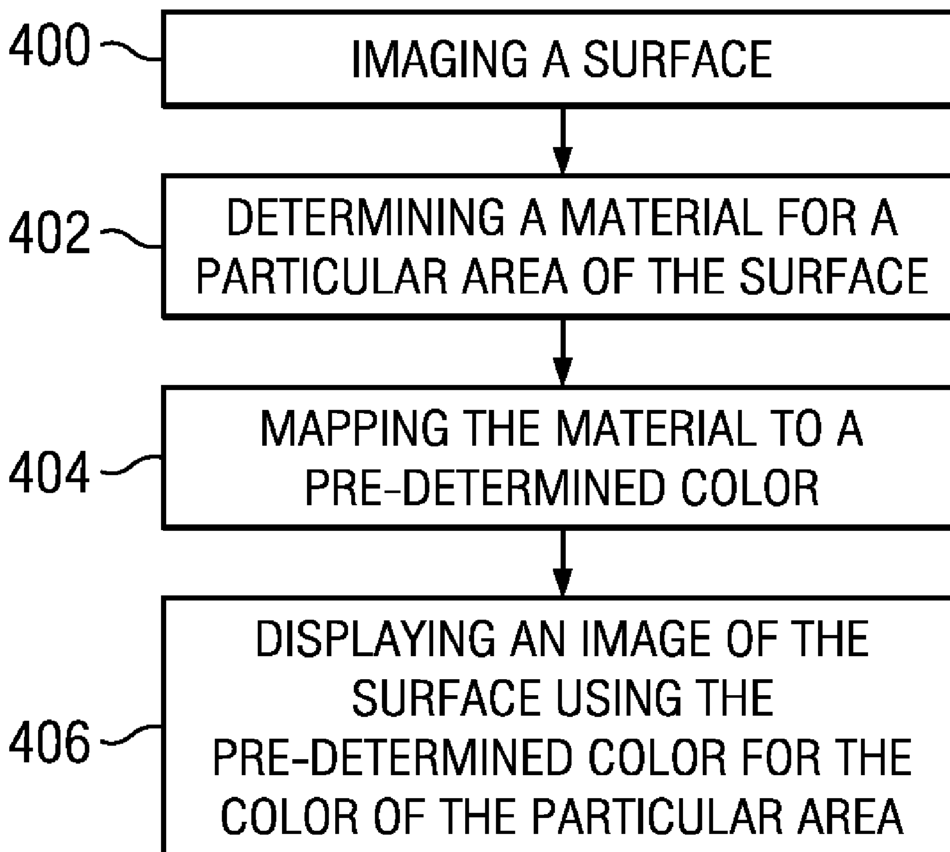
Publication Classification

(51) **Int. Cl.**
H04N 7/18 (2006.01)

(52) **U.S. Cl.**
USPC **348/79**; 348/87

(57) **ABSTRACT**

An imaging system receives a height measurement and a resistance measurement, the measurements being made at a two-dimensional position on a surface. A display system maps the resistance to a predetermined material color value, and displays the height measurement and the material color value at the two-dimensional position on the surface.



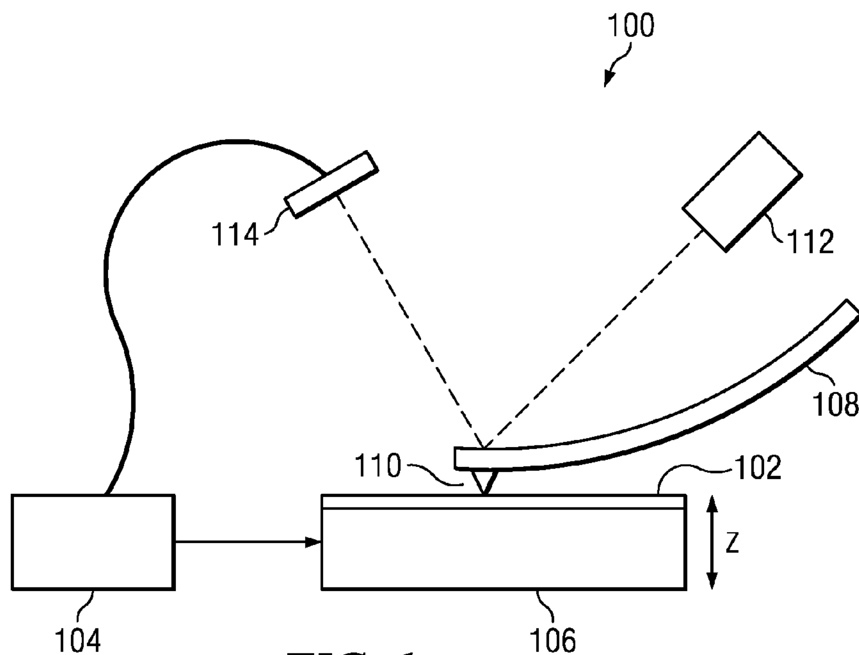


FIG. 1
(PRIOR ART)

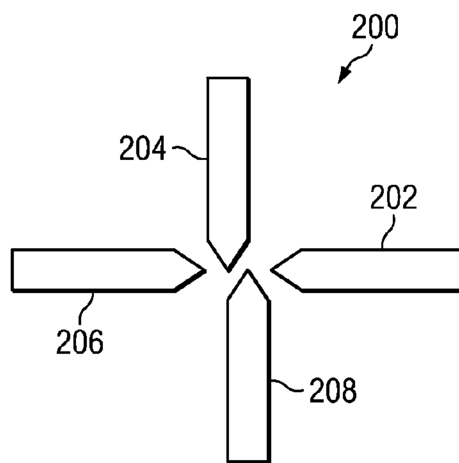


FIG. 2
(PRIOR ART)

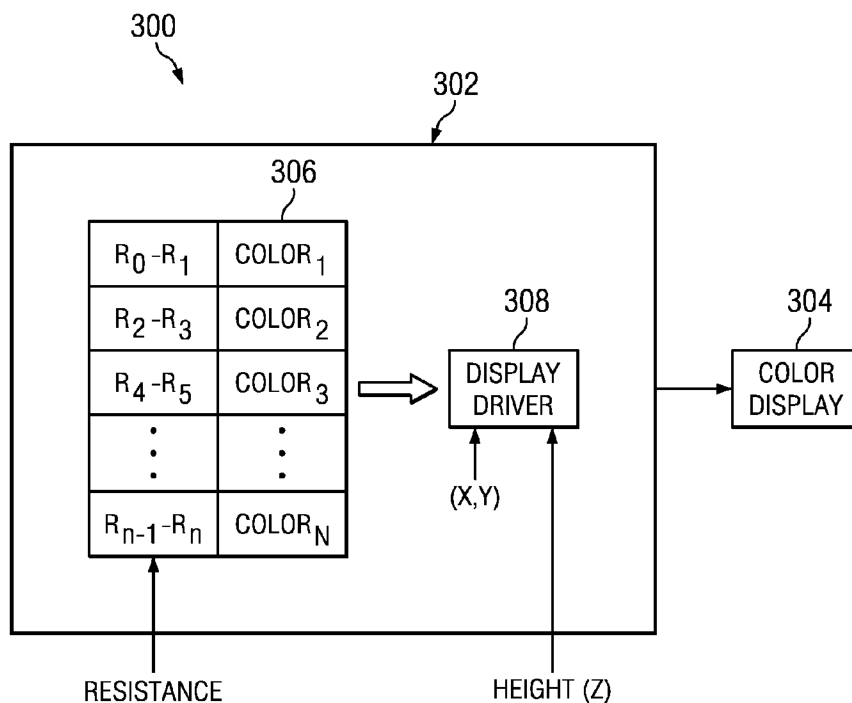


FIG. 3

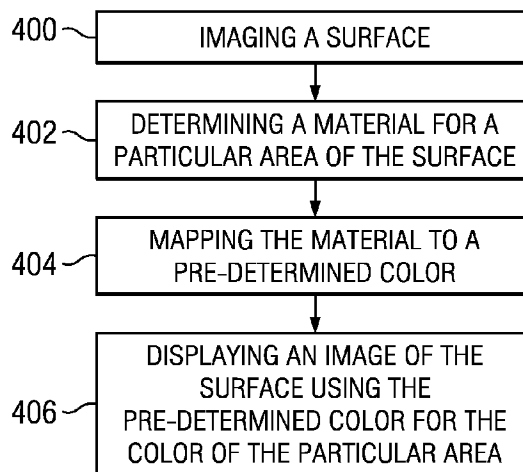


FIG. 4

SURFACE IMAGING WITH MATERIALS IDENTIFIED BY COLOR

BACKGROUND

[0001] There is a general need for imaging the surface of composite materials. One particular example is imaging of the surface of integrated circuits for quality control. The size of many integrated circuit structures and components (for example, transistors) is below the limits of optical based imaging. One common surface imaging tool is Focused Ion Beam (FIB) imaging. Another common surface imaging tool is Scanning Electron Microscopy (SEM). In addition to imaging the shape of a surface, SEM may also provide characteristics of the materials at the surface, for example by using Energy Dispersive X-Ray spectroscopy (EDX). However, exposing a surface to charged beams may alter electrical characteristics of electronic components, or may damage integrated circuit structures, particularly as integrated circuit components and structures become smaller and smaller. For example, FIB imaging may implant Gallium ions or otherwise alter Field Effect Transistor (FET) characteristics. Similarly, SEM-EDX imaging can affect transistor parameters for advanced Complimentary Metal-Oxide Semiconductor (CMOS) technologies.

[0002] There is an ongoing need for improved microscopic surface imaging and surface materials analysis without damaging the surface being imaged and without changing electrical characteristics of the electronic components being imaged.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] FIG. **1** is a simplified block diagram illustrating an example prior art embodiment of an atomic force microscope.

[0004] FIG. **2** is a simplified block diagram illustrating an example prior art embodiment of multiple probes arranged for measurement of resistance.

[0005] FIG. **3** is a simplified block diagram illustrating an example embodiment of an imaging system with a display of material types.

[0006] FIG. **4** is a flow chart of an example embodiment of a method for displaying material types.

DETAILED DESCRIPTION

[0007] Another alternative surface imaging tool is an Atomic Force Microscope (AFM). FIG. **1** illustrates an example embodiment **100** of an AFM. In FIG. **1**, a surface **102** is being scanned. A controller **104** controls a platform **106** that moves the surface **102** vertically (Z-dimension). A flexible cantilever **108** has a very small probe **110**. When the probe **110** makes contact with the surface **102**, the cantilever **108** bends slightly. In the embodiment illustrated in FIG. **1**, a laser **112** projects a light beam that is reflected off the cantilever onto a photosensor array **114**. Vertical deflection of the cantilever causes the reflected light beam to move on the photosensor array **114**, providing a measure of the deflection of the cantilever, which in turn provides a measure of the force at the tip of the probe. In the example of FIG. **1**, the photosensor array **114**, the controller **104**, and the platform **106** are configured as a closed loop system to maintain a constant force on the probe **110**. There are other ways of measuring the deflection of the cantilever, including optical interferometry, capacitive sensing or piezoresistive cantilevers. Platform **106** may be, for example, a piezoelectric device. Other mechanisms (not illustrated) may move the cantilever **108** for scanning in an X-Y dimension, or move the surface **102** being imaged for scanning in an X-Y dimension, or both. For example, a piezoelectric device may move the surface being imaged in two dimensions (X, Y). As the probe and/or surface are moved in an X-Y dimension, the vertical height of the surface **102** changes, and the controller **104** moves the surface **102** vertically to maintain a constant force on the probe **110**. Accordingly, the vertical height Z of the surface **102** at each X-Y position is measured by the controller **104**. By maintaining a constant (relatively small) force on the probe, an AFM does not damage the surface being imaged if proper procedure is followed, and an AFM does not alter the electrical characteristics of electronic structures.

[0008] The AFM depicted in FIG. **1** has a single probe. Other specialized probes exist for measurement of additional characteristics. For example, an array of four probes (called a four-point probe) may be used to detect resistance in addition to force. FIG. **2** depicts an example arrangement **200**. For example, a voltage may be placed across probes **202** and **206** causing a current to flow between them in the surface being imaged. The resistance of the surface being imaged results in a voltage gradient at the surface between the two probes. A portion of that voltage gradient is sensed by probes **204** and **208**. Note that probes **204** and **208** are positioned between probes **202** and **206**. The primary advantage of four-point resistance measurement is that very little current flows in the sensing probes (**204** and **208**) so that surface contact resistance of the sensing probes has very little effect on the measurement. This facilitates very precise measurement of resistance.

[0009] An AFM as in FIG. **1** with four-point resistance measurement as in FIG. **2** can provide a three-dimensional image of a surface overlaid with the resistance of the surface at each location. For a human operator performing quality control for an integrated circuit, it would be more useful to have an image that clearly identifies the material at each location. For example, it would be desirable to have an image clearly identifying materials such as silicon, polysilicon, silicon dioxide, tungsten, copper, etc. Some materials of interest may have similar resistances, so that the materials may not be visually distinct in an image representing just resistance.

[0010] FIG. **3** illustrates an imaging system **300** for displaying surface material types. The imaging system **300** comprises an image processing system **302** and a display **304**. The imaging processing system **302** receives a resistance value and a height (Z) value, where the resistance and height have been measured at a two-dimensional (X,Y) position on a surface. For example, the imaging system **300** may receive height and resistance from an AFM as in FIG. **1** using a four-point resistance probe as in FIG. **2**. The image processing system includes a mapper, depicted as a look-up table **306** in FIG. **3**. The mapper has pre-defined resistance ranges ((R_1-R_2)-(R_{n-}-R_n)). Each received resistance is within a pre-defined range, and each pre-defined range corresponds to a pre-defined material color ($COLOR_1$-$COLOR_N$). For each two-dimensional position being measured, the system maps the corresponding resistance to a material color, and sends the material color to a display driver **308**. The display driver drives the display **306**, which displays a surface, showing the material color and height (Z) at each measured two-dimensional (X,Y) position on the displayed surface. When used for analysis of the surface of an integrated circuit, only those

materials that are used in manufacturing of integrated circuits will have a known color mapping for a specific resistance value.

[0011] Assume, for example, that the resistance of tungsten falls within the first resistance range (R_1-R_2), and that the pre-defined color for tungsten is orange. Assume further, for example, that the resistance of polysilicon falls within the second resistance range (R_3-R_4), and that the pre-defined color for polysilicon is light green. At a first two-dimensional position (X_A, Y_A), a four-point probe measures a resistance R_A and a height Z_A. Assume R_A falls within the first resistance range (R_1-R_2). At a second two-dimensional position (X_B, Y_B), the four-point probe measures a resistance R_B and a height Z_B. Assume R_B falls within the second resistance range (R_3-R_4). At position (X_A, Y_A), the system displays $Color_1$ (orange) and height Z_A, and at position (X_B, Y_B), the system displays $Color_2$ (light green) and height Z_B.

[0012] Height (Z) may be shown on a two-dimensional image by varying intensity (for example, increasing height may result in a lighter less-saturated color or higher intensity). Alternatively, the display may depict the surface at an acute angle so that height is visible. Alternatively, the system may rotate the resulting image in three-dimensional space to facilitate viewing of the height data.

[0013] Note that the material colors $COLOR_1$-$COLOR_N$ may be chosen to enhance distinctiveness in the display and do not necessarily correspond to actual material colors. In particular, colors may be chosen to increase the visibility of certain types of defects or particle contaminants. For example, the color of a conductive trace may be made distinct from a color for an underlying substrate to increase the visibility of voids in a conductive trace.

[0014] The imaging system **300** may be an AFM or part of an AFM. The image processing system **302** may receive resistance as an analog signal (for example, a voltage) to be converted by an analog-to-digital converter, or may receive a digital value. The image processing system **302** may receive two-dimensional (X,Y) position data from a separate system, such as a surface positioning stage. Alternatively, the image processing system **302** may generate the (X,Y) position. For example, the image processing system **302** may also serve as a controller for an AFM and may control the X,Y position of the surface being imaged. The image processing system **302** may comprise a controller, a processor, a microcontroller, a microprocessor, a digital-signal processor, an application-specific integrated circuit, logical modules, or other types of hardware or software capable of performing a mapping of resistance to material color. The mapping may be performed by a look-up table as depicted by table **306** in the example of FIG. **3**, or by hardware comparators, or by a series of if-then-else statements in software, or other logic or software. The display driver **304** may be a separate device or may be integrated.

[0015] A system for scanning the topology of an integrated circuit along with identifying the materials at the surface is particularly useful in quality control. Scanning with an AFM may be automated and may take place in-situ during manufacturing. In particular, scanning with an AFM may take place in a vacuum, and may be repeated as the surface is modified during normal manufacturing process steps. Actually, scanning in a vacuum is preferred, since non-vacuum ambient conditions may result in an oxide layer that would interfere with resistance measurement, and the surface would need to be buffered or etched to remove the oxide layer. The topology and resistance results may be useful independently from other testing (for example, detection of voids or contaminants), or may be combined with other testing. For example, if a circuit fails a functional test, then an earlier surface scan may be examined to see if a defect can be identified that might have caused the failure.

[0016] FIG. **4** illustrates a method for displaying material type for a surface. At step **400**, a surface is imaged. At step **402**, a material is determined for a particular area on the surface. At step **404**, the material is mapped to a pre-determined color. At step **406**, an image of the surface is displayed using the pre-determined color for the color at the particular area.

What is claimed is:

1. An imaging system, comprising:

an image processing system, receiving a height value and a resistance value, the height and resistance having been measured at a two-dimensional position on a surface, the image processing system comprising a mapper that maps the resistance value to a material color; and

a display driver, driving a display, and displaying the material color and the height at two-dimensional positions on the surface.

2. The imaging system of claim **1**, further comprising:

a probe; and

a system to move the surface into contact with the probe.

3. The imaging system of claim **2**, where the probe is a four-point probe.

4. The imaging system of claim **2**, where the surface is a surface of an integrated circuit, and where the material color corresponds to a material in the integrated circuit.

5. The imaging system of claim **2**, where the mapper comprises a look-up table, the look-up table further comprising a table of resistance ranges and a table of material colors, with a one-to-one mapping of material colors to resistance ranges.

6. The imaging system of claim **2**, where the height is displayed as an intensity of the material color.

7. The imaging system of claim **2**, where the imaging system moves the surface to the two-dimensional position at which the height and resistance are measured.

8. The imaging system of claim **1**, where the surface is a surface of an integrated circuit, and where the material color corresponds to a material in the integrated circuit.

9. The imaging system of claim **1**, where the mapper comprises a look-up table, the look-up table further comprising a table of resistance ranges and a table of material colors, with a one-to-one mapping of material colors to resistance ranges.

10. The imaging system of claim **1**, where the height is displayed as an intensity of the material color.

11. The imaging system of claim **1**, where the imaging system moves the surface to the two-dimensional position at which the height and resistance are measured.

12. A process, comprising:

imaging, by an atomic force microscope, a surface;

determining a material for a particular area of the surface;

mapping the material to a predetermined color; and

displaying an image of the surface using the pre-determined color for the color of the particular area.

13. The process of claim **12**, the step of determining further comprising:

measuring a resistance at the particular area of the surface; and

determining that the resistance is within a range of resistance corresponding to the material and the predetermined color.

14. The process of claim **13**, the step of measuring further comprising measuring a voltage along the surface using a four-point probe.

15. The process of claim **12**, further comprising:

determining a height of the surface at the particular area; and

displaying the height of the surface at the particular area in the image of the surface.

16. The process of claim **15**, the step of displaying the height further comprising varying the intensity at the particular area according to height.

17. A process, comprising:

imaging, a surface of an integrated circuit;

determining a material for a particular area of the surface;

mapping the material to a predetermined color; and

displaying an image of the surface using the pre-determined color for the color of the particular area.

18. The process of claim **17**, the step of determining further comprising:

measuring a resistance at the particular area of the surface; and

determining that the resistance is within a range of resistance corresponding to the material and the predetermined color.

19. The process of claim **17**, further comprising:

determining a height of the surface at the particular area; and

displaying the height of the surface at the particular area in the image of the surface.

20. The process of claim **19**, the step of displaying the height further comprising varying the intensity at the particular area according to height.

* * * * *