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(54) **METHOD FOR MEASURING A TEMPERATURE**

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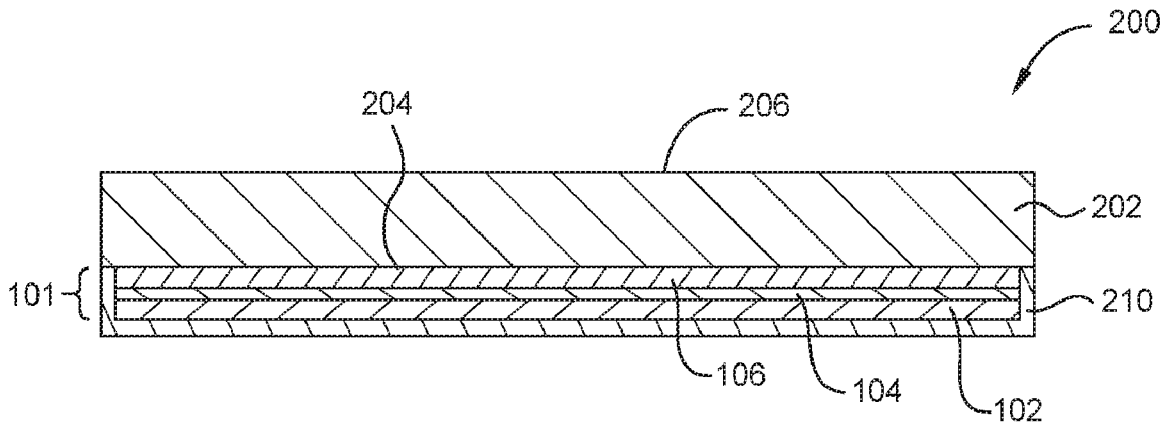
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(57) **ABSTRACT**

Implementations described herein generally relate to semiconductor manufacturing, and more specifically to a temperature measurement device. In one implementation, the temperature measurement device includes a substrate and a stack of metal layers coupled to the substrate. Each metal layer of the stack of metal layers extends continuously uninterrupted from edge to edge of the substrate. The first metal layer has a lower electrical resistivity than the second metal layers. The electrical resistivity of the stack is based on the electrical resistivity of the first metal layer, which is temperature dependent. Utilizing a known relationship between temperature measurements and resistivity measurements, the temperature measurement device can measure and store temperature information in various substrate processing processes.
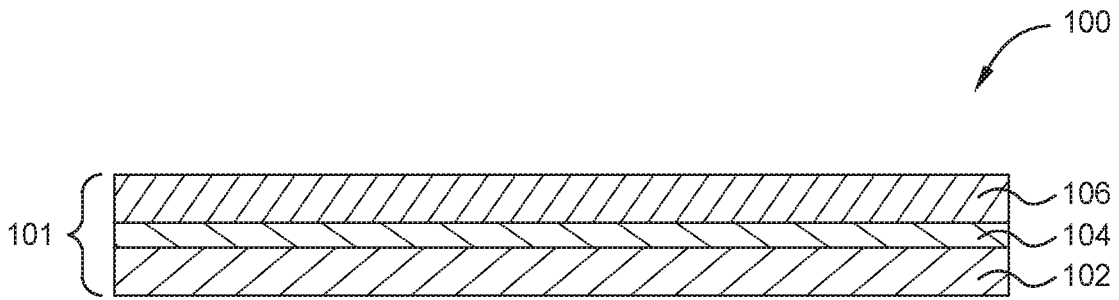
100

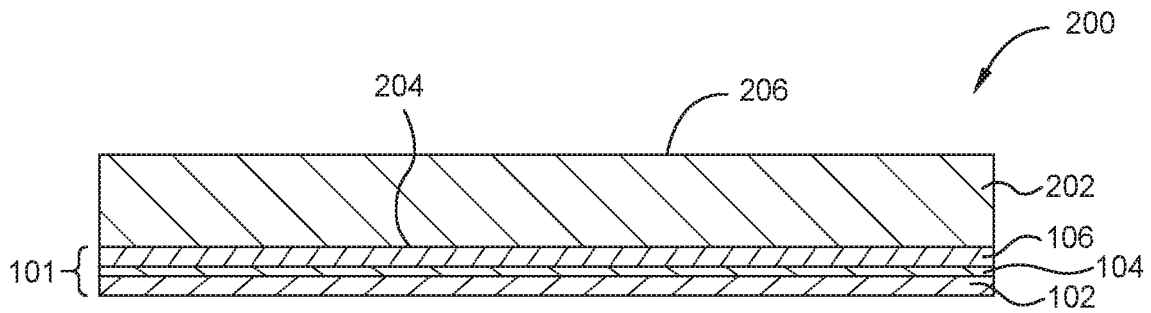101 {
106
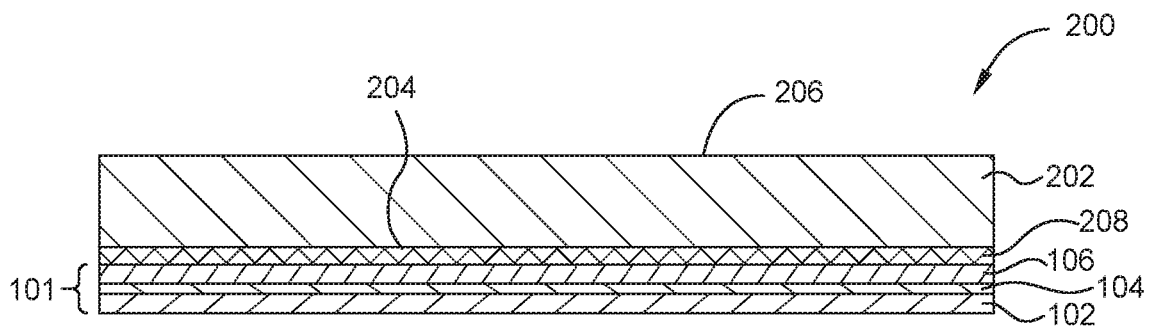104
102

FIG. 1

200

204   206

202
106
104
102

101

FIG. 2A

200

204   206

202
208
106
104
102

101

FIG. 2B

200

204   206

202

101

210

106   104

102

FIG. 2C

200

101

102

302

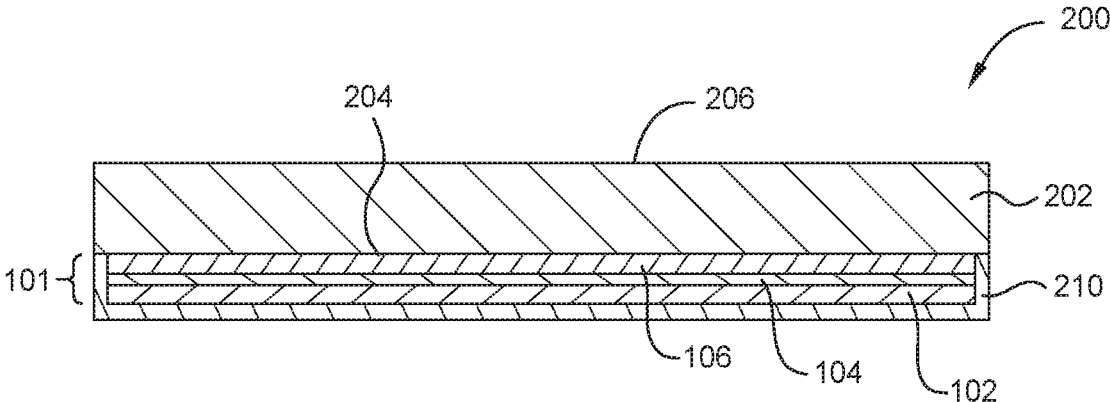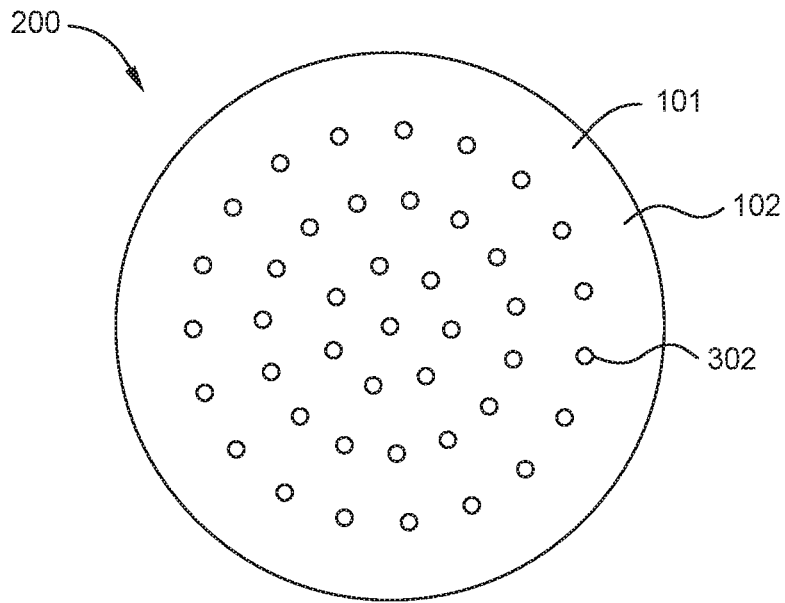## FIG. 3

METHOD FOR MEASURING A TEMPERATURE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application Ser. No. 62/636,765, filed on Feb. 28, 2018, which is incorporated herein by reference.

BACKGROUND

Field

[0002] Implementations described herein generally relate to semiconductor manufacturing, and more specifically to a temperature measuring device.

Description of the Related Art

[0003] Semiconductor devices are commonly fabricated by a series of processes in which layers are deposited on a surface of a substrate and the deposited material is etched into desired patterns. As semiconductor device geometries decrease, precise process control during these processes becomes more and more important.

[0004] Temperature control is particularly important to achieve repeatable semiconductor manufacture with improved yield and high throughput in process chambers, such as deposition or etch chambers, for semiconductor processing. This is because precise manufacturing techniques have small process window, and even slight excursions out of acceptable process control tolerances can lead to catastrophic amounts of production defects.

[0005] Conventionally, temperature information of a substrate is typically obtained by either sensors installed on the process chamber, such as pyrometer, or temperature measuring substrates having on-board electronic temperature sensors. However, these temperature measuring devices or methods are limited to certain processes or require installed hardware.

[0006] Therefore, there is a need for an improved device for measuring substrate temperature.

SUMMARY

[0007] Implementations described herein generally relate to semiconductor manufacturing, and more specifically to a temperature measuring device. In one implementation, a temperature measuring device includes a substrate including a first side and a second side opposite the first side. The substrate is configured to replicate a workpiece used in vacuum processing. The temperature measuring device further includes a stack extends substantially across the first side of the substrate from edge to edge. The stack includes a first metal layer having a first material and two second metal layers each having a second material different than the first material. The first metal layer is disposed between the two second metal layers.

[0008] In another implementation, a temperature measuring device includes a substrate including a first side and a second side opposite the first side. The substrate is configured to replicate a workpiece used in vacuum processing. The temperature measuring device further includes a stack extends substantially across the first side of the substrate from edge to edge. The stack includes a first metal layer having a first electrical resistivity and two second metal layers each having a second electrical resistivity greater than the first electrical resistivity. The first metal layer is disposed between the two second metal layers.

[0009] In another implementation, a method for measuring a temperature includes placing a first temperature measuring device into a process chamber, perform a process on the first temperature measuring device, measuring a sheet resistivity of the first temperature measuring device, and converting the sheet resistivity to a temperature.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to implementations, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only exemplary implementations and are therefore not to be considered limiting of its scope, and may admit to other equally effective implementations.

[0011] FIG. 1 illustrates a schematic cross-sectional side view of a temperature measuring device.

[0012] FIGS. 2A-2C illustrate schematic cross-sectional side views of a temperature measuring device including a substrate and a stack of metal layers.

[0013] FIG. 3 illustrates a bottom view of the temperature measuring device of FIGS. 2A-2C.

[0014] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements and features of one implementation may be beneficially incorporated in other implementations without further recitation.

DETAILED DESCRIPTION

[0015] Implementations described herein generally relate to semiconductor manufacturing, and more specifically to a temperature measuring device. In one implementation, which can include or be combined with one or more implementations described herein, the temperature measuring device includes a substrate and a stack of metal layers coupled to the substrate. Each metal layer of the stack of metal layers extends continuously uninterrupted from edge to edge of the substrate. The stack of metal layers includes a first metal layer fabricated from a first material disposed between two second metal layers fabricated from a second material that is different from the first material. The first metal layer has a lower electrical resistivity than the second metal layers. The electrical resistivity of the stack is based on the electrical resistivity of the first metal layer, which is temperature dependent. Utilizing a known relationship between temperature measurements and resistivity measurements, the temperature measuring device can measure and store temperature information in various substrate processing processes.

[0016] FIG. 1 illustrates a schematic cross-sectional side view of a temperature measuring device 100. The temperature measuring device 100 includes a stack 101 of metal layers. The stack 101 includes a first metal layer 104 disposed between two second metal layers 102, 106. The first metal layer 104 is fabricated from a first material, and the second metal layers 102, 106 are fabricated from a second material different from the first material. For

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example, the first metal layer **104** may be fabricated from aluminum, tungsten, silver, or other suitable metal, and the two second metal layers **102**, **106** may be fabricated from titanium or other suitable metal. The first metal layer **104** has a thickness ranging from about 5 nanometers (nm) to about 10 nm, and the second metal layers **102**, **106** each have a thickness ranging from about 10 nm to about 20 nm.

[0017] The first metal layer **104** has a lower electrical resistivity than the second metal layers **102**, **106**, so the sheet resistivity of the temperature measuring device **100** is based on the resistivity of the first metal layer **104** due to the dominant electrical current path through the first metal layer **104**. The first metal layer **104** acts as a high conductive channel of the temperature measuring device **100**. At elevated temperatures, such as from about 200 degrees Celsius to about 1000 degrees Celsius, atoms in the second metal layers **102**, **106** diffuse into the first metal layer **104**. When the temperature is not uniform across the temperature measuring device **100**, the amount of diffused atoms locally varies across the temperature measuring device **100** following the temperature variation. The diffusion of the atoms from the second metal layers **102**, **106** into the first metal layer **104** locally increases the resistivity of the first metal layer **104**, which in turn locally increases the sheet resistivity of the temperature measuring device **100**. Furthermore, the amount of diffusion is temperature dependent because the diffusion coefficient is a function of temperature. Thus, when separate regions of the temperature measuring device **100** are at different temperatures, the amount of diffusion at each region is different, and the change in resistivity of the first metal layer **104** in each region is different. By plotting changes in sheet resistivity versus temperatures, a relationship between the sheet resistivity of the temperature measuring device **100** and the corresponding temperatures of the temperature measuring device **100** can be identified. In one example, the relationship is a linear relationship, such as y=ax+b, where y is the sheet resistivity of the temperature measuring device **100** or the change in sheet resistivity of the temperature measuring device **100** compared to the baseline sheet resistivity, x is the temperature, and a and b are constants. With this relationship (i.e., a and b constants are known), the highest temperature that the temperature measuring device **100** has experienced can be calculated if the sheet resistivity or a change in sheet resistivity of the temperature measuring device **100** is known or can be measured.

[0018] The temperature measuring device **100** can be fabricated and used as follows. The metal layers **102**, **104**, **106** may be fabricated by a physical vapor deposition (PVD) process at room temperature, such as from about 20 degrees Celsius to about 25 degrees Celsius. After the temperature measuring device **100** is fabricated, the sheet resistivity of the temperature measuring device **100** is measured to obtain a baseline sheet resistivity that corresponds to a highest temperature that the temperature measuring device **100** has so far experienced. In one example, the baseline sheet resistivity corresponds to the temperature the temperature measuring device **100** experienced during the fabrication of the temperature measuring device **100**. In another example, the baseline sheet resistivity corresponds to the temperature the temperature measuring device **100** that is slightly higher than the fabrication temperature. In other words, for example, the temperature measuring device **100** is fabricated at about 25 degrees Celsius, and the temperature measuring

device **100** is heated to about 30 degrees Celsius. The sheet resistivity of the temperature measuring device **100** corresponds to about 30 degrees Celsius.

[0019] A calibration is then performed on the temperature measuring device **100**. The calibration is performed by heating the temperature measuring device **100** to multiple temperatures, such as from about 200 degrees Celsius to about 1000 degrees Celsius at an increment from about 10 degrees Celsius to about 100 degrees Celsius. After each time the temperature measuring device **100** is being heated, a corresponding sheet resistivity of the temperature measuring device **100** is measured. During the calibration, a corresponding sheet resistivity of the temperature measuring device **100** for each temperature of the multiple temperatures that the temperature measuring device **100** is being heated to is identified and recorded. A relationship between the sheet resistivity of the temperature measuring device **100** and the corresponding temperatures of the temperature measuring device **100** can be calculated based on the data obtained from the calibration of the temperature measuring device **100**. For example, sheet resistivity (or change in sheet resistivity) versus temperature can be plotted using the measured sheet resistivity and the corresponding temperatures obtained during the calibration, and a regression analysis is performed to establish a regression model that identifies the relationship between the sheet resistivity of the temperature measuring device **100** and the corresponding temperatures of the temperature measuring device **100**. In some implementations, the relationship is between changes in sheet resistivity compared to the baseline sheet resistivity and the corresponding temperatures. The relationship, such as a linear relationship, for example, y=ax+b, can be calculated based on the data obtained from the calibration of the temperature measuring device **100**. Specifically, the data obtained from the calibration process help identify the constants in the relationship, for example, constants a and b in y=ax+b.

[0020] Because the diffusion of the atoms from the second metal layers **102**, **106** into the first metal layer **104** is irreversible, the calibrated temperature measuring device **100** is no longer able to show a change in sheet resistivity within the calibration temperature range. A newly fabricated temperature measuring device **100** having identical size and shape of the calibrated temperature measuring device **100** can be used to measure a temperature that the newly fabricated temperature measuring device **100** is experiencing. The temperature that the newly fabricated temperature measuring device **100** intends to measure is greater than the highest temperature that the newly fabricated temperature measuring device **100** has experienced. Prior to measuring a temperature, the baseline sheet resistivity of the newly fabricated temperature measuring device **100** is obtained either by measuring the sheet resistivity of the temperature measuring device **100** or by heating the temperature measuring device **100** to a temperature slightly higher than the fabricating temperature and then measuring the sheet resistivity of the temperature measuring device **100**.

[0021] Because the newly fabricated temperature measuring device **100** has the identical size and shape as the calibrated temperature measuring device **100**, the relationship calculated for the calibrated temperature measuring device **100** can be applied to the newly fabricated temperature measuring device **100**. For example, the relationship y=ax+b, where constants a and b are determined from the

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calibration process, can be used on the newly fabricated temperature measuring device **100** that does not go through the calibration process.

[0022] To measure a temperature indicating of a production temperature, the newly fabricated temperature measuring device **100** is placed in a process environment, such as a process chamber, and a process, such as a deposition or etch process, is performed. The newly fabricated temperature measuring device **100** is then removed from the process environment, and the sheet resistivity of the newly fabricated temperature measuring device **100** is measured. The sheet resistivity of the newly fabricated temperature measuring device **100** can be measured by any suitable method. In one example, a probe, such as a four-point probe having four probes equally spaced from each other, is in contact with the newly fabricated temperature measuring device **100** at one location to measure the sheet resistivity of the newly fabricated temperature measuring device **100** at that particular location. The probe may be moved to other locations of the newly fabricated temperature measuring device **100** to measure the local sheet resistivity. The measured sheet resistivity is used to calculate the highest temperature that the newly fabricated temperature measuring device **100** is experienced during the process based on the relationship calculated for the calibrated temperature measuring device **100**. In one example, the relationship is y=ax+b, where a and b are known constants. By plugging the measured sheet resistivity as y, the highest temperature that the newly fabricated temperature measuring device **100** has experienced during the process, which is x, can be calculated. A thermal profile of the newly fabricated temperature measuring device **100** can be created by converting the local sheet resistivity to temperatures.

[0023] FIGS. 2A-2C illustrate schematic cross-sectional side views of a temperature measuring device **200** including a substrate **202** and the stack **101**. As shown in FIG. 2A, the temperature measuring device **200** may be the stack **101** directly coupled to a first side **204** of the substrate **202**. The substrate **202** may be fabricated from a semiconductor, such as silicon, germanium, silicon germanium, group III/V compound semiconductors, for example GaAs or InGaAs, or other semiconductor material. In display or solar technology, the substrate **202** may be fabricated from glass or polymer. In one implementation, the substrate **202** is fabricated from a semiconductor, glass, or a polymer. The substrate **202** may be circular, rectangular, or other suitable shape. The substrate **202** is configured to replicate a workpiece used in vacuum processing, such as a semiconductor workpiece in integrated circuit or light emitting diode (LED) applications or a glass workpiece in solar or display applications. For example, the substrate **202** generally has the shape and size that imitates the shape and size of a production workpiece that is processed in the vacuum processing chamber to fabricate a solar cell, flat panel, integrated circuit and the like, and thus, is sized to be robotically through the vacuum processing chamber slit valve door and sit on a substrate support just like the production workpiece. In one example, the substrate **202** has a diameter of 200 mm, 300 mm, or 450 mm. In another example, the substrate **202** is rectangular and has an area of about 12000 to about 91000 cm². The substrate **202** includes a second side **206** opposite the first side **204**. The stack **101** includes the first metal layer **104** and the second metal layers **102, 106**, and the stack **101** may be formed on the substrate **202** using a PVD process at a

process temperature ranging from about 20 degrees Celsius to about 25 degrees Celsius. The stack **101** or the three metal layers **102, 104, 106**, extends across the first side **204** of the substrate **202** from edge to edge, as shown in FIG. 2A. Thus, the stack **101** covers 100 percent of the first side **204** of the substrate **202**. The stack **101** has the same shape as the substrate **202** and has a dimension, such as a diameter, that is the same as the dimension of the substrate **202**. In one example, the substrate **202** is circular and has a diameter of about 300 mm, and the stack **101** is circular and has a diameter of about 300 mm.

[0024] The temperature measuring device **200** may be used to troubleshoot a process, such as a deposition or etch process, that produces defects, such as non-uniform thickness profile of a deposited layer by a deposition process or non-uniform depths in a plurality of openings formed by an etch process. The temperature measuring device **200** is placed into the process chamber in which the process is performed, and the process is performed on the side **206** of the substrate **202** of the temperature measuring device **200**. The process conditions are the same as the process conditions during the actual process. After the process is performed on the temperature measuring device **200**, such as forming a layer on the side **206** of the substrate **202** or forming a plurality of openings on the side **206** of the substrate **202**, the temperature measuring device **200** is removed from the process chamber and the sheet resistivity at one or more locations on the stack **101** of the temperature measuring device **200** is measured. In one example, sheet resistivity measurements were measured at 10 to 100 locations on the stack **101**. The measured sheet resistivity were converted to temperatures using the relationship identified by the calibration, and a thermal profile of the stack **101** (or substrate **202**) can be mapped from the temperatures. The relationship identified by the calibration is obtained by calibrating a temperature measuring device **200** using the calibration method described above. The calibrated temperature measuring device **200** is not operable to measure any temperatures within the calibration range. The temperature measuring device **200** used to measure a temperature has the same size and shape as the calibrated temperature measuring device **200**. The thermal profile can identify any hot or cold spots that may be the cause of the defects. In one example, the hot spot is caused by residual deposition on the surface of the substrate support.

[0025] FIG. 2B is a schematic cross-sectional side view of the temperature measuring device **200** according to another implementation. As shown in FIG. 2B, the temperature measuring device **200** includes a layer **208** disposed between the substrate **202** and the stack **101**. The layer **208** is in contact with the side **204** of the substrate **202** and the metal layer **106** of the stack **101**. The layer **208** may improve the adhesion of the stack **101** to the substrate **202**. The layer **208** may also reduce damage to the substrate **202** during reclaim process. The layer **208** may be fabricated from a dielectric material, such as an oxide, for example silicon oxide. The layer **208** has a thickness of a few nanometers to micrometers. During the reclaim process, the stack **101** may be removed by a chemical mechanical polishing (CMP) process, and the substrate **202** is protected by the layer **208** from the CMP process. The layer **208** can be removed from substrate **202** by a wet etch process or other suitable process.

[0026] FIG. 2C is a schematic cross-sectional side view of the temperature measuring device **200** according to another

implementation. As shown in FIG. 2B, the temperature measuring device **200** includes a passivation layer **210** surrounding the stack **101**. The passivation layer **210** is in contact with a portion of the side **204** of the substrate **202** and the stack **101**. The passivation layer **210** has a thickness of a few Angstroms to 50 Angstroms. The passivation layer **210** encapsulates the stack **101**, which minimizes any metal contamination. The passivation layer **210** may be fabricated from a dielectric material, such as an oxide, for example silicon oxide. As shown in FIG. 2C, the stack **101**, or the three metal layers **102**, **104**, **106**, extends substantially across the first side **204** of the substrate **202** from edge to edge. The stack **101** covers greater than 95 percent of the first side **204** of the substrate **202**.

[0027] FIG. 3 illustrates a bottom view of the temperature measuring device **200**. As shown in FIG. 3, a plurality of measurement locations **302** is located on the metal layer **102** of the stack **101**. The number and pattern of the measurement locations **302** may be depend on the process. In one example, the number of measurement locations **302** ranges from about 10 to about 100. In one example, the measurement locations **302** form a pattern having concentric circles. Sheet resistivity measured at the measurement locations **302** may be different due to different amount of atoms diffused from the second metal layers **102**, **106** into the first metal layer **104** at different measurement locations **302**.

[0028] The temperature measuring device including a stack having a plurality of metal layers is utilized to measure the highest temperature the temperature measuring device has experienced. Because the relationship between sheet resistivity (or a change in sheet resistivity) and the experienced temperature is identified by a calibration process, the temperature measuring device provides a cheap, easy to prepare, and wide applicable method to measure a temperature in any semiconductor or display processes. Furthermore, the temperature measuring device can provide local sheet resistivity information, so a thermal profile of the temperature measuring device can be mapped to identify any hot or cold spots.

[0029] While the foregoing is directed to implementations of the present disclosure, other and further implementations of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

What is claimed is:

1. A temperature measuring device, comprising:
    a substrate including a first side and a second side opposite the first side, the substrate configured to replicate a workpiece used in vacuum processing; and
    a stack extends substantially across the first side of the substrate from edge to edge, the stack comprising:
        a first metal layer comprising a first material; and
        two second metal layers each comprising a second material different than the first material, the first metal layer being disposed between the two second metal layers.

2. The temperature measuring device of claim **1**, wherein the first material comprises aluminum, tungsten, or silver.

3. The temperature measuring device of claim **2**, wherein the second material comprises titanium.

4. The temperature measuring device of claim **1**, wherein the stack is in direct contact with the substrate.

5. The temperature measuring device of claim **1**, further comprising a layer disposed between the substrate and the stack.

6. The temperature of claim **5**, wherein the layer comprises a dielectric material.

7. The temperature measuring device of claim **1**, further comprising a passivation layer encapsulating the stack.

8. The temperature measuring device of claim **7**, wherein the passivation layer comprises a dielectric material.

9. The temperature measuring device of claim **1**, wherein the substrate comprises semiconductor, glass, or polymer.

10. A temperature measuring device, comprising:
    a substrate including a first side and a second side opposite the first side, the substrate configured to replicate a workpiece used in vacuum processing; and
    a stack extends substantially across the first side of the substrate from edge to edge, the stack comprising:
        a first metal layer having a first electrical resistivity; and
        two second metal layers each having a second electrical resistivity greater than the first electrical resistivity, the first metal layer being disposed between the two second metal layers.

11. The temperature measuring device of claim **10**, wherein the first material comprises aluminum, tungsten, or silver.

12. The temperature measuring device of claim **11**, wherein the second material comprises titanium.

13. The temperature measuring device of claim **10**, wherein the stack is in direct contact with the substrate.

14. The temperature measuring device of claim **10**, further comprising a layer disposed between the substrate and the stack.

15. The temperature measuring device of claim **10**, further comprising a passivation layer encapsulating the stack.

16. A method for measuring a temperature, comprising:
    placing a first temperature measuring device into a process chamber;
    perform a process on the first temperature measuring device;
    measuring a sheet resistivity of the first temperature measuring device; and
    converting the sheet resistivity to a temperature.

17. The method of claim **16**, wherein the converting the sheet resistivity to a temperature comprises using a regression model previously identified during a calibration process, the calibration process performed using a second temperature measuring device different than the first temperature measuring device.

18. The method of claim **17**, wherein the calibration process comprises incrementally heating the second temperature measuring device to multiple temperatures.

19. The method of claim **18**, wherein the calibration process further comprises measuring a sheet resistivity of the second temperature measuring device at each temperature of the multiple temperatures.

20. The method of claim **19**, further comprising establishing the regression model using the multiple temperatures and the corresponding sheet resistivity.

* * * * *