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An Electrical Test Structure to Quantify Microloading after Plasma Dry Etching of Metal Film

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to methods for the testing of semiconductor circuitry for the quantifying the effectiveness of semiconductor parametric control and to the construction and methods of application of testing apparatus for quantifying semiconductor process effectiveness particularly of plasma dry etching of metal film.

Description of Related Art

This invention grew out of the problems involving the tedious processing and material loss in the semiconductor process especially in the area of plasma dry etching of metal films.

In the plasma dry etching process for metal film is shown in Figure 1a, 1b, ..., 1g. In Figure 1a a substrate 10 is shown. In Figure 1b, a substrate 10 has a conductive metal 20 deposited on it by a physical or chemical vapor deposition process to a desire thickness. The substrate

10 is then coated with a material 30 that is resistant to the etchant is shown in Figure 1c. Figure 1d illustrates the etchant resistant material 60 covered with a masking material that will prevent exposure of certain areas of the material to a radiation source 40 such as visible light, infrared light, or X-ray radiation. The substrate 10 with the deposited metal film 20 and unprotected etchant resistant material 30 is exposed to the radiation source 40 and the unprotected etchant resistant material that is exposed to the radiation source 40 is cured in the areas not covered by the mask 30a, 30b. Figure 1e shows the substrate 10 with the deposited metal film 20 and the exposed etchant resistant material 30 is then cleaned with a chemical that will remove the etchant resistant material 30 from the areas 20a, 20b of the metal film 20 that are to be removed from the substrate 10. Figure 1f illustrates the substrate 10 with the deposited metal film 20 exposed to the plasma dry etch 50.

The factors that determine the effectiveness of the plasma dry etch 50 that are under the control of the operator are the Radio Frequency (RF) input power, reactor pressure, excitation frequency, temperature of the reactor, the temperature of wafer surface, the composition of the feed gas to the reactor, and the flow rate of the feed gas.

The areas 22, 24, 26 covered by the etchant resistant material 30 that none of the metal film is removed, while the areas 23, 25 exposed to the etchant 50 have the metal film removed. In Figure 1g the etchant resistant material 30 and the areas 22, 24, 26 of the metal film 20 that were not exposed to the etchant have maintained their original thickness, whereas those areas 23, 25 exposed to the etchant 50 have their thickness significantly reduced. The ratio of the thickness of the metal film 20 in the areas 23, 25 of the metal film 20 that were exposed to the metal film to the thickness of the areas 22, 24, 26 of the metal film 20 that were not exposed to the etchant 50 is defined as the microloading Ψ.

The quantification of the effectiveness of the etchant 50 was accomplished by a cross sectional cut through the substrate and examining the edge of the exposed substrate 20 with a scanning electron microscope. In order to evaluate the effect of changes in the set of parameters that determine the etchant , this process had to repeated many times with subsequent loss of the substrates and expenditure of time.

Apparatus and methods such as disclosed in U.S. Patent 5,326,428 (issued Jul 5, 1994 to Farnsworth et al. for Method For Testing Semiconductor Circuitry For Operablity and Method For Forming Apparatus For Testing Semiconductor Circuitry For Operablity) use

unique patterns on a substrate to allow testing for operability of the semiconductor circuitry as opposed to an ability to evaluate process parameters of the fabrication of the semiconductor circuitry.

SUMMARY OF THE INVENTION

An object of this invention is to minimize the tedium and material loss from the traditional techniques used for the quantification of the microloading from prior art. This object is achieved by the creation of the microloading quantification apparatus that comprises a supporting substrate on which two bond pads and etched conductive patterns are deposited. The two bond pads are operably connected to the etched conductive pattern at opposite ends.

Another object of this invention is to provide a method for the application of the microloading quantification apparatus. This object is achieved by operably coupling to the bond pads a constant current source and a voltage measuring means. The next step is measuring of the voltage developed between the bond pads as a result of the current being forced through the microloading quantification apparatus by the constant current source. The next step is determining the resistance of the microloading quantification apparatus. The next step is calculating of the microloading for the microloading quantification apparatus, The aforementioned steps are repeated on a plurality of microloading quantification apparatus that have been processed with

variations in the processing parameters of the semiconductor process. The final step is comparing of the variations in processing parameters of the semiconductor process with the values of the microloading.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1a - 1g are cross-sectional views showing the prior art processing steps to deposit and etch conductive films on a substrate.

Figure 2 is a cross-sectional view of the preferred embodiment of this invention describing the geometric parameters considered.

Figure 3 is a cross-sectional view of an alternate structure for the preferred embodiment in which the geometric parameters are described.

Figure 4 is a cross-sectional view of another alternate structure for the preferred embodiment, in which the geometric parameters are considered.

Figure 5 is an cross-sectional of an implementation of the preferred embodiment, in which the structure of Fig. 4 is implemented.

Figure 6 is an illustration of another implementation of the preferred embodiment, in which the structure of Fig. 2 is implemented.

Figure 7 is an illustration of still another implementation of the preferred embodiment in which the structure of Fig. 3 is implemented.

Figure 8 is a diagram of the process of using the microloading quantification apparatus.

DETAILED DESCRIPTION OF THE INVENTION

In the development of the process parameters of the plasma dry etch, a method and apparatus needed to be provided that would eliminate the tedium and material loss associated with the cross sectional slicing and evaluation of the microloading with a scanning electron microscope. To accomplish this goal, the invention uses the measurement of the resistance of a structural block fabricated by the deposition of a uniform thickness of a metal film upon a substrate and the etching of a plurality of rectangular areas from the structural block. The resistance of the structural block is directly related to the value of the cross sectional area of the surface orthogonal to the direction of a current flow and the length of the structural block parallel to the direction of the current flow.

In Figure 2 the structural block **180** is the metal film deposited upon the substrate **170**. After the etching process, the structural block **180** is divided into a plurality of rows **180a, 180b, ... , 180g**, wherein the rows exposed to the etchant **180b, 180d, 180f** have a height h_2 **150** that is less than the height h_1 **140** of the rows not exposed to the etchant **180a, 180c, 180e, 180g**. The microloading Ψ of the structural block of metal film **180** is the ratio

$$\Psi = h_2/h_1$$

The structural block **180** further has a dimension in the **X 100** direction that is L_1 **120** and a dimension in the **Y 110** direction that is L_2 **130**. Each row has a width dimension in the **Y 110** direction that is **w 160**. In order to facilitate the calculation of the microloading all of the widths **w 160** should be equal to every other and the number of rows should be

$$L_2/w.$$

The structural block **180** also has a physical property , sheet resistivity r, that is defined as the quotient of the magnitude of a voltage developed across a unit area of a material of uniform thickness divided by the magnitude of a current flowing through the unit area.

The conductance **C** of the structural block **180** will then be:

$$C = \sum_{i=1}^{N} \Delta w i / r L_i$$

where

ΔWi is the width of an arbitrary subdivision of the dimension of the structural block that in the direction orthogonal to the direction of a current flow

r is the sheet resistivity of the material of the structural block

L_i is the dimension of the structural block **180** that is parallel to the direction of the current flow at the Δw.

N is the total number of subdivision of the length L

i is the counting variable of the subdivisions of the length L.

In Figure 2 if the current is forced into the structural block **180** along the **X 100** direction, then the width of the structural block is in the **Y 110** dimension and can be subdivided into the units that are the width **w 160** of each row. The length for the calculation is the dimension L_1 and the sheet resistivity for the unetched blocks r_{ue}. The conductivity of an unetched row C_{ue} is

$$C_{ue} = {}^{W}/_{r_{ue}L_i}$$

Since the height of the etched segments h_2 is proportional to the unetched height h_1 by the factor Ψ the sheet resistivity r_e of the etched segment is then

$$r_e = \frac{r_{ue}}{\Psi}$$

From this ratio the conductivity C_e of the etched rows is

$$C_e = {}^{W\Psi}/_{r_{ue}L_1}$$

If the number of rows of the structural block **180** is odd number with an unetched row as the first **180a** and last row **180g**, then the number of unetched rows N_{ue} can be determined by

$$N_{ue} = \left({}^{L_2}/_{W} + 1\right){}^{1}/_{2},$$

The number of etched rows N_e can be determined by

$$N_e = \left({}^{L_2}/_{W} + 1\right){}^{1}/_{2} - 1 = {}^{1}/_{2}\left({}^{L_2}/_{W} - 1\right)$$

The total conductance C_B of the structural block **180** is then determined by

$$C_B = N_{ue}C_{ue} + N_eC_e$$

$$C_B = \frac{1}{2}\left(\frac{L_2}{w} + 1\right)\frac{w}{r_{oe}L_1} + \frac{1}{2}\left(\frac{L_2}{w} - 1\right)\frac{\Psi w}{r_{oe}L_1}$$

The resistance R_B of the structural block is

$$R_B = \frac{1}{C_B}$$

The measurement of the resistance of the structural block **180** is accomplished by the measurement of the voltage **V** developed across the structural block **180** as a result of a current **I** being forced through it. From Ohm's Law, the resistance is

$$R_B = \frac{V}{I}$$

Once the resistance R_B of the structural block **180** is determined the quantification of the microloading Ψ is calculated from the function for the conductivity C_B by solving for the microloading. This is

$$\Psi = \frac{2r_{oe}L_1}{R_B(L_2 - w)} - \frac{L_2 + w}{L_2 - w}$$

Figure 3 illustrates the case 2 of a current being forced in the Y 110 direction to calculate the conductance of the structural block 580, the Δw_i is in the X 100 direction and is assumed to be equal to w and the number of rows is

$$L_1/w.$$

Since each row 500 now consists of etched and unetched segments, the resistance R_r of the row 500 is now

$$R_r = \sum_{j=1}^{M} r\Delta L_i/w_i$$

where

w_i is the assumed width of the row #

r is the sheet resistivity of the metal film

ΔL_i is the length of the subdivision in the X 100 direction

M is the number of subdivisions in the length of the structural block 30 L_1

j is the counting variable of the subdivisions of the length variable L_1

The resistance R_{ue} for a unetched segments **502, 504, 506, 508** becomes

$$R_{ue} = r_{ue}W/W = r_{ue}$$

and the resistance R_e for an etched segments **503, 505, 507** becomes

$$R_e = r_{ue}W/\Psi_W = r_{ue}/\Psi$$

The total number of segments in the row **500** is

$$L_2/W.$$

If the number of segments in the row **500** is an odd number and if the first **502** and the last **508** segments are unetched then the number of unetched segments N_{ue} is

$$N_{ue} = \left(L_2/W + 1\right)1/2$$

and the number of etched segments N_e is

$$N_e = \left(L_2/w - 1\right) 1/2$$

The total resistance R_{row} is

$$R_{row} = N_{ue} R_{ue} + N_e R_e$$

$$R_{row} = r_{ue}\left(L_2/w + 1\right) 1/2 + r_{ue}/\Psi\left(L_2/w - 1\right) 1/2$$

$$R_{row} = r_{ue}/2\left[\left(L_2/w + 1\right) + 1/\Psi\left(L_2/w - 1\right)\right]$$

The resistance R_b of the structural block 580 then becomes

$$R_b = Rrow/N_{rows}$$

where $N_{rows} = L_1/w$

$$R_b = \frac{r_{ue}/2\left[\left(L_2/w + 1\right) + 1/\Psi\left(L_2/w - 1\right)\right]}{L_1/w}$$

Again using the aforementioned technique to physically determine the resistance of the structural block **580**, the microloading Ψ can be calculated as

$$\Psi = \frac{r_{us}(L_2 - w)}{2R_bL_1 - L_2r_{us} - r_{us}w}$$

Figure 4 illustrates Case 2 wherein the first **601** and last **605** segment of the row **600** of segments is etched, then the number of etched segments N_e is

$$N_e = \left(L_2/w + 1\right)1/2.$$

and the number of unetched segments N_{ue} is

$$N_{ue} = \left(L_2/w - 1\right)1/2.$$

The resistance R_{row} of the row **600** of etched **601, 603, 605** and unetched **602, 604, 606** segments is now

$$R_{row} = r_{us}/2\left[\left(L_2/w - 1\right) + 1/\Psi\left(L_2/w + 1\right)\right]$$

and the total resistance R_b of the structural block **680** is

$$R_b = \frac{r_{sq}/2\left[\left(L_2/W - 1\right) + 1/\Psi\left(L_2/W + 1\right)\right]}{L_1/W}$$

The microloading Ψ for this form of case 2 then becomes

$$\Psi = \frac{r_{sq}(L_2 + W)}{2R_b L_1 - L_2 r_{sq} + r_{sq} W}$$

Figure 5 illustrates an implementation of the preferred embodiment of this invention. The first bond pad **700** is operably connected to the first row **720a** of the structural block **720** and the second bond pad **710** is operably connected to the last **720i** row of the structural block **720**. A constant current source and a voltage measuring means **(not shown)** is operably coupled between the first and second bond pads **700, 710** and the resistance is determined. The microloading is then calculated using the function

$$\Psi = \frac{r_{sq}(L_2 + W)}{2R_b L_1 - L_2 r_{sq} + r_{sq} W}.$$

Figure 6 illustrates another implementation of the preferred embodiment wherein the current from the current source **(not shown)** that is operably coupled to first and second bond pads **800, 810** is forced through the structural

block **820** in the **X 830** direction. The voltage is measured by a voltage measuring means **(not shown)** that is operably coupled between the first and second bonding pads **800, 810** and the resistance is determined. The microloading Ψ is calculated by the function

$$\Psi = \frac{2r_{sq}L_1}{R_s(L_2 - w)} - \frac{L_2 + w}{L_2 - w}$$

Figure 7 illustrates another implementation of the preferred embodiment wherein the current from the current source **(not shown)** is operably coupled between the first and second bond pads **900 910** is forced through the structural block **920** in the **Y 930** direction. The voltage measured by the voltage measuring means **(not shown)** operably coupled between the first and second bond pads **900 910** and the resistance of the structural block **920** is determined. The microloading is calculated using the function

$$\Psi = \frac{r_{sq}(L_2 - w)}{2R_sL_1 - L_2r_{sq} - r_{sq}w}.$$

The method for the application of the microloading quantification apparatus is outlined in Figure 8. The first step **1000** is the processing of the microloading quantification apparatus using known semiconductor process techniques including plasma dry etch. The second step **1010** is the operably

coupling of a constant current source between the bonding pads of the microloading quantification apparatus. The third step **1020** is the operably coupling of a voltage measuring means between the bonding pads of the microloading quantification apparatus. The fourth step **1030** is the measuring of the voltage developed between the bonding pads of the microloading quantification apparatus from the current being forced through the bonding pads of the microloading quantification apparatus. The fifth step **1040** is the determining of the resistance of the microloading quantification apparatus. The sixth step **1050** is the calculation of the microloading effect using the function for the type of microloading quantification apparatus being tested. The seventh **1060** is the repeating of the first six steps for multiple microloading quantification apparatus while adjusting the parameters of the semiconductor process especially those for the plasma dry etch.

Once all of the microloading quantification apparatus have been process and the microloading calculated, the final step **1070** is the comparing of the variation of the microloading effect for the variation of the parameters of the semiconductor process.

While the invention has been particularly shown and described with reference to the preferred embodiments thereof, it will be understood by those skilled in the are that changes in form, materials, and details may be made without departing from the spirit and scope of the invention.

What is claimed:

1. A microloading quantification apparatus comprising

   a) a supporting substrate;

   b) a first bonding pad deposited on the supporting substrate;

   c) a second bonding pad deposited on the supporting substrate; and

   d) a plurality of etched conductive patterns deposited on the supporting substrate operably connected to the first bonding pad and the second bonding pad.

2. The microloading quantification apparatus of claim 1 wherein the plurality of etched conductive patterns are formed by a plasma dry.

3. A method of formation of a microloading quantification apparatus comprising the steps of:

   a) providing a supporting substrate

   b) depositing a conductive material film upon the supporting substrate;

   c) depositing a photoresistive material upon the conductive material film;

   d) exposing the photoresistive material to a radiation source such as visible light, infrared radiation, or X-rays through a photomasking means to define the geometric outlines of a first bonding pad, a

second bonding pad, and a plurality of etched conductive patterns, and to cure the photoresistive material;

e) removing the photoresistive material from the conductive material film for the areas not defined by the first bonding pad, the second bonding pad and the plurality of etched conductive patterns;

f) exposing the conductive material film to the plasma dry etch to remove a portion up to the entire conductive material film that is not concealed by the photoresistive material; and

g) removing the photoresistive material that concealed the conductive material defining the first bonding pad, the second bonding pad, and the etched conductive patterns.

4. A method for the application of a microloading quantification apparatus comprising the steps of:

a) providing said microloaing apparatus comprising a first bonding pad, a second bonding pad, and a plurality of conductive patterns;

b) operably coupling a constant current source between the first bonding pad and the second bonding pad;

c) operably coupling a voltage measuring means between the first bonding pad and the second bonding pad;

d) measuring a voltage that is developed by the constant current source passing a current through the plurality of conductive patterns;

e) determining a resistance of the plurality of etched conductive patterns; and

f) repeating the operable coupling of the first bonding pad and second bonding pads to the current source and the voltage measuring means, the measuring the voltage developed across the plurality of conductive patterns, and determining the resistance for a multiplicity of microloading quantification apparatuses.

5. The method of claim 4 wherein each microloading quantification apparatus are formed by the variation of a set of parameters of the plasma dry etch.

6. The method of claim 4 wherein the resistance of the plurality of etched conductive pattern is defined by the quotient of the voltage developed between the first bonding pad and the second bonding pad divided by the value of the current being forced through the plurality of conductive pattern by the constant current source.

7. The method of claim 4 where in the resistance of the etched conductive patterns is determined by the set of parameters of the plasma dry etch step.

8. The method of claim 4 further comprising the step of determining the correlation of the variation of the resistance to the change of the set of parameters of the plasma dry etch.

9. A microloading quantification apparatus comprising

a) a supporting substrate;

b) a first contact bonding pad deposited on the supporting substrate;

c) a second contact bonding pad deposited on the supporting substrate; and

d) a etched conductor pattern deposited on the supporting substrate and operably connected to the first bonding pad and the second bonding pad.

10. The microloading quantification apparatus of claim 9 further comprising:

a) a current source operably coupled between the first contact bonding pad and the second contact bonding pad; and

b) a voltage source operably coupled between the first contact bonding pad and the second contact bonding pad.

11. The microloading quantification apparatus of claim 9 where in the etched conductor pattern comprises:

a) a first geometric area with a first uniform thickness of a conductive material not removed during the plasma dry etch; and

b) a second geometric area with a second uniform thickness of conductive material.

12. The microloading quantification apparatus of claim 11 where in the second geometric area with a second uniform thickness of conductive material is determined by the set of parameters of the plasma dry etch.

13. A microloading quantification apparatus of claim 12 wherein the etched conductor pattern further comprises:

a) a cross-sectional area determined by the function

$$\sum_{i=1}^{X} t_i \Delta x_i$$

where

X is the dimension of the conductor pattern orthogonal to the direction of the current flow from the current source and orthogonal to the thickness of the conductive material

Δx is an arbitrarily small subdivision of the X dimension

i is the counting variable for the subdivisions Δx

t_i is the thickness of the conductive material at each Δx;

and

b) a length that is the dimension of the conductive material parallel to the direction of the current flow from the current source and orthogonal to the X dimension and to the thickness.

14. The microloading quantification apparatus of claim 12 wherein the first thickness is proportional to the second thickness and this ratio is defined as the microloading.

15. A method for the application of a microloading quantification apparatus comprising the steps of:

a) providing said microloading quantification apparatus, comprising a first contact bonding pad, a second contact bonding pad, and etched conductor patterns;

b) operably coupling a constant current source between the first contact bonding pad and second contact bonding pad;

c) operably coupling a voltage measuring means between a first contact bonding pad and a second contact bonding pad;

d) measuring of a voltage that is created by the current flow from the constant current source passing through the etched conductor patterns;

e) determining the measured resistance of an etched conductor pattern;

f) comparing the determined resistance of the etched conductor pattern with an expected resistance of the etched conductor pattern;

g) determining a microloading variation of the etched conductor pattern; and

h) repeating the aforementioned steps for a multiplicity of microloading quantification apparatuses.

16. The method of claim 15 wherein each microloading quantification apparatus of the multiplicity of microloading quantification apparatuses are formed by the variation of a set of parameters of the plasma dry etch step of the integrated circuits process.

17. The method of claim 15 wherein the resistance of the plurality of etched conductor pattern is defined by the quotient of the voltage developed between the first bonding pad and the second bonding pad divided by the value of the current being forced through the plurality of conductive pattern by the constant current source.

18. The method of claim 16 wherein the expected resistance of the etched conductor pattern is determined by the function

$$\sum_{j=1}^{M} r\Delta L_i / w_i$$

where

r is the sheet resistivity of the conductive material

L_j is the dimension of the conductive material parallel to the flow of the current from the current source

ΔL_j is an arbitrary subdivision of the length of the conductive material

w_j is the width of the conductive material at the subdivision of the length L_j and the dimension of the conductive material orthogonal to the flow of the current from the current source

j is the counting variable for the each of the subdivisions of L_j

M is the total number of subdivisions of the length L_j.

19. The method of claim 15 wherein the microloading variation is the ratio of the calculated resistance to the expected resistance.