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Probes Vacillating and Mapping Technique at Testing Micro-area Sheet Resistance

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Abstract

This article briefly elaborated the basic concepts of the probe vacillated at testing a large silicon wafer with square four point probe equipment. The importance of the micro-area's sheet resistance is discussed and the basic principles of four point probe measurement technology are analyzed. Some factors that affect the measurement accuracy are studied, and interference can be avoided while measuring and analyzing the impact on square four point probe measurement by probe vacillate. The calculation formula of the square micro-area probe measurement is deduced when probes vacillated discretionarily. An experiment was made with a small wafer sample and accurate resistivity was gotten. The electrical resistivity is tested for another silicon wafer by a square four point probe equipment. Color Mapping graphics was designed for displaying the micro-area resistance.

Keywords*: four-point probe method, sheet resistance, uniformity, vacillations, mapping*

1. Introduction

With the rapid development of science and technology, computer is upgraded constantly that the size of the integrated circuit is more smaller than before. The whole device features will be affected by the electrical resistivity's uniformity in a large silicon wafer. So it is significant to discuss the micro-area resistivity with silicon wafers [1].

2. The Testing Method of Micro-area's Resistance

Micro-area's resistance is surface resistance of an object ignoring the thickness, and it is expressed with Rs [2] and the unit is Ω. The testing methods are classified into two kinds. One is non-contact measurement method [3], the other is contact measurement method. Comparing with both of them, the former has many advantages, such as non-contact, non-damage and non-stain with the tested sample, its disadvantages are which the equipment is more complicated and the cost is too high. The testing area is more limited. But the contact testing method is the economic and mature method relatively. Among them, four-point probe testing method is used widely. They mainly include the conventional straight line four point probe, modified Van Der Pauw [4] methods and modified Rymaszewski four point probe methods [5]. Conventional straight line square four-point probe method [6] has become a means of semiconductor production process [7] in many factories. Table 1 is the advantages and disadvantages of testing micro area sheet resistance.

Table 1. The Test Method of Micro-area 's Resistance

the testing method of resistance	testing conditions	minimum testing area	Used for the micro area testing
the conventional straight line four point probe	the spacing of four-point probe is one mm	>3 mm	No
Rymaszeuski method	require to accommodate four vertical probe, will produce the edge effect	>1 mm	No
Van Der Pauw method	the contact probe is placed in the edge of the sample	all the testing sample	No
Expanding resistance method	requiring large area ohmic contact in back	>10 um	No
Improved Van Der Pauw method	no special requirements	≤300 um	Yes

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3. The Impacting Analysis of Square Four-point Probe Testing Method

When measuring thin wafer sample, square four-probe method will be used. Current will radiate out spreading in sample when it flows to silicon wafer as shown in Figure1.

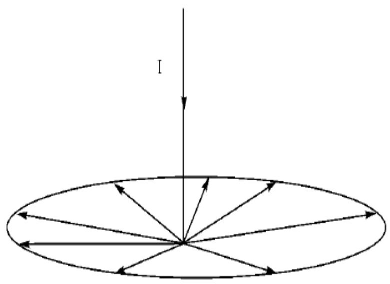

Figure 1. The Scheme of the Flow of Current

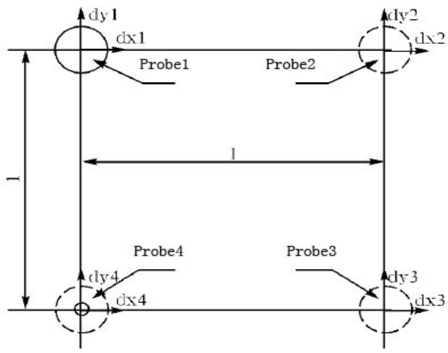

Figure 2. The Error Calculation Chart

In ideal situation, probes should be separated and lay on the middle of the circle in the square corner, but the position error will be produced in actual measurement. Four circles in Figure 2 are the corresponding range of probe vacillating [8] when measuring the silicon wafer sample.

In ideal situation:

$$U_{12} = F_1 - F_2 = (\frac{R_s I}{2p}\ln\frac{1}{r_1} - \frac{R_s I}{2p}\ln\frac{1}{r_2}) - (\frac{R_s I}{2p}\ln\frac{1}{r_3} - \frac{R_s I}{2p}\ln\frac{1}{r_4}) \quad (1)$$

When the probe vacillated:

$$U_{12}' = F_1' - F_2' = \frac{R_s I}{4p}\ln\frac{(S - dx_1 + dx_3)^2 + (S - dy_3 + dy_1)^2}{(S - dy_4 + dy_1)^2 + (dx_4 - dx_1)^2} \bullet \frac{(S - dx_4 + dx_2)^2 + (S - dy_4 + dy_2)^2}{(S - dy_3 + dy_2)^2 + (dx_3 - dx_2)^2} \quad (2)$$

$$\frac{U_{12}}{U_0} = \frac{1}{2\ln 2}\ln\frac{(1 - dx_1 + dx_3)^2 + (1 - dy_3 + dy_1)^2}{(1 - dy_4 + dy_1)^2 + (dx_4 - dx_1)^2} \bullet \frac{(1 - dx_4 + dx_2)^2 + (1 - dy_4 + dy_2)^2}{(1 - dy_3 + dy_2)^2 + (dx_3 - dx_2)^2} \quad (3)$$

Among the formulas, Rs is the sheet resistance, I is current, $r_1$and r_2 refer to the distance from probe 1 to probe 4 and probe 3; r_3 and r_4 refer to the distance from probe 2 to probe 4 and probe 3; r_1, r_2, r_3, r_4 refer to the distance after the probe vacillated; $\Phi_1$andΦ_2 are the electric potential of probe 1 to probe 2 under the ideal state; Φ_1' and Φ_2' refer to the electric potential difference after the probe 1and probe 2 vacillated.

In order to make the comparative analysis of measurement results more clearly, 60 sets of data are listed randomly. Hypothesis every item of (dx_1, dy_1), (dx_2, dy_2), (dx_3, dy_3), (dx_4, dy_4) is equal to one of following array: (0, 0), (0.1, 0.1), (- 0.1, - 0.1), (0.05, 0.05), (- 0.05, - 0.05). Among the random 60 sets of data, the first 16 sets of data means that the four probes are the offset in the horizontal direction and vertical direction; from No.17 to No.48, it is considered the offset in the direction of 45 degree angle [9]; from the No. 49 to the end, a larger offset data is amplified and its purpose is to test this method's validity. Through the calculation and comparative analysis, the final result was obtained as shown in Figure 3 and Figure 4.

The horizontal coordinate axises in Figure 3 and Figure 4 are the tolerance distribution of Rs ' / Rs, longitudinal coordinate axises are their numbers of occurrences for the same error value. Through the observation of above two figures, it can be found that the testing result and the actual result are similar, and the only difference between this two figures is data's quantity. This paper just lay out 60 sets of data, and the 625 sets of data are used in the actual measurement, so the actual measurement results are more close to the normal distribution curve. In order to further express this idea, further statistics are made below: among 53 sets of data, there are 29 sets that the tolerance is less than 10%; and there are 37 sets its tolerance is less than 15%; but there are 321 sets which tolerance is less than 10% among the actual 625 sets of data; and then the corresponding statistical figures are made as shown in Figure 5 and Figure 6.

Figure 3. Statistical Results

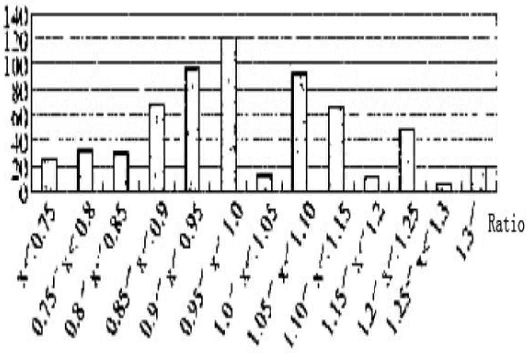

Figure 4. Actual Testing Results

From Figure 3, we can get the result that most of the data is distributed between 0.84 to 1.16, about 80. 5%, and there is not a normal distribution. And the reason is that the named offset is only a "special case", but in fact, probes vacillat randomly with continuous distribution. In Figure 5, there are 29 sets its tolerance is less than 10% among 53 sets of data. There are 37 sets that its tolerance is less than 15%. But in the actual 625 sets of data, there are 321 sets that its tolerance is less than 10%. That is to say, the accuracy rate is very high. According to the above result that probes vacillated, it is easy to find that there are two worst statuses, which causing the probe vacillated shown as Figure 7 and Figure 8. So, the actual measurement should avoid the two worst statuses.

We can clearly see the measurement tolerance by the contrast of figures, so we should avoid this situation.

4. Measured Data Analysis and Calculations

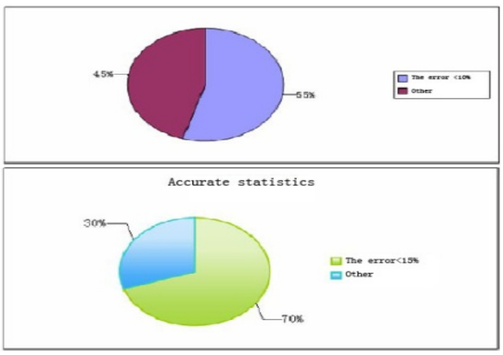

Figure 5. Error Statistic of Measurement Data

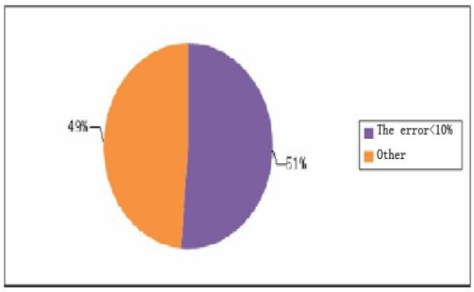

Figure 6. Error Analysis of Actual Result

In this experiment, a silicon wafer which number is sheet 7, and one side length of a square is 10mm is measured. Extending layer thickness is 0.5mm, and growth layer thickness is 10nm. When the wafer is measured, the multimeter is reversed twice, and current once.

40,000ohms was connected in series circuit when measuring, the substrate was arranged in accordance with Si (100), the 10nm cobalt was grown. Initial state is that the current enter into back probe [5], and the current flows out from left probe. The corresponding ten sets of data were tested, selecting which better four sets of characteristics data and compared with each other, the resistivity is gotten according to the formula, then the selection data of sheet 7 is showed in Table 2.

Table 2. The Actual Measurement Data

input current [uA]	output voltage [mV]	multimeter reversing[mV]	current reversing[mA]	multimeter reversing[mV]
200	1.47	-1.51	1.45	-1.46
250	1.87	-1.87	1.82	-1.84
400	2.98	-2.99	2.96	-2.97
500:	3.71	-3.73	3.68	-3.67

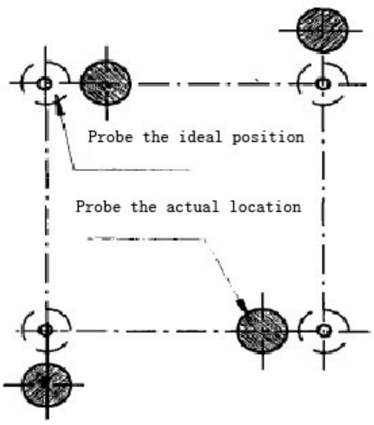

Figure 7. R_S'/R_S=0.7

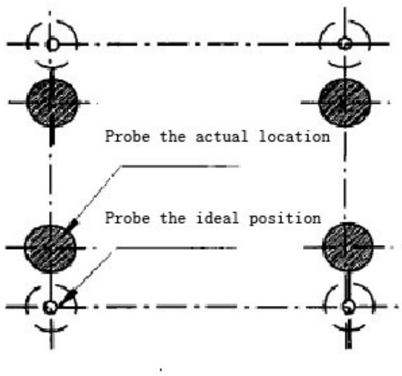

Figure 8. R_S'/R_S =1.35

In Table 2, the current of 200 and 400 are ranged for a group, and 250 and 500 are ranged for another group. Calculations for 200 and 400 of the group are as follows:

V1= 2（U1+ U2)/2=(1.49+1.455)/2=2.945 (mV) (4)

V2= (U3+ U4)/2=(2.985+2.965)/2=2.975 (mV) (5)

V1 /V2=2.945/2.975=0.958 (mV) (6)

Let V1/V2=x , according to the Van Der Pauw formula [10], so
$f(x)=1+0.3237715x-0.04037679x^2+0.00857882x^3-0.00077693x^4+0.00002604x^5+0.00017171$
When f(x)=1.0002564, R_s=πf(V1/V2) (V1+V2)/Iln2, so R_s =67.0693 (Ω)

Because the epitaxial layer is too thin, epitaxial layer and substrate can be considered parallel conductive, and there is a result according to resistance`s parallel formula [11]:

$$R_S = V / I = (t_{epi} / \rho_{epi} + t_{sub} / \rho_{sub})^{-1} \quad (7)$$

Because t_{epi} =10nm (extended layer thickness), ρ_{sub} =2.14*103Ω.cm (extended-layer resistivity [12]), t_{sub} =0.5mm (growth thickness) is known, so ρ_{epi} =6.7069×10^{-4} (Ω.cm)

For the group of 250 and 500 of the current, the same calculation is made, then

$$\rho_{epi} = 6.70598\times10^{-4} \text{ (Ω.cm)} \quad (8)$$

Compared with the two resistivity, the results is the same basically, indicating that the experimental data is more reliable. So, it is concluded that the resistivity is accurate.

5. Three Inch Silicon Wafer Testing and the Application of Mapping Technical Method

A square four tilt probe instrument was used in testing a three inch silicon wafer shown in Figure 9. It was developed with the improved Rymaszewski method and the function of image recognition and automatic measurement [13].

One of four probes for measuring is driven by a stepping motor and the requirement testing structure can be adjusted. So it can test large silicon wafers resistivity uniformity. And then the internal quality control can be carried out. The overall instrument consists of three parts: testing platform and mechanical driving system, testing system, computer visualization testing platform. Figure 9 is the shape of square four probe instrument. The mechanical structure of four point probe testing is designed as three layers of pyramid structure. The bottom layer is used for fixing the sample platform. The sample platform can move along the X and Y axis bidirectionally, and it can rotate 360 degrees around the platform center. It is also the instrument base. The middle layer is the four probe mechanism, and it is the measuring components of the instrument. Four probe can adjustment and mobile independently according to the requirements.

The probe mechanism is connected sample platform of apparatus firmly by the bracket through the back side of the bow pole, and it is composed of form the basic framework. The upper is made of the eyepiece and a camera, and it is the monitoring component of the instrument. It can monitor samples if the position of the probe is correct about measuring point, and then it can be adjusted through the computer, monitor and the driving motor. It should be ensured that the camera, an eyepiece, the measurement center of four probes and the center of sample testing point should be remained in the same vertical line when using the instrument.

A position is measured and processed according to the order of the samples, and after the completion of measurement, the measuring position will be adjusted automatically, until the measuring points of entire sample were measured at the end.

The whole probe holder can be driven by stepping motor to achieve moving up and down. Testing sample platform is driven by two stepping motor to realize the longitudinal and transverse moving quickly. The whole testing instrument is driven by 7 stepping motor. 300mm silicon wafer can be tested through the moving of testing platform. Four stepping motors are used to control corresponding four probes to move back and forth respectively, and the each minimum movement distance is 0.0025mm. There is a stepping motor to control probe holder movable vertically along the bracket. An eccentric wheel is driven to control the probe frame up and down, and the largest movable range is 3mm.

The apparatus has the function of probe image recognition and automatic positioning. The whole wafer resistance can be tested automatically by setting measurement number. So, the whole sheet resistance of a wafer will display in the corresponding area to the testing location by Mapping technique.

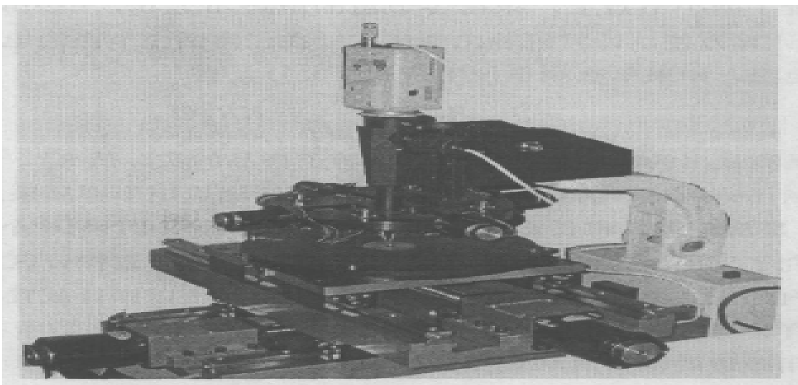

Figure 9. Square Four Tilt Probe Instrument

The thickness of wafer sample is 1.2mm. 180 points of micro-area sheet resistance in a silicon wafer are tested. It was displayed successful by the use of MATLAB software technology for the testing results. Color display map and gray display map were obtained successfully shown in Figure 10 and Figure 11. It can be seen gray display map is more intuitive and effective.

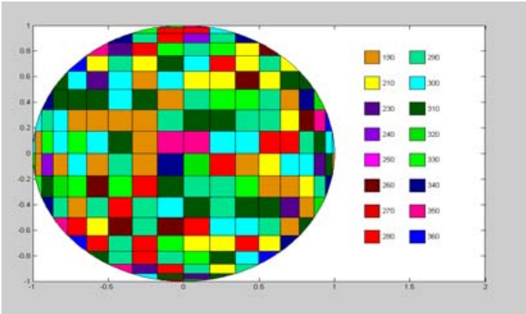

Figure 10. Color Display Map of Testing Results

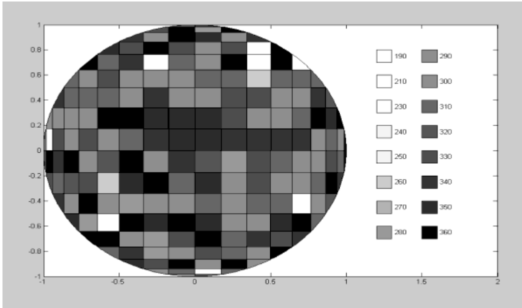

Figure 11. Gray Display Map of Testing Results

6. Conclusion

This paper systematically analyzed various methods of measuring sheet resistance, and analyzed many influence factors of the accuracy in testing micro area sheet resistance. The straight line four point probe method, Van der Pauw method, four point square probes method were mainly compared. The largest position measurement error of square four point probes method when the probe vacillated was found. It was verified by the actual testing samples. At last, a sheet resistance testing equipment was used, and a three inches silicon wafer sample was tested. 180 values of micro-area sheet resistance in a silicon wafer are tested. Color display map and gray display map were given successfully.

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References

[1] Zhengping Zhao. The expected development of micro-electronic technology in the 21th century. *Semiconductor Information*. 1999; 36(1): 1-3.

[2] Yicai Sun, Jing Wang. The development of DRAM in IC manufacture technology. *Semiconductor Technolog*y. 2002; 27(12): 10-12.

[3] David JM, Beuhler MG. A numerical analysis of various cross sheet resistor test structure. *Solid-State Electronics*. 1978; 20 :539-543.

[4] Buehler MG, Grant SD, Thurber WR. An experimental study of various cross sheet resistor test structures. *J Electrochem Soc*. 1978; 125 (4): 645-649.

[5] Van der Pauw LJ. A method of measuring specific resistivity and Hall effect of discs of arbitrary shape. *Philips Research Reports*. 1958; 13 (1): 1-9.

[6] Swartzendruber LJ. Four-Point Probe Measurement of Nonuniformities in Semiconductor Sheet Resistivity. *Soild-State Electronics*. 1964; 7:413-422.

[7] Sun Yicai, Shi Junsheng, Meng Qinghao. Measurement of Sheet Resistance of Crose Microareas Using a Modified van der Pauw. *Semiconductor Sci & Tech*. 1996; 11: 805-811.

[8] Yicai Sun. Several microfigures Suitable to the Measurement of Sheet Resistance for them. *Materials and Process Characterization for VLSI*. 1994; 11: 124-126.

[9] Smith FM. Measurement of sheet resistivities with the four-point probe. *Bell System Tech J*. 1958; 37: 711.
[10] Liangrui Tang, Quanming Ma, Xiaojun Jing, et al. Image processing operative technology. Beijing: Chemical Industry Publishing Company. 2002.
[11] Hannoe S, Hosaka H. Electrical Characteristics of Micro Mechanical Contacts. *Microsystems Technologies*. 1996; 3: 31-35.
[12] Qinghao Meng, Xinyu Sun, Yicai Sun, et al. Mapping technique for measurement of sheet resistance distribution. *Chinese Journal of Semiconductors*. 1997; 18(9): 701.
[13] Xinfu Liu, Yicai Sun, Yanhui Zhang, Zhiyong Chen. The measurement of square resistance for micro area by square four probes techniques and using a modified Rymaszewski method. *Acta Phys. Sin*. 2004; 53(8): 2461-2406.