Development of Fine-Pitch Four-Point Probe for High Spatial Resolution Sheet Resistance Measurement

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A 0.1-mm-pitch four-point probe for sheet resistance measurement is fabricated. Four probes are contacted to four metal leaf springs both mechanically and electrically. They are electrically separated by insulator films and sandwiched with these films. The probe tip is rounded by mechanical polishing preceded by electropolishing. Using this probe sheet resistances of various kind of samples are successfully measured. The validity of the measurement is confirmed by the comparison of the data to those from a conventional 1-mm-pitch probe. Spatial resolution as small as 0.5 mm is confirmed by measuring sheet resistance of uniformly phosphorus doped polysilicon films whose pattern size is 0.5 × 0.5 mm^2.

1.Introduction

A four-point probe is a well-established technique for measuring sheet resistance of thin layers, such as ion-implanted layers, metal thin films and semiconductor wafers [1]. In semiconductor manufacturing facilities, the probe is frequently used for monitoring doping and deposition processes. For example, doping nonuniformity of ion implantation process due to chargeup can be easily detected by mapping sheet resistances of several tens of points on a wafer [2]. Conventionally a collinear probe whose pitch is 1 mm is widely used. Spatial resolution of this probe is about 5 mm because electric flux from a current source point spreads in a sample. This resolution is high enough to map sheet resistances on a wafer whose area is about 10-1000 cm^2. However, this is too low for the resistance mapping on a small chip whose area is about 1 cm^2. This kind of small chip is often used in material research and there is a strong demand among researchers to get sheet resistance mapping on the chip. In this study, in order to make resistance mapping on small area of a sample come true, we develop a 0.1-mm-pitch four-point probe whose spatial resolution is about 0.5 mm. In developing the probe, we devise probe polishing and assembling techniques, and adopt tungsten carbide as probe material to allow compatibility to the conventional probe.

2. Probe Fabrication

To realize high-resolution resistance measurement, we first developed a four-point probe whose pitch is 0.1 mm. A schematic of internal parts of the probe is shown in Fig. 1. Each probe is connected to a metal leaf spring both mechanically and electrically. An electric brush touching the probe also electrically connected to the probe. The spring and the brush are sandwiched with an insulator films for electrical isolation. Photos of probe head and probe tip are shown in Fig. 2. The probe is made of tungsten carbide wire containing molybdenum as a binder element. This material has long been being used for conventional four point probes. Diameter and curvature radius of the probe are 0.05 mm and 0.02 mm. To realize this curvature, we devised two-step process: the first is electropolishing and the second is mechanical polishing. In the electropolishing process, a piece of tungsten carbide wire (56 mm × 0.05 mm ϕ) was placed in an electropolishing bath filled with diluted sodium hydrate and connected to AC voltage source with using platinum wire and plate, which is schematically shown in Fig. 3. AC voltage (450 Hz, 8 V, 1 A) was applied to the wire for 20 seconds. By doing so, we made the tip of the wire 0.022-0.026 mm in curvature radius. After this process the wire was cleaned by deionized water, dried and set to a lathe for the following

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mechanical polishing step. A wire set to the lathe was guided by a bearing and observed by an optical microscope, which is schematically shown in Fig. 4. Using this apparatus the wire was rotated and mechanically polished by a flexible file. After this polishing the wire was again cleaned by deionized water and dried. By these processes we can obtain a wire whose tip curvature is 0.020±0.001 mm in radius. A photograph of the wire tip taken by a scanning electron microscope is shown in Fig. 2. Specification of thus fabricated four-point probe is summarized in Table 1. Contact force between a probe and a sample is 25 gram-weight, which is realized by combination of leaf and U-shaped springs schematically shown in Fig. 1.

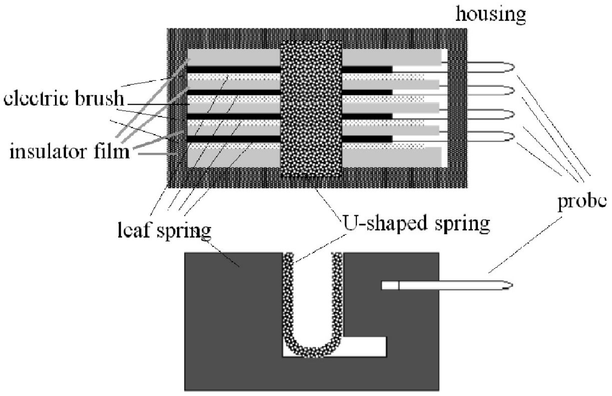

Fig.1. Internal parts of the probe.

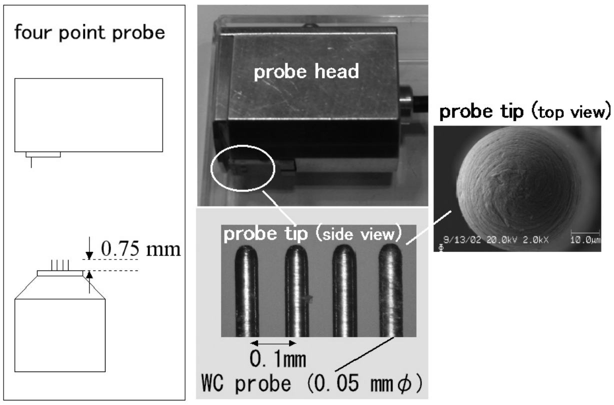

Fig.2. 0.1-mm pitch four point probe.

Table.1. Specification of the new four-point probe.

material	WC(Co)
diameter	0.05 mm
tip curvature radius	0.02±0.002 mm
pitch	0.1±0.005 mm
contact force	25 g at 0.25-mm stroke

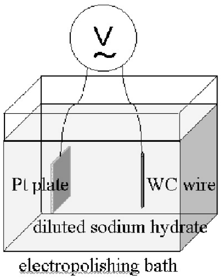

Fig.3. Primary process in the probe fabrication.

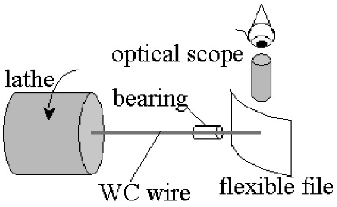

Fig.4. Secondary process in the probe fabrication.

Durability test was undertaken for 150,000 probings against a silicon wafer. After the test, the probe tip and the silicon surface were observed by a scanning electron microscope (SEM) and an atomic force microscope (AFM), respectively. There observed no difference in the probe tip appearance taken by SEM before and after the test. The depth of the probing spots observed by AFM was about 300 nm: a scratch of silicon for one probing is calculated to be 300/150,000 = 0.002 nm, which is virtually zero.

3. Sheet Resistance Measurement

In order to check the performance of our four-point probe, we set an apparatus to measure sheet resistances of a slab sample equipped with this probe. A schematic and a photograph of the apparatus are shown in Fig. 5 and 6.

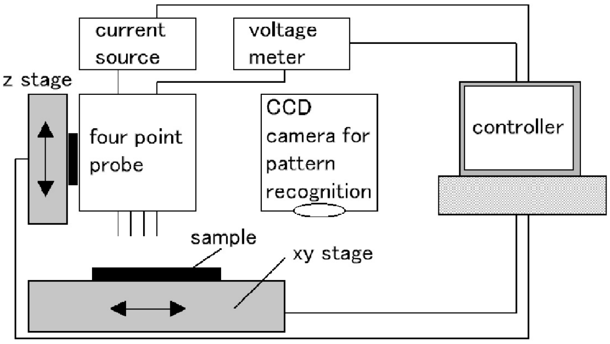

Fig.5. Schematic of sheet resistance measurement system.

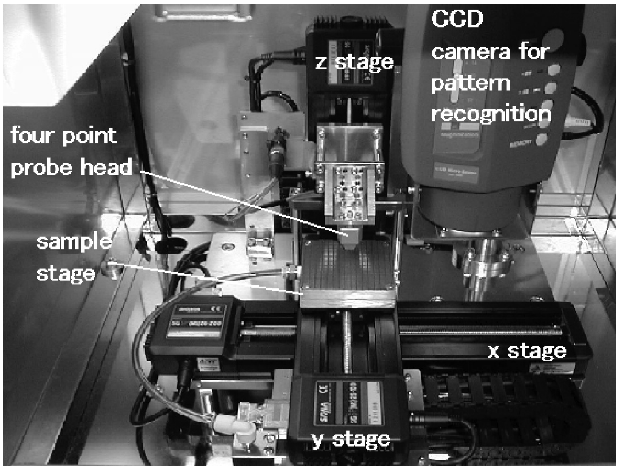

Fig.6. A photograph of sheet resistance measurement system.

Table.2. Samples measured by the new probe.

B implanted layer	Si substrate	P-doped poly-Si
boron implantation (1E15 cm^{-2}, 30 keV) into (100) silicon wafer (5-15 Ω cm) + annealing (900°C, 10 min in N$_2$)	p-type (100) silicon wafer (0.01-0.02 Ω cm)	phosphorus heavily doped (>1E20cm^{-3}) amorphous silicon on 280-nm oxidized silicon wafer + annealing (900°C, 10 min in N$_2$) + patterning (5 mm × 5 mm)

Using this apparatus, sheet resistance measurement was performed by applying constant current of 0.5 mA between the outer two probes and measuring voltage drop in inner two probes. We measured three samples: boron implanted layer, silicon substrate and phosphorus doped polysilicon. The detail of the samples is summarized in Table 2. The sheet resistance of the boron implanted layer was measured 11.6(mV)/0.5(mA)×4.53=105(Ω/□) which was the same value as measured by a conventional 1-mm-pitch probe. The voltage drop measured for the silicon substrate was 0.020 mV for our 0.1-mm-pitch probe and 0.099 mV for the conventional probe. To convert these values to the sheet resistances, correction factor (f) calculated from the ratiobetween the substrate thickness (0.625 mm) and the probe spacing (0.1 mm or 1 mm) must be considered. For 0.1-mm and 1-mm probes, the correction factor is calculated to be 0.22 and 0.99, respectively [3]. Therefore, the sheet resistance is calculated to be measured 0.099(mV)/0.5(mA) × 4.53 × 0.22=0.197(Ω/□) for the 0.1-mm probe, and 0.21(mV) / 0.5(mA)×4.53×0.99=0.188(Ω/□) for the 1-mm probe, which are almost the same value. Furthermore, the wafer resistivity calculated from this sheet resistance value is 0.2(Ω / □) × 0.063(cm) = 0.013 (Ω cm): this is consistent with the wafer specification (0.01-0.02 Ω cm). These two measurement results confirm the validity of the measurement by the new probe.

Next we performed resistance mapping of the patterned polysilicon to see the spatial resolution of the measurement by our new probe. The measurement was made along the center of the pattern with 0.1-mm step for the new probe and 1-mm step for the conventional one. Fig. 7 shows the measured sheet resistance (Rs = measured voltage/0.5 mA × 4.53) plotted against the measurement position. A schematic measurement configuration is also shown in the figure. This result shows the new probe can successfully measure sheet resistance at the points more than 0.5 mm apart from the pattern edge, in contrast that data by the conventional probe are invalid because of the electric flux being distorted by the pattern edge. From this result we conclude the spatial resolution of our new probe is about 0.5 mm.

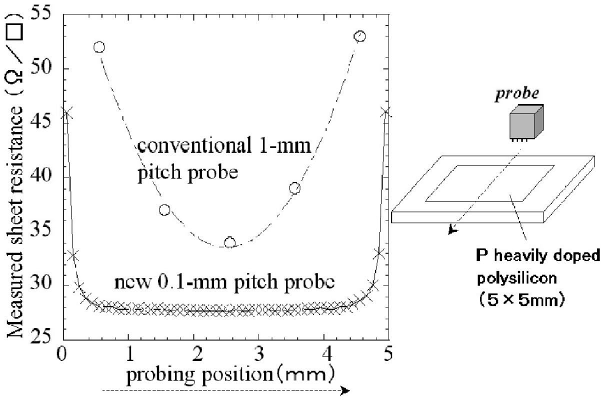

Fig.7. Sheet resistances of heavily phosphorus doped polysilicon film whose pattern size is 0.5mm×0.5mm.

4. Summary

We have developed a 0.1-mm-pitch four-point probe for sheet resistance measurement with high spatial resolution. We have shown its validity and demonstrated its usefulness. We believe this probe will become a powerful tool in mapping sheet resistances on a small sample. The other potential applications would be:

(1) determining doping concentration near the wafer edge,
(2) test pattern measurement on a processed wafer,
(3) direct measurement of electrical wiring pattern, and
(4) estimation of dopant amount using a small chip for the secondary-ion mass spectrometry measurement.

Acknowledgement

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