USING MERCURY PROBES TO CHARACTERIZE USJ LAYERS

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It is well established that uniformity and dosage of drain-source ion implantation on test wafer are most clearly revealed by mapping through automatic four-point probe measurement of the implanted layer's sheet resistivity at multiple sites. However the 65 nm and 45 nm node drain and source implanted layer is so shallow that needle four-point probe have problem of measuring its sheet resistivity correctly, especially if the background to which implantation is made is highly doped such as a p-well layer on test wafer. The reasons are explained. From the reasoning, it leads us to realize that using automated mercury four-point probe can solve this kind of sheet resistivity measurement problem. Actual measurement data of mercury four point-probe and best conditioned needle four-point probe to such USJ layer is shown, compared and discussed.

Also, suggestion is made on how to monitor leakage and punch-through voltage at drain and source of such kind of USJ. The reasoning is presented.

INTRODUCTION

When using four-point probe system for measuring and mapping sheet resistivity of metal film, epitaxial layer, ion implanted layer or raw wafer, it is important for the user to be sure that the measurement repeatability is adequate enough for revealing the distribution of the sheet resistivity. Of course, variation of four-point probe's needle contact distance is an important factor in determining measurement repeatability. But among the precision four-point probe systems, the most important factors that influence measurement repeatability are probe needle tip's shape, material and pressure. Measuring sample of different materials needs different combinations of these three factors for getting the best result. For example, when measuring a raw Si wafer, sharp tungsten carbide tips with high pressure work the best. But when measuring a shallow ion implanted layer, the needle tips are the best being blunt tungsten carbide with lighter pressure.

In case of measuring an ultra-shallow drain-source ion implanted layer, four-point probe head with bluntest possible tungsten carbide needle tips still have problem of making repeatable measurements in some cases. We introduce automatic mercury four-point probe to solve this problem. In next section, measurement results of needle four-point probes and mercury four-point probes are shown and compared.

MEASUREMENT OF NEEDLE FOUR-POINT PROBE AND MERCURY FOUR-POINT PROBE TO USJ LAYER

Reports have been made, (1), (2), that regular needle four-point probe is not suitable for measuring ultra shallow ion implanted layers because its measurement accuracy and repeatability are not good enough. However, if the probe tips are conditioned correctly, experiments show that needle four-point probe measurements can still be accurate and repeatable even to a 130 A deep implanted layers, as long as the doping density of the background to which the implantation is made is not too high (lower then 10^{16} cm^{-3}). But as the doping density of the background increases, even measuring by four-point probe with specially blunted and polished needles, the measurement repeatability deteriorates. Therefore, efforts have been made to replace the needle four-point probe with mercury four-point probe, since mercury probe tips should provide the bluntest, smoothest and most uniform contacts.

Experiments have been done to compare measurement results of the specially conditioned needle four-point probe with the mercury four-point probe. Table 1 summarizes the experimental results. In it, one can see that, if the background doping is increased to lower than 1Ω.cm in resistivity, measurement repeatability of the specially conditioned four-point probe to ultra-shallow ion implanted layer starts to be deteriorating with increasing background doping; but mercury four-point probe can still keep having good enough repeatability. Since drain-source implantation in 65nm and lower node processes are supposed to be on a very highly doped background, such as a P-well with $4x10^{18}cm^{-3}$ doping density, there should be need of monitoring USJ implanted layer on such highly doped background. Mercury four-point probe is introduced for such need.

Implanted Layer Thickness [Angstrems]	Background resistivity / Type [Ω.cm]	Mean measured ρ_s SC needle 4PP / Hg 4PP [Ω/square]	Repeatability (σ) SC needle 4PP / Hg 4PP [%]
50	7.3 / N	6330 / 6249	0.283 / 0.148
100	0.95 / N	774.4 / 770.0	0.674 / 0.045
175	0.018 / N	1930 / 6689	15.3□ / 1.06
100	0.02 / P	32.02 / 18.04	26.8 / 1.03

Table 1 Comparison of the repeatability of mercury and specially conditioned needle four-point probes.

EXPLANATION OF MEASUREMENT REPEATABILITY DIFFERENCES WITH DIFFERENT PROBE TIPS

The reason of needle four-point probe does not measure shallow ion implanted layer repeatably is not just because of penetration of probe through the layer. Even if none of the four needles penetrates through the layer, bad repeatability can occur due to a) minority carrier injection to the opposite type substrate, b) thickness variation of the depletion layer at the isolating P-N junction, and c) defects in the implanted layer. More explanations on these three effects are as follows:

a) Minority Carrier Injection:

Usually, each four-point probe needle's probing force is about 100 g. It can be effectively concentrated on an effective area of about 15 microns in diameter. This means about 5660 kg/cm^2 pressure is applied on the ion implanted layer under the probe. Since the forbidden energy band gap of Si decreases with the pressure by $2.4x10^{-6}$ eV per kg/cm^2, (3), it means that Si forbidden energy band gap under this pressure is decreased by 136 meV. Correspondingly, at room temperature (kT = 26 meV), the minority carrier density under the probe increases 187 times.

The current from the current probe to the implanted layer also causes minority carriers injection. The ratio of minority current to majority current increases with the current density, (4). Needle four-point probe usually means high current density under the current probe and hence higher minority carrier density under the current probe.

Both of the above mentioned minority carrier creation mechanisms help forming of unrepeatable leakage paths under the current probes, as shown in Fig.1. This causes unrepeatable test current leaking into the opposite type substrate and helps causing the measurements unrepeatable.

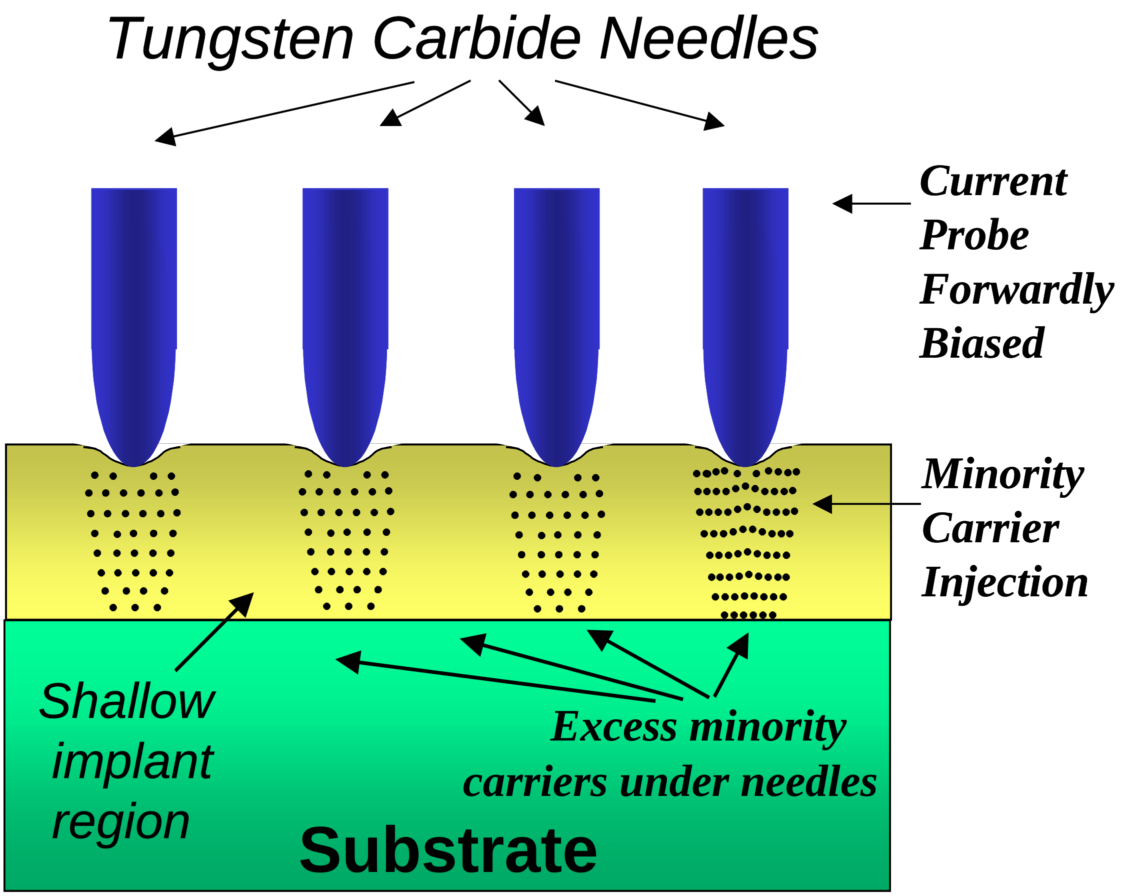


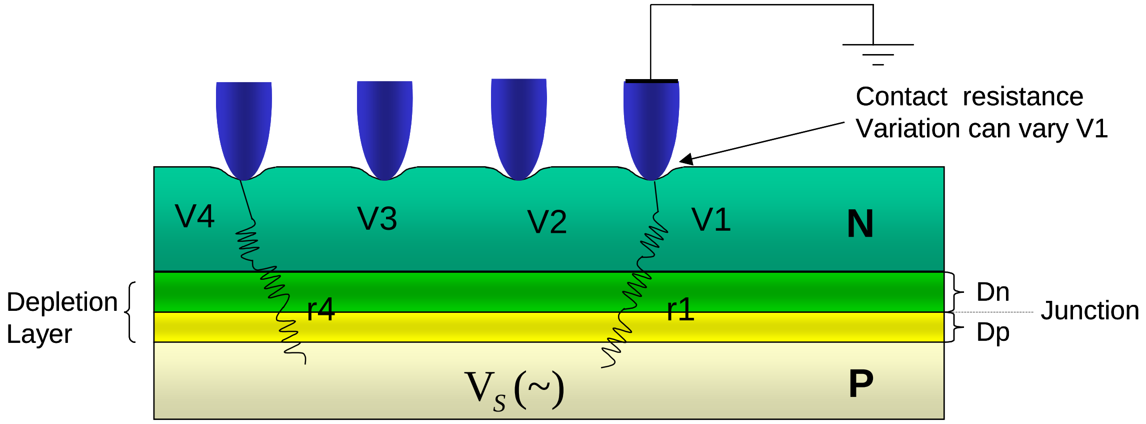
Fig.1. Needle four-point probe creates high pressure in the implanted layer thus increasing the leakage current. There is minority carrier injection under the forwardly biased current probe too. Notice that this drawing is intentionally not to scale for better illustration.

b) Variation of the Depletion Layer

In usual four-point probe measurement of an ion-implanted layer, the opposite substrate is at a floating potential. This potential is settled by how the potentials under the current probes and how the leakages from the ion implanted layer to the substrate are combined together as shown in Fig.2. Variations of the current probe contact areas, minority carrier concentration under the current probes, current density and defects at the junction can change this combination significantly, and that can vary the substrate potential with respect to the implanted layer. Whenever substrate potential with respect to the ion implanted layer varies, the depletion layer thickness at the junction also changes and the sheet resistivity of the ion implanted layer changes correspondingly. This of course, deteriorates measurement repeatability. If the substrate resistivity is relatively high then the depletion layer is mostly extended toward the substrate. In this case, the substrate potential variation does not varies the ion-implanted layer’s sheet resistivity as much as in the case of substrate resistivity being low. Since mercury probe provides much more consistent contact area, it should result in much less potential variation in the substrate and thus much less depletion layer variation.

c) Defect Density in the Implanted Layer

It is reasonable to expect that the more the defect density is in an implanted layer the less the four-point probe measurement repeatability to the layer can be. This is because defects in Si crystal have unstable and complicated effects to the Si resistivity. Since all USJ ion implanted layers are heavily doped and rapidly annealed, high defect density is hard to avoid, we suggest that in developing a USJ ion implantation process, measurement repeatability of mercury four-point probe can be used as an indicator of the layer defect density, because mercury four-point probe is least subjected to other measurement instability mechanisms.



$$V_S(\sim) = V1(\sim) + \frac{V4(\sim) - V1(\sim)}{r1 + r4} r1$$

Fig.2 Variation of the depletion layer during needle four-point measurement of USJ layer. If the doping of P is high enough, the variation of Dn with V_S can be high enough to cause noticeable variation to the sheet resistance of the thin implanted layer. V1, V4, r1 and r4 are depending on the contacts of the probe.

MEASURING USJ LEAKAGE BY MERCURY PROBE

Leakage of USJ is one of the major reasons in heating and power consumption of the advanced ICs. To develop a process of minimized leakage, a convenient method for of monitoring USJ leakage truthfully is useful. We suggest using a mercury probe to contact a group of USJ implanted drain-source openings as shown in Fig.3 for leakage measurements. These openings can be formed by using a regular drain-source mask for opening drain-source windows to the thin thermally grown oxide on a Si wafer, then going through USJ implantation into the windows and then annealing to the wafer. This Si wafer may be highly doped or has an implanted layer on the top for emulating isolation well that drains and sources are supposed to be implanted into.

This way, the shape and size of the drain and source are the same as the real devices and so is the background doping. Therefore the leakage measured between the mercury contact to the openings and the substrate reflects the real condition closely. The area of junction where the leakage is measured can be obtained by figuring out the number of drain-source openings contacted by the mercury dot.

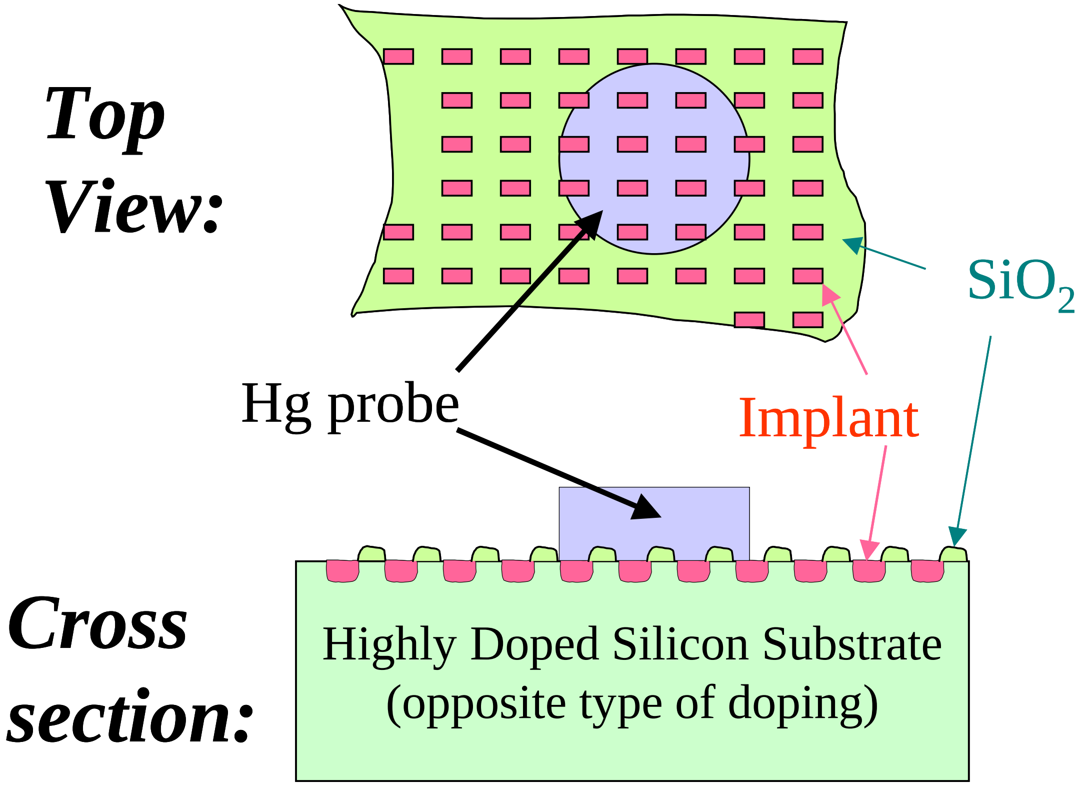
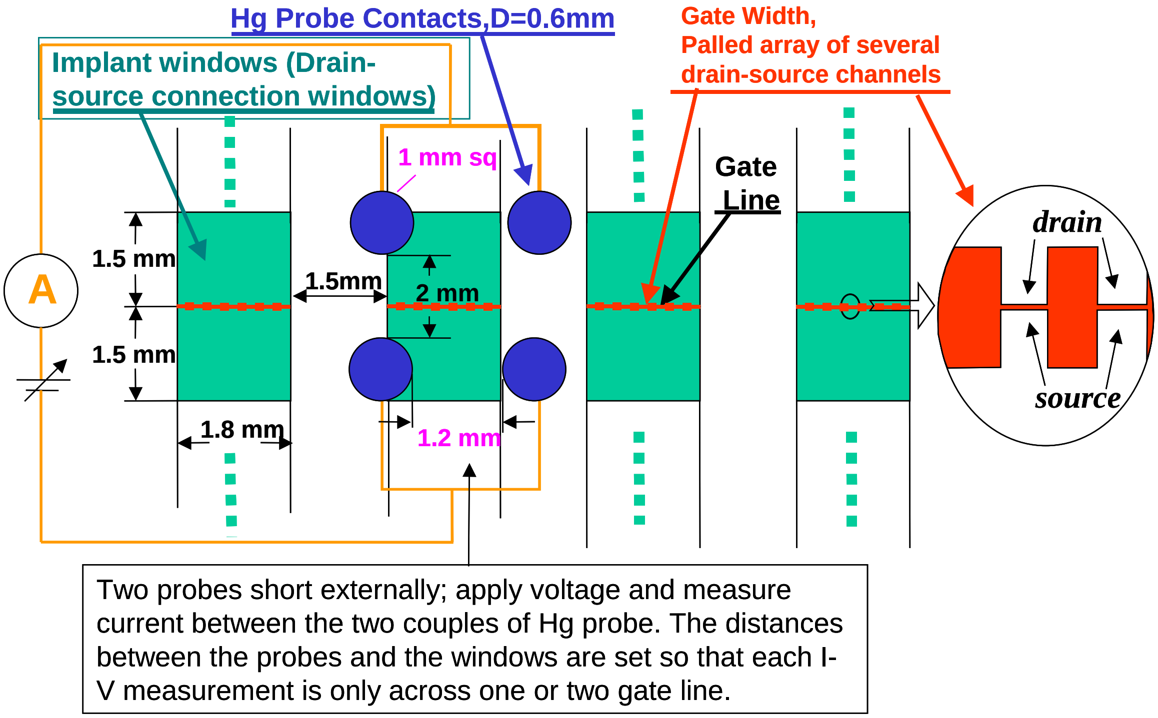


Fig. 3. Schematic drawing of the test structure used for measuring of the leakage current of USJ layers.

SUGGESTED WAY OF DETERMINING DRAIN-SOURCE PUNCH THROUGH VOLTAGE

Since the main reason of monitoring USJ junction depth is for detecting whether the USJ is shallow enough for avoiding drain to source distance being too close that punch through can happen at a too low voltage, one actually can directly measure the punch through voltage if simple layout for emulating drain-source structure can be made for such measuring. To do this, one can design a mask for opening oxide windows for implantation on wafer so that four specially made mercury probes can be used to contact one to two pairs of adjacent windows as shown in Fig.4. Each two adjacent windows are separated by several drain-source channels in parallel. If I-V curve is measured between these two windows, punch through voltage can be easily identified. Each of the above mentioned window is called drain-source connection window. Fig.4 shows a design for enabling the proposed punch through voltage test. Drain-source connection windows, in rectangular shape of 1.8 mm x 1.5 mm, can be lined up in stripes. Separating any two adjacent drain-source connection windows in a stripe is a parallel array of drain-source channels in real size. Applying a voltage between two adjacent drain-source connection windows can cause a current to flow through these channels. Whenever the punch through voltage is reached, a sudden increase of the current signals it’s happening. Four specially arranged mercury probes of 0.8 mm in diameter each with center-to-center distance of 1.2 mm can be used for making contacts to drain-source connection windows. Each pair of the probe in the same row is shorted together for making probing not so easily missing these windows for testing.



Two probes short externally; apply voltage and measure current between the two couples of Hg probe. The distances between the probes and the windows are set so that each I-V measurement is only across one or two gate line.

Fig. 4. Illustration of how to use of Hg mercury probes for drain-source punch through voltage check.

CONCLUSION

As the doping density of the background increases toward 10^{18}cm^{-3}, four-point probe's measurement repeatability deteriorates quickly, even if the probe tips are conditioned to be very smooth and flat. In this case, mercury four-point probe, with its smoothest flattest, and most elastic tips possible, is shown theoretically and experimentally, providing the best repeatability. Therefore it is proposed to use mercury four-point probe measurements as the reference for other USJ layer sheet resistivity measurements techniques. We also suggest to use repeatability of mercury four-point probe measurements to such highly doped USJ layer for checking whether the layers defect density is too high. USJ layer's leakage can be measured and mapped using an automatic single-dot mercury probe to contact the USJ in drain and source windows. Instead of constantly monitoring USJ junction depth, determining the punch though voltage through specially prepared punch through test patterns is more direct and accurate for the purpose and may be more practical in production environment.

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