Measurements of Ultra-Shallow Junction (USJ) Sheet Resistance with a Non-Penetrating Four Point Probe

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ABSTRACT

An accurate method to measure the four point probe (4PP) sheet resistance (R_s) of USJ Source-Drain structures is described. The new method utilizes Elastic Material probes (EM-probe) to form non-penetrating contacts to the silicon surface. The probe design is kinematic and the force is controlled to ensure elastic deformation of the probe material. The probe material is selected so that large direct tunneling currents can flow through the native oxide thereby forming a low impedance contact. Sheet resistance measurements on USJ implanted P+/N structures with SIMS junction depths as shallow as 15 nm have been measured. The sheet resistance values obtained with the new EM-probe 4PP method were found to be consistent with expectations. In this paper, the method will be demonstrated on a variety of implanted USJ structures.

INTRODUCTION

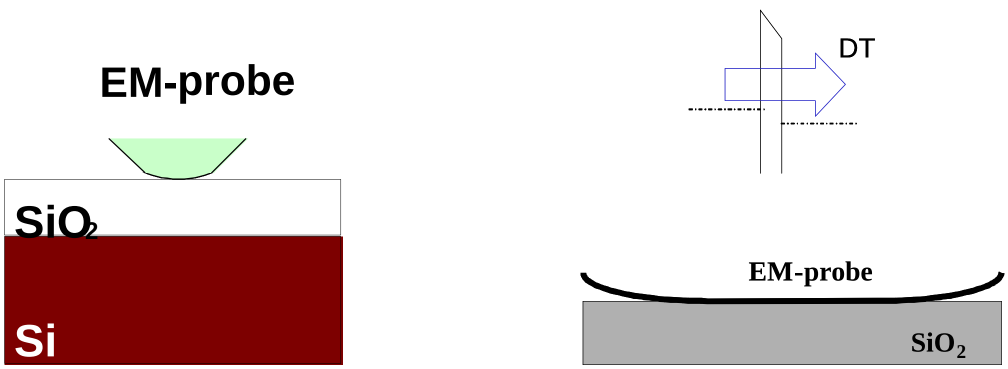
Source-Drain(S/D) engineering is an important area in existing and future device development. Critical device parameters such as on-state drive current ($I_{DS, ON}$) are highly dependent on the S/D series resistance (R_{DS}). It is therefore desirable to have S/D structures that have low sheet resistances. This requires S/D structures with high carrier densities. At the same time, Threshold Voltage (V_T) roll-off due to Short Channel Effects (SCE) increases as the channel length is decreased [1]. These effects need to be minimized. This requires producing a rectangular overall device structure [2] where the gate dielectric thickness, S/D junction depths and channel carrier profile are thin. Highly abrupt, steep gradient carrier density profiles are also necessary in order to reduce SCE via channel charge sharing [3]. Careful consideration of all of these device performance issues leads to the fact that the S/D carrier density profiles must be highly abrupt "Box" type profiles with a high peak carrier density and a shallow junction depth (x_j). As an example, S/D structures with activated dopant densities at or near solid solubility with x_j's less than 20 nm are under development for the 65 nm technology node

To produce these Ultra-Shallow Junction (USJ) structures careful process design of the Pre-amorphization implant (PAI), S/D implant and the dopant activation and implant anneal are required. The USJ junction depths and level of dopant activation depend heavily on processing [3]. A suitable method for characterizing these USJ structures is the Conventional Four Point Probe (4PP) Sheet Resistance (R_S) technique [4]. The measured R_S is highly sensitive to the activated carrier density and x_j. This is a highly accurate, absolute method that has been used successfully on structures with deeper junction depths and layer thicknesses. Conventional 4PP R_S measurements generally use four penetrating, scrubbing probes placed in contact with the top layer of the semiconductor wafer. It is necessary for conventional 4PP probes to penetrate through any existing native oxide that exists on the semiconductor surface in order to make good electrical contact to the top semiconductor layer. A common problem that now exists in the industry is the conventional 4PP method penetrates through the USJ S/D structure into the semiconductor substrate. Under these circumstances, the R_S of the underlying substrate is measured. Generally this results in low R_S values and all sensitivity to the top USJ layer is lost.

In this paper, a new technique is presented that uses non-penetrating, non-damaging Elastic Material probes (EM-probe) to make accurate and repeatable 4PP R_S measurements on USJ S/D structures. There is no fundamental limit of this technique on USJ x_j. Layers as thin as 15 nm have been measured and will be presented.

EM-PROBE DESCRIPTION

A basic description of an EM-probe Metal-Oxide Semiconductor Capacitor (MOSCAP) structure is shown in Figure 1.



a) b)

Figure1 Illustrations of EM-probe Contact to the surface of a dielectric material.

The contact shown in Figure 1a is formed by controlled elastic deformation of the probe. A highly repeatable, non-damaging and non-penetrating contact is formed. In the case of silicon, the contact is made on the surface of an existing native oxide. Conduction through the native oxide occurs by Direct Tunneling(DT) as shown in Figure 1b. The probes are made of a material whose properties are such that no or little metallic oxide forms on the probe and, the oxide that does form is conductive. These properties make the probe ideal for IV applications. Examples of EM-probe IV measurements made on 10 Ang., 30 Ang. and 90 Ang. oxides are shown in Figure 2. The current that flows through the 10 Ang. and 30 Ang. oxides is due to Direct Tunneling (DT). DT current is primarily dependent on oxide thickness and to a lesser extent on injection barrier height. The current flow in the 90 Ang. oxide is due to Indirect Tunneling (IDT) or Fowler-Nordheim Tunneling and depends heavily on injection barrier height or work function of the probe material. The DT mechanism is essential for EM-probe 4PP. All of the EM-probe probes are mounted on a kinematic bearing system with controlled descent and ascent. The kinematic system ensures that no probe scrubbing occurs. The EM-probe contacts shown in Figure 1 are formed by lowering the probe onto a semiconductor surface or dielectric and elastically deforming the probe material. The resultant contact diameter is typically 40 to 60 um and depends on the probe geometry and applied force. EM-probe MOSCAPs formed in the manner discussed have been used to measure IV and CV (using a different probe material with an insulating oxide) on oxides as thin as 0.7 nm [5].

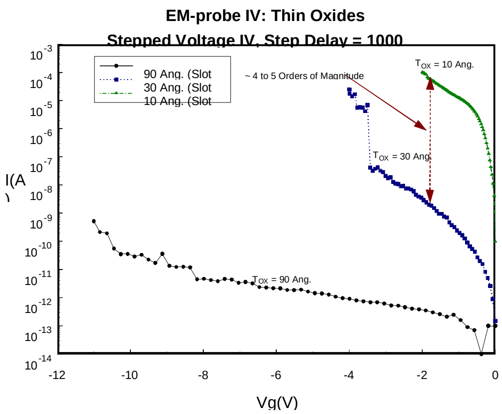


Figure 2: EM-probe IV curves measured on thin oxides with a Type C probe

EM-PROBE 4PP DESCRIPTION AND THEORY

The conventional 4PP measurement relied upon penetrating probes to make good electrical contact to the doped semiconductor surface. The use of conventional 4PP measurements on sub-500 Ang. USJ structures can produce erroneous results. The actual limit and amount of probe penetration depends on the probe design, conditioning, and the probe load. Generally loads of about 100 gm are used.

EM-probe 4PP measurements overcome all of the problems associated with conventional 4PP systems by using the same non-penetrating, non-damaging probes used to measure Ultra-Thin Gate Dielectrics(< 10 Ang.). A depiction of an EM-probe 4PP co-linear setup is shown in Figure 3. The current sourcing probes allow for conduction through thin oxides as explained above. The voltage sensing probes are connected to a high impedance voltmeter (~10^{14} ohms). The resistance of oxides that can be measured by 4 PP is ~10^{9} ohms. These impedances allow for an open loop circuit for the voltage sensing with negligible voltage drop across the oxide.

Examples of EM-probe 4PP Rs

Several cases are presented of EM-probe 4PP measurements on USJ S/D structures. Case 1 is for P+/N junctions and case 2 is for N+/P junctions.

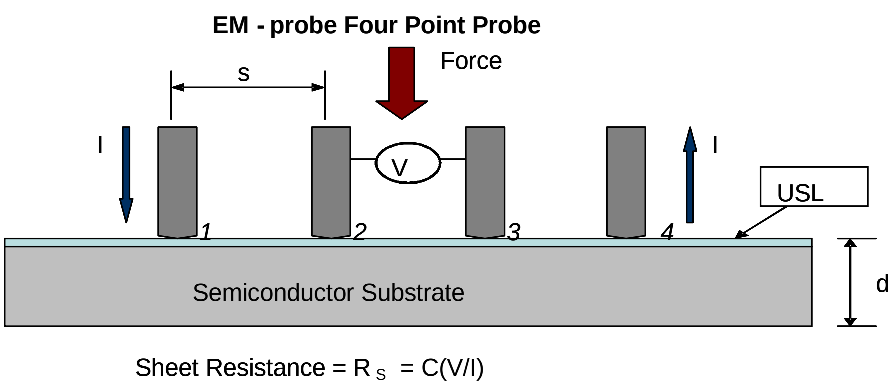


Figure 3 Depiction of an EM-probe 4PP measurement setup. The probes form a circular contact by elastic deformation and are non-penetrating and non-damaging.

Case 1:

The results of EM-probe and conventional 4PP R_S measurements made on P+/N USJ S/D structures are shown in Figure 4 for a 550 Degrees C. anneal. The samples are from a matrix of anneals. It is seen that conventional 4PP and EM-probe 4PP agree for the deeper junctions and diverge for shallower. Note that, although all samples were annealed at the same temperature, the deeper junctions had an experimental implant after the main implant that resulted in atom knock-in . SIMS values for the chemical junction depth are also shown. The values obtained from the EM-probe 4PP are consistent with expectations. Three day repeatability was 0.2%. The total atomic or chemical profile, obtained from SIMS, for representative samples is given in Figure 5. “Post implant” is the ID for the experimental implant mentioned above.

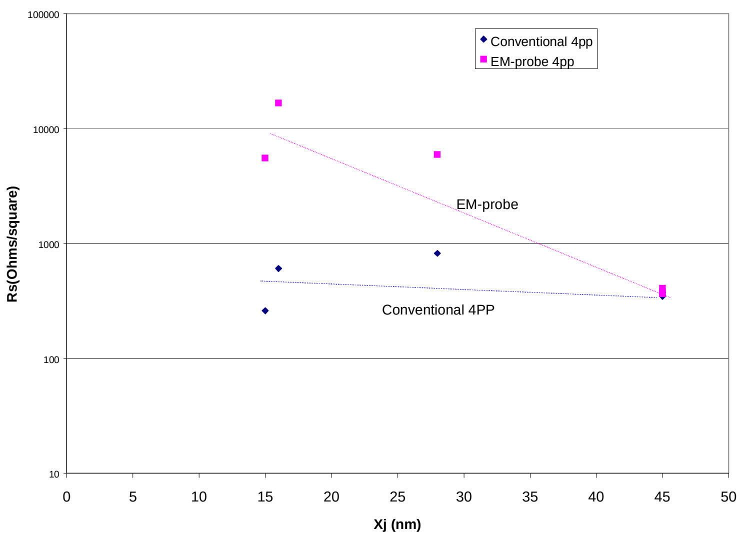


Figure 4 EM-probe and Conventional 4PP R_S comparison for samples annealed at 550 °C

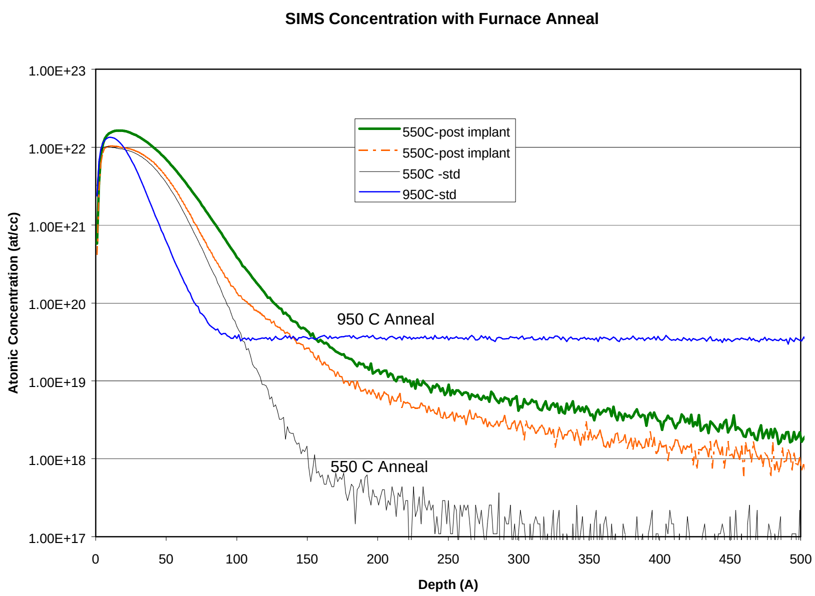


Figure 5 SIMS profiles for representative samples

Case 2:

Arsenic implanted USJ S/D (N+/P) structures were evaluated with the EM-probe 4PP. The junction depths determined from SIMS and SRP are about 300 Ang.

The sheet resistance for the Case 2 samples was measured with EM-probe 4PP and with the SRP Variable Probe Spacing(VPS) method[6]. Also, standard 4PP measurements were done (labeled Rs Advanced).This 4PP used a kinematically based 4PP designed to be non-scrubbing and less penetrating than standard 4PP systems. Standard 4PP was performed on the backside of the wafer to measure the substrate. The results obtained are summarized in Table I.

Table I: Various R_S measurements on Arsenic Implanted USJ structures. X_j = 300 Ang.

Wafer	Rs Advanced 4pp	Rs VPS	Rs EM-gate 4pp	Rs Backside
2	237.1	300.6	288.5	122.9
22	225.0	280.8	278.1	122.0
23	233.0	274.4	284.5	121.7
24	234.8	269.9	286.6	121.9

The conventional 4PP measurements yielded low sheet resistances due to probe penetration through the top USJ S/D structure. This occurred despite the kinematic mount. Three day repeatability of the EM-probe 4PP was 0.65%. That the Em-probe 4PP probe is the correct value is verified by comparison to another nonpentrating technique as discussed below.

In addition to the two cases presented, comparisons have been made to another non-penetrating 4PP design that uses Mercury (Hg) probes. Hg contacts are non-penetrating since they are formed with a liquid metal and use a pressure near atmosphere. However, the use of Hg may be undesirable for in-line or off-line tools in some wafer fabrication facilities. A comparison between EM-probe and Hg probes for S/D structures with junction depths around 120 Angstroms is given in Figure 6 showing good agreement between both measurement methods. Backside Rs was also measured for these samples.

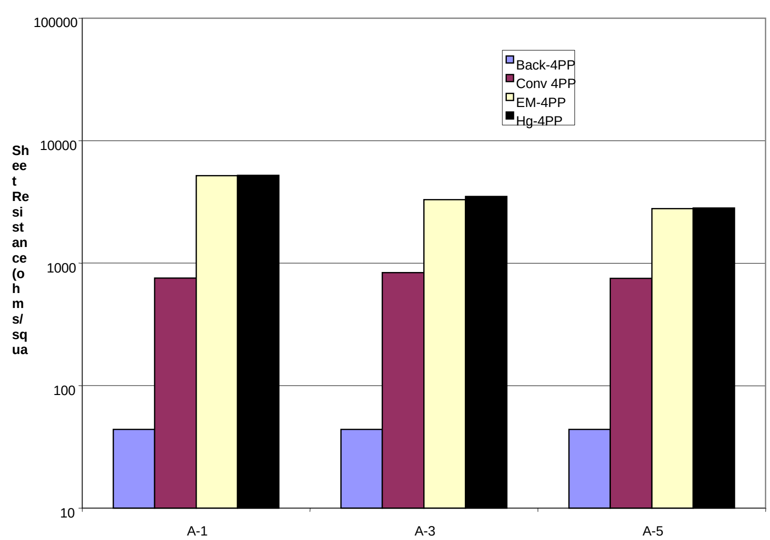


Figure 6 Comparison between 4PP, EM-probe 4PP, and Hg 4PP.

SUMMARY

A new, non-penetrating and non-contaminating method has been presented for measuring the sheet resistance of ultra-shallow S/D structures. Elastic Material 4PP R_S measurements were described and it was explained that gate dielectrics as thin as 7 Ang. were credibly measured with EM-probe CV and IV. The physics of EM-probe 4PP were then discussed and it was shown that EM-probe 4PP works on the principle of DT tunneling. This means that EM-probe 4PP measurements can be made on semiconductor wafers that have a native oxide present.

Several cases were presented; one for USJ P+/N and one for N+/P USJ S/D structures. It was found that the EM-probe 4PP could competently measure S/D structures with minimum junction depths of at least 150 Angstroms. Conventional 4PP were found to be limited to about 300 to 400 Angstroms and deeper. The three day repeatability of EM-probe 4PP R_S was found to be better than 1 %.

ACKNOWLEDGEMENTS

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