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Ultra-shallow junction (USJ) sheet resistance measurements 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 ultra shallow junction (USJ) Source–Drain Extension structures is described. The method utilizes Elastic Material probes (EM-probes) to form non-penetrating contacts to the silicon surface [R.J. Hillard, P.Y. Hung, William Chism, C. Win Ye, W.H. Howland, L.C. Tan, C.E. Kalnas, Characterization and Metrology for ULSI Technology, AIP Conference proceedings 683 (2003) 802.]. The probe design is kinematic and the force is controlled to ensure elastic deformation of the probe material. The probe material is such 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 Secondary Ion Mass Spectroscopy (SIMS) junction depths less than 15 nm have been measured. The method is demonstrated on implanted USJ structures and found to be consistent with expectations.

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Keywords: 4PP; USJ; SDE

1. Introduction

Source–Drain Extension (SDE) 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 SDE series resistance (R_{DS}). It is therefore desirable to have SDE structures that have low sheet resistances [2]. This requires SDE 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 [3]. These effects need to be minimized. This requires producing a "rectangular" overall device structure [4] where the gate dielectric

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thickness, SDE 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 [4]. Careful consideration of all of these device performance issues leads to the fact that the SDE 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, SDE structures with activated dopant densities at or near solid solubility with an x_j less than 20 nm are under development for the 65 nm technology node.

To produce Ultra-Shallow Junction (USJ) structures careful process design is needed. The USJ junction depths and level of dopant activation depend heavily on processing [4]. A suitable method for characterizing these USJ structures needs to be found. In the past, the conventional Four Point Probe (4PP) Sheet Resistance (R_S) technique was useful. [5]. 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 SDE 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 technique is presented that uses non-penetrating, non-damaging Elastic Material gate (EM-probe) probes to make accurate and repeatable 4PP R_S measurements on USJ SDE 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.

The EM-probe 4PP is shown and compared to a conventional 4PP in Fig. 1. The probes are made of a metal 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 current sourcing applications. The probe mounts are a kinematic bearing system with controlled descent and ascent. The kinematic system ensures that no probe scrubbing occurs. More details can be found in the published literature [1].

The EM-probe contacts shown in Fig. 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 40–60 μm and depends on the probe geometry and applied force. EM-probe MOSCAPs formed in the manner discussed have been used to measure *CV* and *IV* on oxides as thin as 0.7 nm [1].

The current that flows through the outer probes is due to Direct Tunneling (DT). DT current is primarily dependent on oxide thickness and to a lesser extent on injection barrier height. The DT

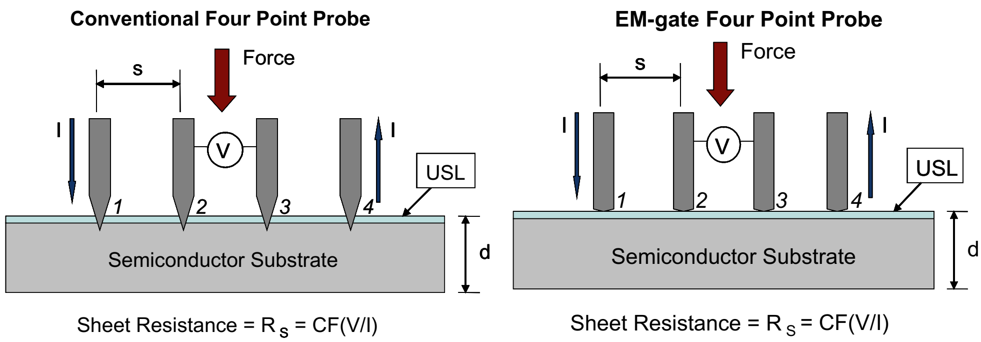

Fig. 1. Schematic of both conventional and EM-probe 4PP.