SHEET RESISTANCE MEASUREMENTS OF IMPLANTED LAYERS ON SILICON WAFERS USING A MICROWAVE RESISTIVITY PROBE

M. S. Wang†, H. Bhimnathwala, S. S. Yao*, and J. M. Borrego

Electrical, Computer and Systems Engineering Department
Rensselaer Polytechnic Institute, Troy, New York 12180-3590.

*IBM Corporation, Hopewell Junction, New York 12533.

ABSTRACT

In this paper we present the use of microwave radiation at 35 GHz from an open ended waveguide for measuring the sheet resistance of implanted layers on high resistivity silicon with dynamic range and spatial resolution comparable to the one of four point probes. The technique is capable of measuring implanted layers with doses in the range of 10^{12} ions/cm^2 to 10^{16} ions/cm^2.

INTRODUCTION

The successful fabrication of silicon integrated circuits depends upon the precise control of many processing steps. One of these steps is the implantation of doped layers in order to form the source and drain regions in the MOS transistors or the collector, base, and emitter regions in a bipolar transistor. The standard technique used to evaluate the doping density achieved in these implanted layers is to measure the sheet resistance of these layers using a four point or a spreading resistant probe. The usual geometry of the four point probe is to place the the four probes in a line with equal spacing between them. The two outer probes are used for supplying current in and out of the layer whose sheet resistance is to be measured and the two inner probes are used for measuring the voltage drop. The sheet resistance of the layer is related to the voltage to current ratio by some geometric factor.

In spite of the simplicity the four point probe has a large number of drawbacks. First of all surface preparation can affect the apparent resistivity. If an inversion layer forms on the wafers surface then the probes may not punch through the inversion layer giving erroneous results. This is particularly troublesome for the low doped layers. Although the technique is considered to be non-destructive, it is possible for the probes to damage the surface of the wafer. Another drawback is that the resistivity measurements using the four point probe are geometry dependent and very sensitive to boundary conditions. It is necessary to calculate many correction factors which depend upon the wafer thickness, probe spacing, position of the probe within the wafer etc. It is because of its many drawbacks we present in this paper an alternate method using microwaves for measuring the sheet resistance of implanted layers in high resistivity silicon with spatial resolution comparable to what it can be achieved using four point probes.

† Present address:
Hittite Microwave Corporation, Woburn MA 01801.

PROPOSED MEASURING METHOD

The alternate method we propose is to use microwave reflection for measuring the resistivity of the implanted layers. The use of microwaves for measuring the bulk resistivity of semiconductors has been proposed by several researchers [1,2]. The methods suggested have recieved little attention and strong criticism because the samples have to fit the waveguide exactly. Recently the advantage of using microwaves for the non-destrucive characterization of semiconductors has recieved renewed interest because some of the past drawbacks have been removed by using special antennas so that the samples are placed outside the waveguide [3,4]. The basis of the measuring technique proposed is illustrated in Fig. 1. A CW microwave signal is incident on a semiconductor wafer which is backed by a perfectly reflecting surface which can be the metallic stage on which the wafer is placed. The principle feature of the scheme proposed is to use the open end of a waveguide as antenna for directing the microwave radiation to the sample without the need to place it inside the waveguide. If the semiconductor wafer is placed close to the open end of WR-28 waveguide, (a distance of 0.020" to 0.040") the spatial resolution achieved is of the order of 3 mm x 3 mm which is similar to what can be achieved using four point probes.

The reflected power is a function of the bulk resistivity of the wafer, its

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thickness, its dielectric constant, frequency of operation and of the sheet resistance of the implanted layer which is at the top surface of the wafer. Assuming that the wave propagation in the wafer is same as in the waveguide, we have calculated the reflection coefficient at the front of the wafer as a function of the sheet resistance of the implanted layer. The input impedence Z_{in} of the implanted wafer can be modelled as a parallel combination of the sheet resistance R_s of the implanted layer and the input impedance Z_{in}' looking into the bulk of the wafer, that is:

$$Z_{in} = \frac{R_s . Z_{in}'}{R_s + Z_{in}'} \quad \text{....(1)}$$

The above equation assumes that the thickness of the implanted layer is small compared to the wavelength which is usually the case. Assuming wave propagation in the wafer to be the same as in the rectangular waveguide, the input impedance Z_{in}' can be expressed as:

$$Z_{in}' = \frac{j\omega\mu \tanh[(\frac{\pi}{a})^2 + j\omega\mu(\sigma + j\omega\varepsilon)]^{1/2} t}{[(\frac{\pi}{a})^2 + j\omega\mu(\sigma + j\omega\varepsilon)]^{1/2}} \quad \text{....(2)}$$

where:

ω = frequency of operation

σ = wafer bulk conductivity

ε = wafer electric permittivity

μ = wafer magnetic permeability

a = waveguide broad dimension

t = wafer thickness.

The reflected power coefficient is then obtained from

$$P_r = \left| \frac{Z_{in} - Z_o}{Z_{in} + Z_o} \right|^2 \quad \text{....(3)}$$

where Z_o is the wave impedance of the waveguide.

We have calculated the reflected power coefficient as a function of the sheet resistance of the implanted layer for silicon wafers 0.025" thick with bulk resistivity of 60 Ω-cm and the results are as shown in Fig. 2. The calculation were carried out for a microwave signal at 35 GHz because at this frequency the wafer is approximately $\lambda/4$ long resulting in higher sensitivity for detecting the implanted layer. The curve indicated that it is possible to measure sheet resistance between 1 Ω/square to 10^4 Ω/square. This range of sheet resistances is compatible with the range of sheet resistances found in semiconductor device manufacturing. Since for some values of reflection coefficient there are two possible values of sheet resistance it is necessary in some cases to measure not only the magnitude of the reflection coefficient but also its phase.

MICROWAVE MEASUREMENT SET UP AND RESULTS

As mentioned previously, in order to determine unambiguously the sheet resistance of implanted layers using this method it is necessary in some cases to measure the phase of the reflected wave as well as its magnitude. The microwave setup we have used for the measurements is the microwave bridge shown in Fig. 3. It consists of a Gunn diode as a microwave source and uses a 3 db hybrid as the main component of the bridge. In one of the arms of the 3 db hybrid there is an attenuator and a sliding short. The other two arms contain the open ended waveguide used as antenna and a microwave detector for measuring the reflected power. There are two ways in which the bridge can be used. In one of them the attenuator is set to full attenuation so the detector can measure the reflected power without phase information. In the other way of operation the attenuator and the sliding short are adjusted to null the detector. In this mode of operation it is possible to resolve the ambiguity in the sheet resistance shown in Fig.2.

Using the above set up we have measured the reflected power in silicon wafer with implanted layers with doses from 10^{12} ions/cm^2 to 10^{16} ions/cm^2. The wafers were p-type and the implantations were done with boron. The magnitude of the detector voltage as a function of implanted dose is shown in Fig. 4. Notice that the curve has a shape similar to the curve shown in Fig. 2. The results show that the technique is capable of determinig implanted layers in the range of 10^{12} ions/cm^2 to 10^{16} ions/cm^2 i.e. four orders of magnitude in implanted dose. This dynamic range is similar to what can be achieved using a four point probe.

CONCLUSIONS

In summary we have presented a contactless microwave technique for measuring sheet resistance of implanted layers on high resistivity silicon with spatial resolution and dynamic range comparable to what can be achieved using four point probes.

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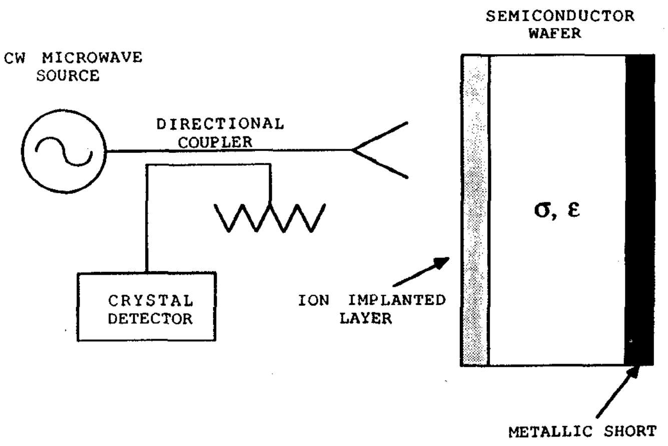

Fig. 1. Schematic diagram of measurement technique.

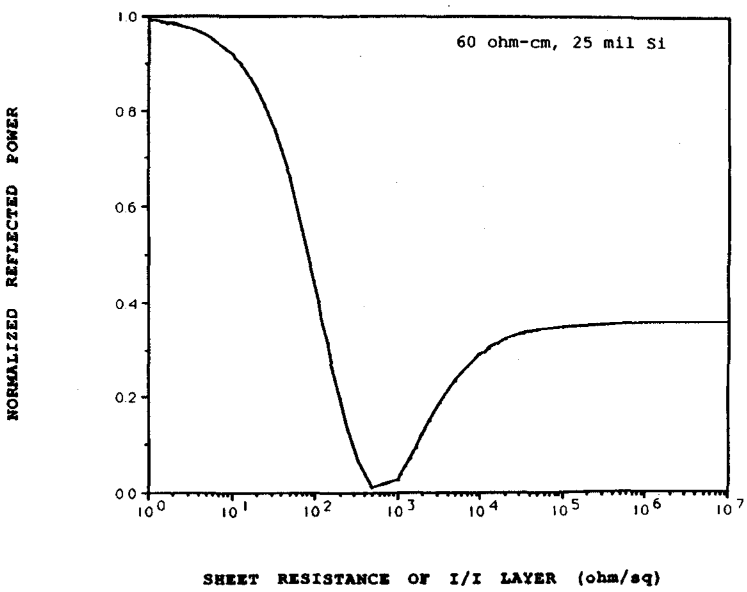

Fig. 2. Power reflection coefficient of a 60 Ω-cm silicon wafer as a function of sheet resistance of implanted layer.

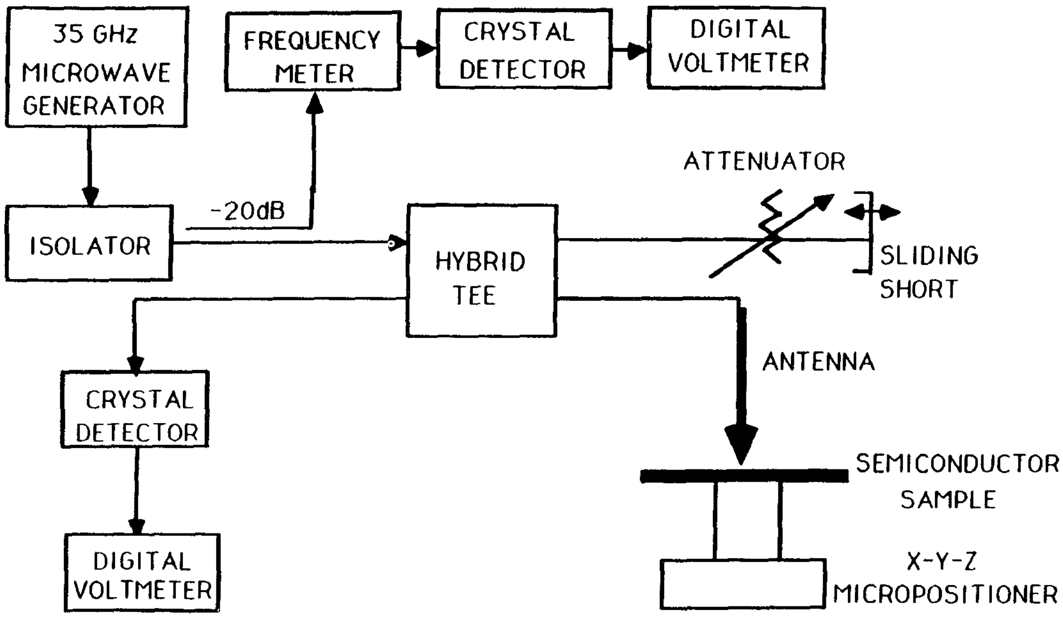

Fig. 3. Schematic diagram of 35 GHz microwave reflection bridge.

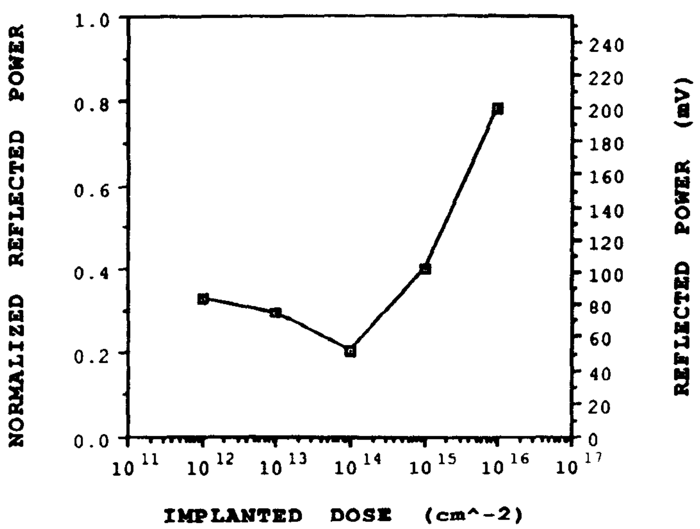

Fig. 4. Microwave detector voltage as a function of implanted layer dose.