Application Note

Non-Contact Thickness Measurement of Semiconductor Wafers

Capacitance Probes

Thickness measurement is an integral part of semiconductor wafer manufacturing. From an as-cut to a polished, epi-ready wafer, thickness measurement provides the process engineer with the information necessary to ensure that manufacturing processes are under control at all times and material removal rates are within customer specifications. The thickness measurement device must not only be capable of producing a highly accurate reading, it must do so without contacting the wafer surface. Capacitance based measurement probes have long been employed as a means of non-contact measurement of electrically conductive materials.

Traditionally, capacitance-based thickness gages utilize insulated sensing electrodes which detect changes in distance between the probe face and the target surface (See Figure 1). This distance, often referred to as the sensing gap, is directly proportional to a change in capacitance. Electrical current flows from the probe face through the sensing gap and target. The circuit is completed by the target laying on an electrically grounded stage.

By comparing the change in capacitance between a known sensing gap, and the gap when an object of unknown thickness is placed beneath the probe face, a thickness can then be calculated.

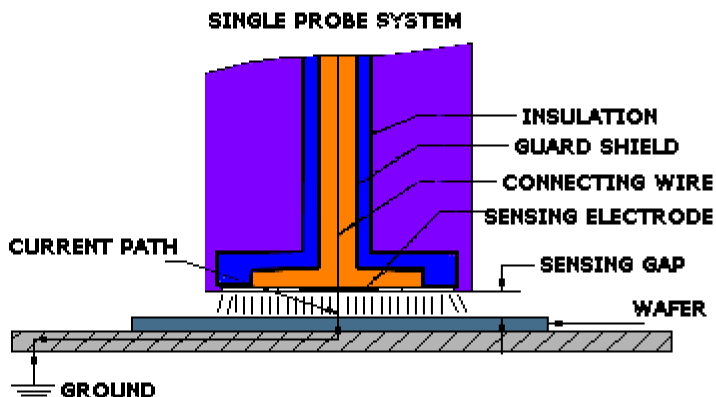
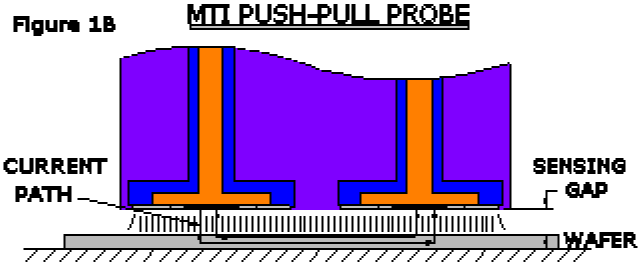


FIGURE 1A

Capacitance measurements of electrically grounded targets are, however, affected by changes in the electrical conductivity of the target being measured. When measuring wafers of varying resistivity, device accuracy becomes compromised when the electrical ground path from the target to the sensing probe becomes intermittent, uncertain, or non-existent.

To eliminate the affect of varying target conductivity, MTI Instruments Inc. developed a thickness measurement device that utilizes a unique version of their Accumeasure probe/amplifier series called the Push-Pull (MTI-1560).

Figure 1B



Shown in Figure 1B, the push-pull probe eliminates the need for a consistent ground between the wafer and the stage. The individual probes are calibrated to produce an AC voltage signal that is of equal amplitude from 0 to 5 VAC. There is, however, a 180 degree phase shift between the signals, that allows the current path to travel across the target surface rather than through the target to ground. The individual output signals are summed by the amplifier producing a single 0 to 10 VDC output.

System Design

Processing of semiconductor wafers (slicing, lapping, polishing) introduces bow and warp to the wafer profile. True thickness measurement ,therefore, requires placing a probe on each side of the wafer to remove these surface anomalies from the thickness calculation. Figure 2 shows a basic schematic of the measurement system.

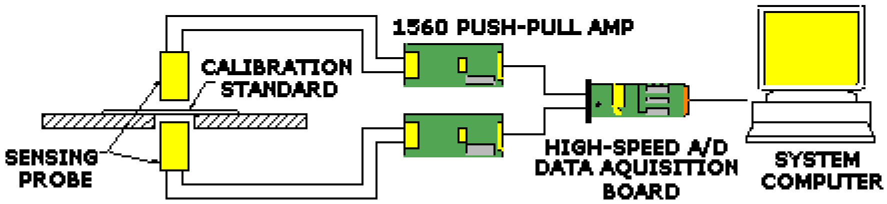


Figure 2 Wafer Measurement Gage Schematic

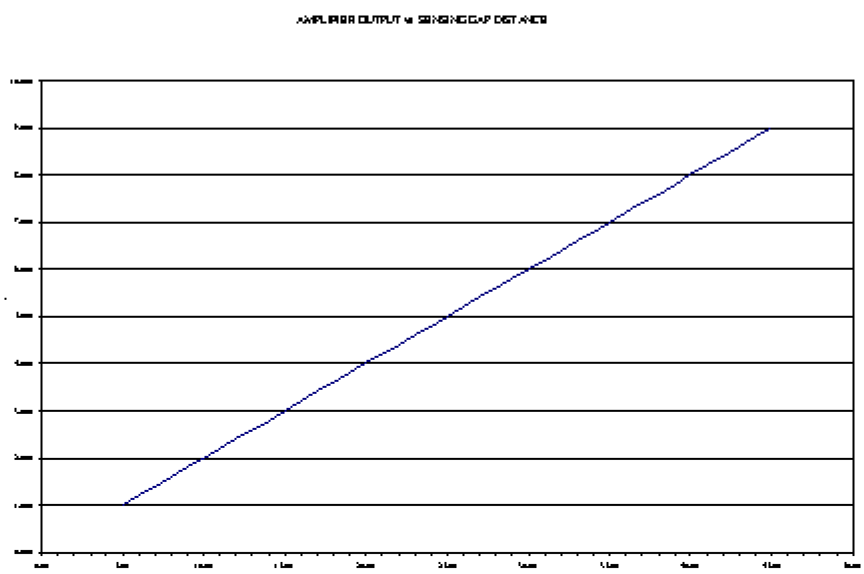
Each probe/amp combination is calibrated to produce a linear, analog voltage output from 1 to 9 volts over a sensing gap range of 0.045 in. (1143 um). During the calibration procedure, a calibration table is generated at equally spaced intervals over the output range. This table is then stored in the onboard computer. The thickness of the calibration standard and the corresponding sensing gap distances when the standard is between the probes are also stored in computer memory.

When a wafer is placed between the probes, analog voltage outputs are passed from the 1560 amplifiers to a high speed PC-104 A/D data acquisition board. The CPU then converts the voltage to a gap distance using the calibration table. The conversion involves performing a linear interpolation of the voltage based on the points on the calibration curve immediately above and below the acquired value. The wafer thickness is calculated and displayed on the LCD.

When taking thickness measurements of semiconductor wafers, the software has two modes of operation : continuous and 5-point measurement. In continuous read mode, the data acquisition card continually transfers voltage outputs to the CPU which calculates an average thickness based on 50 data points and displays the result on the LCD.

In 5-point measurement mode, the user moves the wafer such that the appropriate point on the surface is between the probes, and initiates a reading by pressing a key on the user interface. The measurement from each of the five points is stored, and can be output to a printer or PC via the on-board RS-232 port. For total thickness variation (TTV) measurements, a zero function is also available. The thickness at any point on the wafer can be stored, and the data display set to zero. Thickness is then displayed as the variation relative to the stored value.

Wafer Measurements

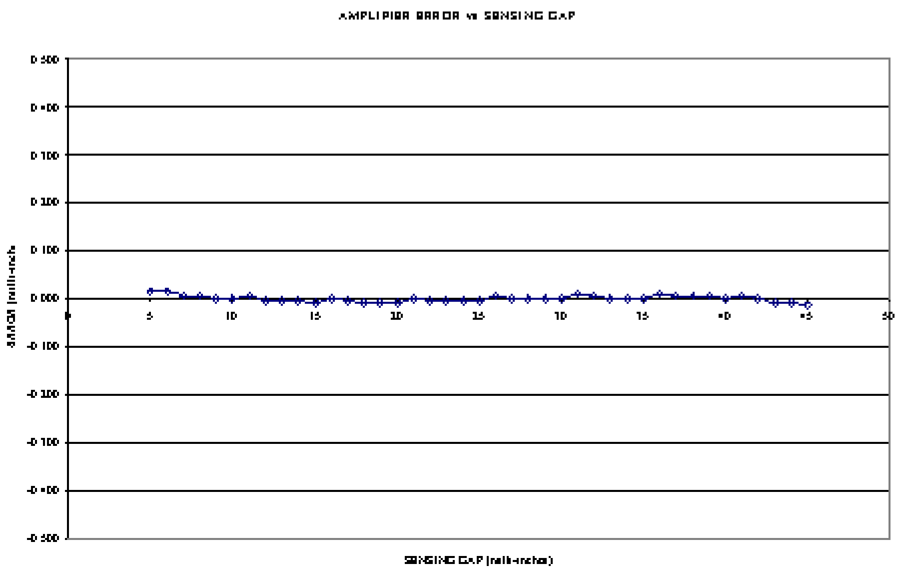


Prior to assembling the measurement system, the amplifiers circuits were calibrated using a Mitutoyo Calibration Stand (Model 521-104) capable of moving the target in increments of 0.00001 in. The probe calibration curve is shown in Figure 3A.

Voltage output values were recorded at 0.001 in. intervals over a total range of 0.005 to 0.045 in. (1 to 9 VDC). Voltage outputs less than 1.000 VDC and greater than 9.000 VDC are considered to be too non-linear to produce a thickness measurement with an accuracy of +/-10 micro-inch (+/-0.25 um). An amplifier with a perfectly linear output would produce a straight line output of 0.200 V/mil.

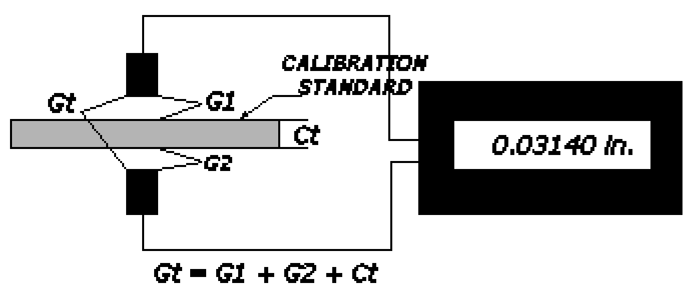
The error illustrated in Figure 3B is the actual variance from this line. This error is compensated for when the linear interpolation of output voltage is performed by the system computer.

The measurement system is assembled such that the voltage output from each of the capacitance probes is at mid-scale (5.000) when a calibration standard is placed on the wafer stage. The effective range of the device therefore becomes +/- 4.000 volts, or +/- 0.020 in. (500 um) from standard thickness. For this test the calibration standard was 0.03140 in. Probe stand-off distance from target is 0.0250 in.



With the calibration standard between the probes, the computer program which controls the system is in "calibration mode". The calibration thickness (Ct) is stored in non-volatile memory, an output voltage from each probe is acquired and the corresponding gap distance (G1,G2) calculated (See Figure 4). The total gap (Gt) between the two probes is then calculated and stored in memory.

The computer is now switched to operational or "read mode" and is ready to begin taking thickness measurements. Placing a wafer between the probes generates a new G1 and G2 value through the same linear interpolation process when the device was calibrated. The results are summed and subtracted from the total probe gap. The result is the wafer thickness.



Results

By eliminating the need for a consistent and repeatable electrical ground path through the wafer and measurement stage, a measurement accuracy of +/-10 micro-inch (+/-0.25 um) is obtained. Measuring wafers of differing resistivities has no effect on device accuracy. Tests measuring materials with significantly different bulk resistivity (Computer Hard Disks, Si Wafers. Ge Wafers, Optical Disks) showed that there is no need to recalibrate the probes for changes in target material. Electrically grounding the measurement stage or leaving it un-grounded also had no effect on measurement accuracy. Thickness measurements were taken using every portion of the voltage output range with no decrease in device accuracy.

The MTI-1560 amplifier and probes proved capable of accurately measuring any material with an electrically conductive surface. The thickness device can be easily customized to accommodate either a maximum thickness sensing range of 0.040 in (1000 um) or maximum probe to target standoff of distance of 0.040 in (1000 um) and a sensing range of +/- 0.005 in (+/- 125 um).

MTI INSTRUMENTS

Pioneers in Noncontact Measurement, MTI Instruments Inc. has been at the forefront of high-precision, noncontact measurement for more than 30 years. We offer fiber-optic, capacitive, and laser technologies designed to measure position, displacement, and vibration in the production process and in the laboratory.

MTI Instruments specializes in providing in-depth technical support before, during and after the sale. Our staff of application engineers and our worldwide network of factory-trained representatives are ready to answer your questions and solve your measurement needs.

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