Designation: F390 – 98 (Reapproved 2003)

Standard Test Method for Sheet Resistance of Thin Metallic Films With a Collinear Four-Probe Array[1]

This standard is issued under the fixed designation F390; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the measurement of the sheet resistance of metallic thin films with a collinear four-probe array. It is intended for use with rectangular metallic films between 0.01 and 100 µm thick, formed by deposition of a material or by a thinning process and supported by an insulating substrate, in the sheet resistance range from 10^{-2} to 10^{4} Ω/□ (see 3.1.3).

1.2 This test method is suitable for referee measurement purposes as well as for routine acceptance measurements.

1.3 The values stated in Si units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 *This standard does not purport to address the safety concerns, if any, associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E1 Specification for ASTM Liquid-in-Glass Thermometers

F388 Method for Measurement of Oxide Thickness on Silicon Wafers and Metallization Thickness by Multiple-Beam Interference (Tolansky Method)[3]

3. Terminology

3.1 *Definitions:*

3.1.1 *thin film*—a film having a thickness much smaller than any lateral dimension, formed by deposition of a material or by a thinning process.

3.1.2 *thin metallic film*—a thin film composed of a material or materials with resistivity in the range from 10^{-8} to 10^{-3} Ω·cm.

3.1.3 *sheet resistance, R_s[Ω/□]—in a thin film*, the ratio of the potential gradient parallel to the current to the product of the current density and the film thickness; in a rectangular thin film, the quotient of the resistance, measured along the length of the film, divided by the length, *l*, to width, *w*, ratio. The ratio *l/w* is the number of squares.

4. Summary of Test Method

4.1 A collinear four-probe array is used to determine the sheet resistance by passing a measured direct current through the specimen between the outer probes and measuring the resulting potential difference between the inner probes. The sheet resistance is calculated from the measured current and potential values using correction factors associated with the geometry of the specimen and the probe spacing.

4.2 This test method includes procedures for checking both the probe assembly and the electrical measuring apparatus.

4.2.1 The spacings between the four probe tips are determined from measurements of indentations made by the tips in a suitable surface. This test also is used to determine the condition of the tips.

4.2.2 The accuracy of the electrical measuring equipment is tested by means of an analog circuit containing a known standard resistor together with other resistors which simulate the resistance at the contacts between the probe tips and the film surface.

5. Apparatus

5.1 *Probe Assembly*:

5.1.1 *Probes*—The probe shaft and tip shall be constructed of tungsten carbide, Monel, hardened tool steel, or hard copper and have a conical tip with included angle of 45 to 90°. Alternatively, the tip may be formed from a platinum-palladium alloy and resistance welded to the shaft. The tip shall have a nominal initial radius of 25 to 50 µm. In all cases all of the four paths from the electrical measurement equipment inputs to the film surface must be identical.

[1] This test method is under the jurisdiction of ASTM Committee F01 on Electronics and is the direct responsibility of Subcommittee F01.17 on Sputter Metallization.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Withdrawn. The last approved version of this historical standard is referenced on www.astm.org.

5.1.2 *Probe Force*—The probes shall be uniformly loaded to exert a force sufficient to deform the metal film but insufficient to puncture the film. A rough guide for loading is a load of 20 g/Mohs (unit of hardness) of the film material on each probe.

5.1.3 *Probe Characteristics*—The probes shall be mounted in an insulating fixture such as a sapphire bearing in a methyl methacrylate or hardened polystyrene block in an equally spaced linear array. The electrical insulation between adjacent probe points shall be at least 10^5 times greater than the *V/I* ratio of the film. The spacing shall be 0.64 to 1.00 mm inclusive (0.025 to 0.040 in. inclusive) as agreed upon between the parties concerned with the test. The precision and reproducibility of the probe spacing shall be established according to the procedure of 7.1.

5.1.4 *Probe Support*—The probe support shall allow the probes to be lowered perpendicularly onto the surface of the specimen so that the center of the array is centered on the specimen within ±10 % of the specimen length *l* and width *w*.

5.2 *Electrical Measuring Apparatus*:

5.2.1 The electrical apparatus shall consist of a suitable voltmeter, current source, ammeter, and electrical connections (see 7.2).

5.2.2 *Voltmeter* with input impedance 10^4 times the *V/I* ratio of the film. A vacuum-tube voltmeter, a digital voltmeter, or similar high-impedance input apparatus is suitable.

5.2.3 *Current Source* with current regulation and stability of ±0.1 % or better. The recommended current range is from 0.01 to 100 mA.

5.2.4 *Ammeter* capable of reading direct current in the range from 0.01 to 100 mA to an accuracy of ±0.1 % or better.

5.2.5 The current source and ammeter are connected to the outer probes; the voltmeter is connected to the inner probes.

5.3 *Specimen Support*—A copper block at least 100 mm (approximately 4 in.) in lateral dimensions and at least 40 mm (approximately 1.5 in.) thick, shall be used to support the specimen and provide a heat sink. It shall contain a hole that will accommodate a thermometer (see 5.4) in such a manner that the center of the bulb of the thermometer shall be not more than 10 mm below the central area of the top of the block where the specimen is to be placed.

5.4 *Thermometer* having a range from −8 to 32°C and conforming to the requirements for Thermometer 63C as prescribed in Specification E1.

5.5 *Vernier Calipers*.

5.6 *Toolmaker's Microscope* capable of measuring increments of 2.5 µm.

6. Test Specimen

6.1 The specimen shall consist of a continuous rectangular thin metallic film with a thickness greater than 0.01 µm and less than 100µ m. Thickness variation shall be less than ±10 % of the nominal thickness for thickness from 0.01 µm to 0.1 µm, inclusive; for greater thicknesses, the variation shall be less than ±5 % of the nominal thickness. The specimen shall be used as prepared by deposition of a material or by a thinning process, with no further cleaning or preparation. The test specimen shall be supported by a substrate consisting of a suitable insulating material.

6.2 *Geometry*—Measure the length, *l*, and width, *w*, of the specimen with vernier calipers. Record the values.

6.3 Measure the thickness, *t*, of the film in accordance with Method F388.

7. Suitability of Test Equipment

7.1 *Probe Assembly*—The probe spacing and tip condition shall be established in the following manner. It is recommended that this be done immediately prior to a referee measurement.

7.1.1 *Procedure*:

7.1.1.1 Make a series of indentations on the surface of the specimen to be tested or other surface of similar hardness with the four-probe array. Make these indentations by applying the probes to the surface using normal point pressures. Lift the probes and move either the specimen surface or the probes 0.05 to 0.10 mm in a direction perpendicular to a line through the probe tips. Again apply the probes to the specimen surface. Repeat the procedure until a series of ten indentation sets is obtained.

NOTE 1—It is recommended that the surface or the probes be moved twice the usual distance after every second or every third indentation set in order to assist the operator in identifying the indentations belonging to each set.

7.1.1.2 Place the specimen so indented on the stage of the toolmaker's microscope so that the *Y*-axis readings (Y_A and Y_B in Fig. 1) do not differ by more than 0.15 mm (0.006 in.). For each of the ten indentation sets record the readings *A* through *H* (defined in Fig. 1) on the *X*-axis of the toolmaker's microscope and the readings Y_A and Y_B on the *Y*-axis.

7.1.2 *Calculations*:

7.1.2.1 For each of the ten sets of measurements calculate the probe separations, S_{1j}, S_{2j}, and S_{3j} from the equations:

$$S_{1j} = [(C_j + D_j)/2] - [(A_j + B_j)/2],$$

$$S_{2j} = [(E_j + F_j)/2] - [(C_j + D_j)/2], \text{ and}$$

$$S_{3j} = [(G_j + H_j)/2] - [(E_j + F_j)/2]$$

where the index *j* is the set number and has a value from 1 to 10.

7.1.2.2 Calculate the average value for each of the three separations using the S_{ij} calculated above and the equation:

$$\bar{S}_i = \left(\frac{1}{10}\right)\sum_{j=1}^{10} = S_{ij}$$

where the index *i* successively takes the values 1, 2, and 3 (see 7.1.2.1).

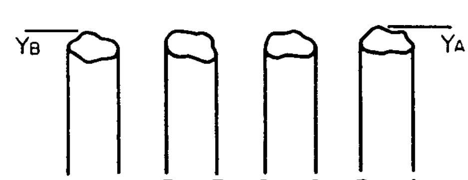

FIG. 1 Measurement Locations for Typical Probe Indentation Pattern