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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Practice for Measuring Sheet Resistance of Thin Film Conductors For Flat Panel Display Manufacturing Using a Noncontact Eddy Current Gage[1]

This standard is issued under the fixed designation F 1844; 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 practice describes methods for measuring the sheet electrical resistance of sputtered thin conductive films deposited on large insulating substrates (glass or plastic), used in making flat panel information displays.

1.2 This practice is intended to be used with Test Methods F 673. This practice pertains to a "manual" measurement procedure in which an operator positions the measuring head on the test specimen and then personally activates the test apparatus. The resulting test data may be tabulated by the operator, or, alternatively, sent to a computer-based data logging system. Both Methods I and II of Test Methods F 673 (paragraphs 3.1 through 3.3.3 of Test Methods F 673) are applicable to this practice.

1.3 Sheet resistivity in the range 0.020 to 3000 Ω per square (sheet conductance in the range 3 by 10^{-4} to 50 mhos per square) may be measured by this practice. The sheet resistance is assumed to be uniform in the area being probed.

NOTE 1—Typical manual test units, as described in this practice, measure and report in the units "mhos per square"; this is the inverse of" ohms per square".

1.4 This practice is applicable to flat surfaces only.

1.5 This practice is non-destructive. It may be used on production panels to help assure production uniformity.

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

2. Referenced Documents

2.1 *ASTM Standards:*

F 673 Test Methods for Measuring Resistivity of Semiconductor Slices or Sheet Resistance of Semiconductor Films with a Noncontact Eddy-Current Gage[2]

3. Summary of Practice

3.1 This practice describes the preferred means of applying Test Methods F 673 to measure the electrical sheet resistance of thin films on very large, flat, nonconducting substrates. The substrate, oriented with the conducting thin film up, is placed between the transducers of the eddy current sensor assembly at the point of interest. The test arrangement is illustrated in Fig. 1.

3.2 A typical conductance apparatus is described in detail in a paper by Miller, Robinson, and Wiley.[3] This paper also discusses skin-depth as a function of thickness and resistivity.

3.3 A typical apparatus operates as follows: when a specimen is inserted into the fixed gap between the two parallel sensing elements, or transducers, in a special oscillator circuit, eddy currents are induced in the specimen by the alternating field between the transducers. The current needed to maintain constant voltage in the oscillator is determined internally; this current is a function of the specimen conductance.

3.4 Further details are given in Test Methods F 673, paragraphs 3.1 through 3.3.3.

3.5 This practice includes calibration procedures for using NIST Silicon Standard Reference Material[4] to ensure proper operation before testing panels.

4. Significance and Use

4.1 Resistivity is a primary quantity for characterization and specification of coated glass plates used for flat panel displays. Sheet resistance is also a primary quantity for characterization, specification, and monitoring of thin film fabrication processes.

4.2 This practice requires no specimen preparation.

4.3 The eddy current method is non-destructive to the thin film being measured. Special geometrical correction factors, needed for some four-point probe electrical resistivity measurements, are not required to derive the true sheet resistance so long as the transducers have a continuous layer of conductive thin film between them.

[1] This practice is under the jurisdiction of ASTM Committee F-1 on Electronics and is the direct responsibility of Subcommittee F01.17 on Sputtered Thin Films.

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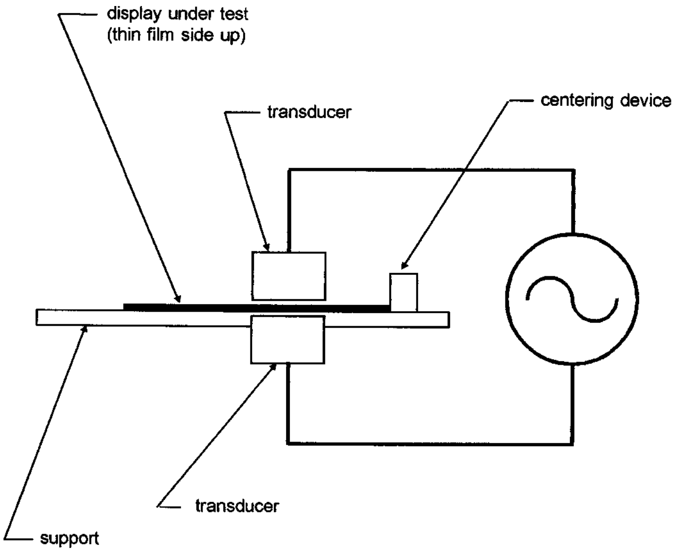
[2] *Annual Book of ASTM Standards*, Vol 10.05.

[3] Miller, G.L., Robinson, D. A. H., and Wiley, J. D., "Contactless Measurement of Semiconductor Conductivity by Radio Frequency-Free-Carrier Power Absorption," *Review of Scientific Instruments*, Vol 47, No. 7, July 1976.

[4] Available from NIST, Gaithersburg, MD 20899.



NOTE 1—This figure is partially copied from Fig 1 of Test Methods F 673.

FIG. 1 Schematic Diagram of Eddy-Current Sensor Assembly

4.4 Test Methods F 673 refers to a testing arrangement in which the transducers and specimen (a semiconductor grade silicon wafer) are rigidly positioned. Similar apparatus is commercially available for testing large glass or plastic substrates, not envisioned in the scope of Test Methods F 673. A hand held probe can also be used, depending on throat depth required.

4.5 For use as a referee method, the probe and measuring apparatus must first be checked and qualified before use by the procedures of Test Methods F 673 (9.1.1 through 9.1.3 and 9.1.4.2 through 9.1.4.5), then this practice is used.

4.6 For use as a routine quality assurance method, this practice may be employed with periodic qualifications of probe and measuring apparatus by the procedures of Test Methods F 673 (9.1.1 through 9.1.3 and 9.1.4.2 through 9.1.4.5). The parties to the test must agree upon adequate qualification intervals for the test apparatus.

5. Apparatus

5.1 *Eddy Current Sensor Assembly*—See Fig. 1 and Test Methods F 673.

5.1.1 Different transducer designs may be required to cover the full range of sheet resistance values.

NOTE 2—Three transducers will generally cover the ranges of interest. For convenience these are denoted "High" (15 to 3000 Ω per square), "Low" (0.2 to 15 Ω per square) and "Extra Low" (0.035 to 0.2 Ω per square).

NOTE 3—The usual "High" range transducer diameter is approximately 12.7 to 15.2 mm. The "Low" and "Extra Low" diameter is approximately 10.1 to 12.7 mm. A very large transducer, 63.5-mm diameter, may be used for all ranges for thicker than normal substrates (up to approximately 2.54 mm) and for calibration and measurement ease.

5.2 *Electrical Measuring Apparatus*—The electrical apparatus must meet the requirements of Test Methods F 673, paragraphs 6.1 through 6.4.

5.3 *Specimen Support*—The flat panel to be tested must be supported firmly to ensure that the thin film is parallel with the transducer surfaces.

5.4 *Reagents and Materials* in accordance with Test Methods F 673, Section 7.

6. Test Specimen

6.1 The test article shall be a display substrate that has been sputter coated with the conductive thin film of interest or ion implanted and annealed, or made conductive by another process.

6.2 The conductive film must be thick enough that it is continuous. Generally this requires that the film be at least 15-nm thick.

6.3 The area to be tested shall be free of contamination and mechanical damage, but shall not be cleaned or otherwise prepared.

6.4 Note that a sputtered film may also coat the edge of the glass and can coat the back side of the substrate ("overspray"). All overspray, for example, coating on back of glass, must be removed before measurement.

6.4.1 Any remaining overspray will be included in the measurement, lowering the measured film resistivity.

6.4.2 Scribing the substrate near the edge using a glass scribe is not a reliable remedy.

6.4.3 Use a simple 2-point probe ohmmeter to verify that the back side of glass or plastic substrate is insulating.

7. Interferences

7.1 Caution must be taken that the transducer gap is fixed, in accordance with the recommendations of the equipment supplier. This may be ensured by firmly tightening the gap adjustment screws after checking the spacing with gages. Use caution, too, that the electrostatic covers (see Miller, et. al.[3]) are not damaged by the panel under test. The electrostatic cover should be located approximately 0.02 mm below the support surface.

7.2 Radial resistivity variations or other resistivity nonuniformity under the transducer are averaged by this practice in a manner that may be different from that of other types of resistivity or sheet resistance techniques, which are responsive to a finite lateral area. The results may therefore differ from those of four-probe measurements depending on film properties and the four-probe spacing used (see Test Methods F 673 paragraph 5.1).

7.3 Spurious currents can be introduced in the test equipment when it is located near high-frequency generators. If the equipment is located near such sources, adequate shielding must be provided. Power line filtering may also be required. (Note the precautions in Test Methods F 673 paragraph 5.4)

7.4 *Soda Lime Glass Substrates*—Special care may be required in measuring the sheet resistance of sputtered thin films on soda lime glass substrates. The surface of this glass can be somewhat electrically conductive (on the order of 1×10^6 Ω per square) when the ambient relative humidity is 90 % or higher.

7.4.1 The glass conductivity degradation may interfere with the sheet resistance measurement when specimen sheet resistivity is 1000 Ω/square or higher.

7.4.2 Ensure that films > 1000 Ω/square sheet resistance deposited on soda lime glass are conditioned at less than 50 % humidity for at least 48 hs prior to measurement, and that the measurement is performed at an ambient relative humidity of less than 50 %.

NOTE 4—At relative humidity < 50 % of the surface resistance of soda lime glass is on the order of 1 by 10^{12} Ω/square.

8. Procedure for Fabrication and Use of Sheet Resistance Reference Specimens

8.1 It is useful to maintain sheet resistance reference specimens for use in verifying the proper performance of the measuring apparatus (see Fig. 2).

8.1.1 Rectangular sheets of etched glass nominally 50 by 75 mm are suitable substrates. The roughness of the etched surface greatly improves abrasion resistance.

8.1.2 The reference film, applied to the substrate, may be a nominally 40-nm thick sputtered tin-oxide coating, doped with nominally 5 wt. % antimony or fluorine. This material demonstrates good chemical stability and abrasion resistance, and sheet resistance on the order of 1500 Ω/square.

8.1.2.1 Tin oxide is a photo conductor with very long carrier lifetimes. Thus the lighting conditions must be controlled to prevent exposure to direct light, or the film must be recalibrated before each use.

8.1.3 A double layer of nominally 100-nm sputtered indium-tin oxide at 90/10 composition ratio covered with 40-nm doped tin oxide (paragraph 8.1.2) for abrasion resistance forms a satisfactory reference film in the 25-Ω/square sheet resistance range. The photo conductive effect is negligible, but films may exhibit long term resistivity drift. Periodic recalibration is required.

8.1.4 After applying the reference film, highly conductive bus bars, nominally 12.5 mm wide, are deposited over the film along two opposite“ short” edges of the substrate, as illustrated in Fig. 2. The free conducting area of film is thus a nominally 50 by 50 mm square.

8.1.4.1 A sputtered chromium adhesion layer, nominally 100-nm thick, upon which is sputtered a thick copper conductive layer nominally 1000 nm with a sheet resistance of 50 milliOhms per square or less is a satisfactory bus electrode for reference films of 20 Ω per square or greater. Reference films less than 20 Ω per square should have a copper wire soldered to the lengths of the bus electrodes, or should have the thickness of the copper film electrodes increased proportionately.

8.1.4.2 The sheet resistance of the reference film may be calibrated using a 2-point or 4-point method, using the bus bars as contact lines. The measured V/I ratio is the sheet resistance for the square reference sample. No correction factors are required.

8.1.5 The conditions and precautions prescribed in 7.2-7.4.2 pertain to sheet resistance reference specimens.

8.1.6 The probe and associated measuring apparatus are checked by applying the measuring procedure (Section 10), to the reference film with the probe near the center of the reference film.

9. Calibrations

9.1 If using a NIST Standard Reference Material (SRM) (or specimen as prepared under Section 8), refer to Test Methods F 673 paragraphs 9.1.1 through 9.1.3.

9.2 Position the center plane of the thickness of the S.R.M. between the eddy current transducers in the same plane as that occupied by the conductive film of the flat panel during actual sheet resistance measurements. This is illustrated in Fig. 3.

9.3 Continue with Test Methods F 673 paragraphs 9.1.4.2 through 9.1.4.5.

10. Measurement Procedure

10.1 Position the flat panel so the surface of the thin film is facing “up” and is parallel with the flat surfaces of the transducers, with the thin film plane lined up where the calibration SRM center was. This is illustrated in Fig. 3.

10.2 *Measurement Procedure*:

10.2.1 Because of differences in manufacturer’s recommended procedures for the various flat panel display measuring instruments, refer to the operator’s manual for explicit measurement instructions for the equipment employed. The steps

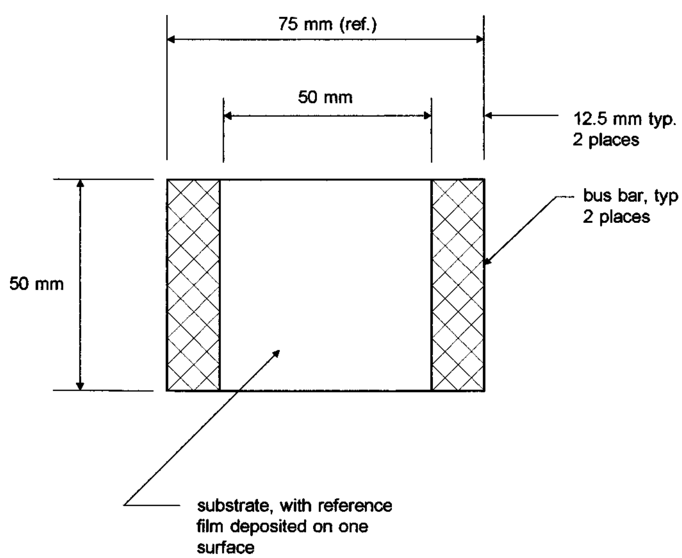


FIG. 2 Calibration Sample

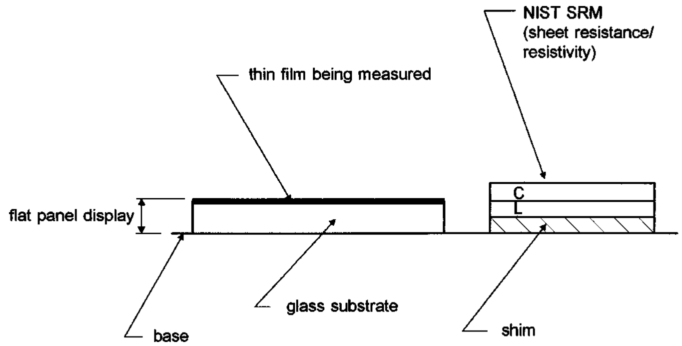


FIG. 3 Specimen Positioning Between Transducers

following are general statements, intended to outline the procedure.

10.2.2 Manually zero the instrument or record the resistivity/conductivity meter reading. If reading the meter without zeroing the instrument, this is the "offset".

10.2.3 Place flat panel display on base with the conductive thin film side "up" (in the same position as shown in Fig. 3) so that the region to be measured is roughly centered in the transducers'" footprint" area.

10.3 If previously zeroed, the reading taken after the flat panel display is placed between the transducer heads is the sheet conductance in mhos per square.

10.4 If not previously zeroed, subtract the "offset" from the second reading. The result is the sheet conductance in mhos per square.

11. Report

11.1 For a referee test the report shall contain the following:

11.1.1 Operator name, date, description of test equipment,

11.1.2 A description of the specimen, including:

11.1.2.1 Type of film,

11.1.2.2 Specimen identification, and

11.1.2.3 Brief description of visual appearance and physical condition,

11.1.3 Dimensions and data, including:

11.1.3.1 Length and width of specimen,

11.1.3.2 Description of eddy current instrument including transducer diameter and spacing between the two transducers, and

11.1.3.3 Measurement system validation data obtained from testing one or more reference specimens (Section 9) or NIST Silicon Standard Reference Materials. When using SRM wafers they should be supported so that the center of the wafer thickness is in plane with the center of the flat panel thin film.

11.1.4 Ambient temperature and humidity,

11.1.5 Measurement locations,

11.1.6 Measured individual values of sheet resistance, and

11.1.7 Computed average sheet resistance, and standard deviation.

11.2 For a routine test, only such items as are deemed significant by the parties to the test need be reported.

11.3 *Film uniformity*—A recommended method of describing film uniformity for the rectangular substrates is to measure the sheet resistance R_s in five or more locations, typically near the four corners and at the center. The uniformity measure, U, is computed from the following equation:

$$U = 100(R_{smax} - R_{smin})/(R_{smax} + R_{smin})\%, \quad (1)$$

where R_{smax} and R_{smin} are the maximum and minimum respectively of the five measured sheet resistance values.

12. Precision and Bias

12.1 Standard deviation, s, from measured sheet resistance, R_s, is to be determined by pilot study and subsequent interlaboratory test.

13. Keywords

13.1 conductance; electrical conductance; electrical resistance; electrical sheet conductance; electrical sheet resistance; flat panel displays; noncontact eddy current; resistance; sputtered thin films; thin conductive films on glass; thin film