Designation: D2149 − 13 (Reapproved 2021)

Standard Test Method for Permittivity (Dielectric Constant) and Dissipation Factor of Solid Dielectrics at Frequencies to 10 MHz and Temperatures to 500 °C[1]

This standard is issued under the fixed designation D2149; 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 determination of the relative permittivity (dielectric constant) and dissipation factor of solid dielectrics from 50 Hz to 10 MHz over a range of temperatures from −80 to 500 °C.[2,3] Two procedures are included as follows:

1.1.1 *Procedure A*—Using Micrometer Electrode.

1.1.2 *Procedure B*—Using Precision Capacitor.

NOTE 1—In common usage the word "relative" is frequently dropped.

1.2 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.3 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[4]

D150 Test Methods for AC Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulation

D1711 Terminology Relating to Electrical Insulation

E197 Specification for Enclosures and Servicing Units for Tests Above and Below Room Temperature (Withdrawn 1981)[5]

3. Terminology

3.1 *Definitions:*

3.1.1 Permittivity and dissipation factor are fully defined in Terminology D1711. Briefly, the permittivity of an insulating material is the ratio of the capacitance between two conductors when embedded in the material to the capacitance between the same configuration of conductors in a vacuum (or air). The dissipation factor is the ratio of the resistive to capacitive currents in the dielectric. The product of the permittivity and dissipation factor is the loss index.

4. Significance and Use

4.1 Permittivity and dissipation factor are sensitive to changes in chemical composition, impurities, and homogeneity. Measurement of these properties is, therefore, useful for quality control and for determining the effect of environments such as moisture, heat, or radiation.

5. Apparatus

5.1 *Measuring Circuits*—Suitable measuring circuits are described in Test Methods D150. For measurements from 50 Hz to 100 kHz a substitution method using a low-voltage capacitance bridge is recommended. For measurements at 1 MHz and above, a resonant-circuit susceptance variation method is recommended. The *Q* of the circuit has to be at least 200 except for very low loss materials, for which a *Q* of 500 or higher is desirable.

5.2 *Test Enclosure*—Unless testing only at room temperature, it is necessary to adapt a Hartshorn-Ward type specimen holder to a temperature-controlled test enclosure. Where applicable, use the requirements for a grade A enclosure as in Specification E197. A suggested arrangement is shown in Fig. 1. This arrangement provides terminal connections away from the temperature zone.

[1] This test method is under the jurisdiction of ASTM Committee D09 on Electrical and Electronic Insulating Materials and is the direct responsibility of Subcommittee D09.12 on Electrical Tests.

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[2] "Alternating-Current Loss and Permittivity Measurements," Chapter 2 of *Engineering Dielectrics Volume IIB Electrical Properties of Solid Insulating Materials: Measurement Techniques, ASTM STP 926*, ASTM International, 1987.

[3] "Dielectric Loss in Solids," Chapter 1 of *Engineering Dielectrics Volume IIA Electrical Properties of Solid Insulating Materials: Molecular Structure and Electrical Behavior, ASTM STP 783,* ASTM International, 1983.

[4] 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.

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

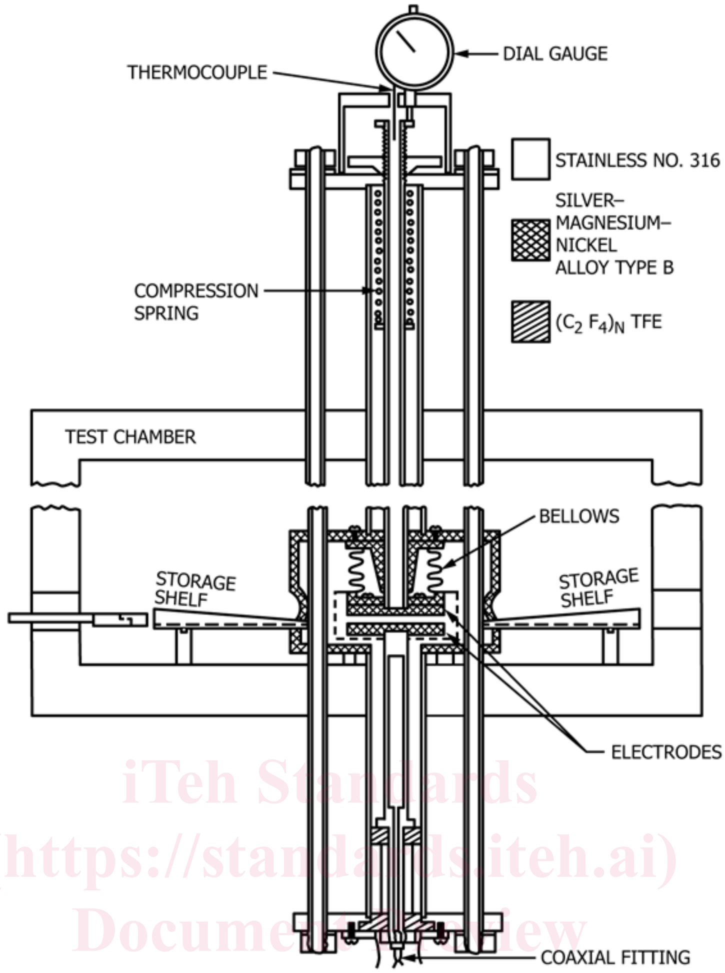

FIG. 1 Suggested Specimen Holder

5.3 *Specimen Holder*—The suggested arrangement shown in Fig. 1 incorporates the following requirements:

5.3.1 The selection of the metals is of utmost importance. The metal has to be of good thermal and electrical conductivity and yet be oxidation resistant and have sufficient strength to maintain its mechanical dimensions after repeated heating. AISI Stainless No. 316 fulfills these requirements except for the thermal conductivity. The time required for a specimen to reach equilibrium in a holder made from this material is quite long. Precious metal alloys such as type B silver-magnesium-nickel have better overall properties but require special heat treating.

5.3.2 The preferable insulator materials are aluminum oxide, beryllium oxide, or polytetrafluoroethylene.

5.3.3 Use electrodes 50 mm in diameter and at least 5 mm thick, with sharp corners. Maintain electrode parallellism to within 0.01 mm.

5.3.4 Select a length and cross-section for the lower tube so that the temperature of each insulator does not exceed 100 °C when the oven is at 500 °C. Select a length and cross-section for the upper tube so that the drive nut can be touched with the operator's fingers (keep the drive nut less than 60 °C) when the oven is at 500 °C.

5.3.5 Use a micrometer or dial gage with a precision of 0.005 mm to determine electrode separation and to monitor specimen expansion.

6. Electrodes

6.1 Prior to measurement, apply conducting film or foil electrodes to both flat surfaces of the specimen. (The specimen thickness is to be determined before applying electrodes.) Silver paint, tin or tin-lead foil, or evaporated metal electrodes have ranges of usefulness. Evaporated metal electrodes are the most suitable. When the specimen is porous sprayed-on metal electrodes are useful. Additional information on the suitability of various electrode systems is contained in Test Methods D150.

7. Sampling

7.1 See ASTM standards for specific materials.

8. Test Specimen

8.1 Use a disk test specimen with a diameter of 40.00 ± 0.01 mm and a thickness of 2 to 3 mm. Finish the surfaces to 1.8 µm or better and maintain parallel surfaces to within 0.01 mm. The samples have to be free of bubbles and other defects.

9. Standard Test Frequencies

9.1 Unless otherwise specified, make measurements at one or more of the following frequencies:

60 Hz	100 000 Hz
100 Hz	1 MHz
400 Hz	10 MHz
1000 Hz	

Common test frequencies are 60 Hz, 1000 Hz, and 1 MHz.

10. Temperature Control

10.1 Take measurements at frequent temperature intervals (not to exceed 20 °C), until the required temperature range has been traversed. Reduce the temperature to the lowest required test temperature and leave until equilibrium has been achieved. Determine equilibrium by clamping a specimen between the holder electrodes and balancing or peaking the measuring circuit until no change takes place between balances made 2 min apart. After the required measurements have been made at the lowest test temperature increase the temperature at the rate of 2 ± 0.5 °C/min to the next test temperature. Follow this procedure for achieving the test temperature until the required temperature range has been traversed. Take measurements at approximately the same test temperatures as the temperature is increasing and as the temperature is decreasing. Measurements as temperature is being increased and decreased are necessary to guard against possible hysteresis in electrical properties due to such factors as moisture and chemical change.

11. Conditioning

11.1 Prior to applying electrodes condition the specimens at 23 ± 1 °C and 50 ± 2 % relative humidity for a minimum of 40 h. Carry out room-temperature tests in the Standard Laboratory Atmosphere of 23 ± 1 °C and 50 ± 2 % relative humidity.

12. Procedure A (Using Micrometer Electrode)

12.1 Refer to Test Methods D150. Center the specimen between the electrodes and rotate the drive nut until the friction is felt to suddenly decrease. Read this micrometer setting and check it against the setting at which the friction first increases on increasing the electrode spacing. Balance or peak the measuring circuit. Open the electrodes and remove the specimen. Then restore the balance of the measuring apparatus without changing its capacitance setting by reducing the spacing between the electrodes and adjusting the measuring circuit to balance the loss component. Note the new dissipation factor and micrometer setting, and so forth.

12.2 At each test temperature and each required frequency determine the capacitance and dissipation factor of each specimen.

13. Procedure B (Using Precision Capacitor)

13.1 Procedure B can be used when the frequency can be kept constant or when the measuring circuit, as is the case with the bridges, is stable with frequency changes. In this procedure determine the ΔC at room temperature for each frequency required as in Procedure A. Then center and clamp the specimen between the electrodes and change the temperature to the first temperature, taking measurements at each required frequency to determine the change in capacitance of the specimen.

13.2 Procedure B requires a variable-precision capacitor with a precision of 0.01 pf in parallel with the specimen holder to determine the change in specimen capacitance with temperature and frequency.

14. Calculation

14.1 *Procedure A*—Calculate the capacitance, C_s, and dissipation factor, D_s, of the specimen as follows:

$$C_s = C_o - C_t + C_v \tag{1}$$

$$C_s = \Delta C + C_v \tag{2}$$

$$D_s = C_t / C_s (D_i - D_v) \tag{3}$$

where:

C_o = capacitance of the specimen holder with the specimen out,
C_i = capacitance of the electrodes set at the average measured thickness of the specimen (Note 2),
C_v = equivalent geometric vacuum capacitance of the specimen,
C_t = total capacitance at the unknown terminals of the measuring circuit,
D_i = dissipation factor of the measuring circuit as indicated by the measuring circuit when the specimen is between the electrodes, and
D_o = dissipation factor of the measuring circuit as indicated by the measuring circuit when the circuit has been rebalanced with the specimen removed from the electrodes.

NOTE 2—If the secondary electrodes are quite thin and the maximum thickness of the specimen is close to the average thickness, this setting can be considered the same as the micrometer reading when the specimen is clamped between the electrodes.

14.2 *Procedure B*—Calculate the capacitance of the specimen as follows:

$$C_s = \Delta C + C_{RT} - C_T + C_v \tag{4}$$

where:

C_{RT} = capacitance of the precision capacitor at room temperature when the measuring circuit is balanced, and
C_T = capacitance of the precision capacitor at a temperature test point when the measuring circuit is balanced.

14.3 Calculate the dissipation factor as in Procedure A (Eq 3).

15. Lead Length Correction

15.1 In both Procedures A and B, keep the length of the leads to a minimum between the measuring circuit and the