Resistivity is the key to measuring electrical resistance

Martin Rowe - May 21, 2012

When a voltage is applied to a material or device, current will flow through it. How much current will flow is based on the resistance that the material applies to a circuit. The resistance of a material is based on a number of factors, the most important being its resistivity. Resistance and resistivity are often used interchangeably, but they have slightly different meanings. Knowing the difference helps you understand how electrons will flow.

Basic physics and Ohm's law teaches us that resistance ($R$) of a material or device is the quotient of the voltage, also called electromagnetic force or electromotive force, ($E$) applied to a circuit divided by the resulting current ($I$) through the circuit. By simple substitution of Ohm's law ($I=\frac{E}{R}$), resistance is

$$R=\frac{E}{I}$$

In general terms, resistance is the capacity of a circuit or material to oppose the flow of an electrical current and is referred to as Ohms ($\Omega$). Resistivity is the measurement of a device's resistance. Like all units in the metric system, resistance of a pure element is given in a standard unit ($\Omega \cdot m$) at room temperature. The resistivity of pure copper, for example, is $1.68 \times 10^{-8} \Omega \cdot m$.

Elements that are highly resistant to the flow of electrons are considered insulators. Insulators are typically tested for their resistance as well as their dielectric strength. Elements that are low on the periodic table are conductors.

Solid elements are classified as insulators, semi-insulators, or conductors by their "static resistivity" in the periodic table of elements. Resistance in an insulator, semiconductor, or conductive material is a primary property attribute that needs to be considered in any application.

The measured resistivity of a material sample depends on its size and thickness. Temperature, humidity, and electrification time, among other factors, also affect resistivity. In general, when two otherwise identical material specimens are compared from the same sample and all other factors are the same, the resistance of the wider specimen is less than the smaller specimen and the resistance of a longer specimen is greater than a shorter specimen. Resistance is dependent on a specimen's size, but resistivity isn't.

Common resistivity measurements

The three most common resistivity measurements are
• Surface resistivity
• Bulk or volume resistivity, and
• Contact resistivity

Surface Resistivity is the measurement of resistance across the surface of a material in contact with the electrodes.

![Figure 1. Measure resistivity of a material using two 1-in. electrodes spaced 1-in. apart.](image)

To measure the surface resistivity of a flat material, use a set of equal-sized electrodes placed in good contact with the surface of the material and separated by a space equal to the width of the electrode. In **Figure 1**, the two probes are both 1-in. wide and separated by a 1-in. insulator. Because one divided by one equals one, the length divided by the width of the area cancels out the effect of the size of the measured area.

Surface Resistivity measurement units are given as Ohms per Square (Ω/square) regardless of the size of the electrode:

\[
\text{R} \times \left(\frac{L}{W}\right) = \Omega/\text{square}
\]

A Surface-resistivity measurement of very conductive flat material of a uniform substance is also the resistance measurement of the volume between the electrodes, because the path of the electrode includes the depth or thickness of the test specimen.

Bulk resistivity is the measurement of resistance \(R\) multiplied by the cross-section of a specimen (Width x Thickness) divided by the Length of the material between the electrodes. **Figure 2** shows an ASTM D 257 strip

![Figure 2. A pair of strip electrodes makes a bulk-resistivity measurement on the material crossing between them.](image)
electrode designed to measure bulk resistivity through tape or flat, solid specimen. In this case, the electrodes are in contact with both sides of the material at each end.

Bulk resistivity units are typically given in Ohm-centimeters (Ω-cm). The length, width and thickness of the material are all in centimeters. Bulk resistivity is also known as volume resistivity.

\[ R \frac{(W \times T)}{L} = \text{Ω-cm} \]

Contact resistivity is the measure of the resistance through a material or composite. It’s not actually a measurement of the material itself, but a measure of the quality of the electrical connection.

**Figure 3** has two 1-in. square stainless-steel blocks with the test material sandwiched between them. Contact resistance is that amount of resistance to current flow in the contact surface or juncture of a composite material or leads of a device that contributes to the total resistance of a circuit. You can calculate contact resistance by subtracting the inherent resistance of each conductor or insulator in a set from

![Figure 3. Two 1-in. square blocks let you measure the resistivity of the material between them.](image)

the total resistance of a circuit. Contact resistance units are given in milliohms (mΩ) because the resistance within the circuit is relatively minimal. Sometimes, this measurement is also described as Z-axis resistance.

**How is Resistance Measured?**

Resistance is affected by a number of factors including, surface cleanliness, humidity, temperature, applied voltage or applied current. Temperature and relative humidity readings are integral to the test. Some meters have auto-ranging voltage applied and even low power settings for very low and sensitive resistivity measurements. Ohms cannot be measured directly by any meter; it is a calculated value found by dividing the applied voltage by the current through a conductor. A typical Ohmmeter or Multimeter applies low current though a material; measures the voltage and displays the resistance in Ohms (Ω).

Numerous instruments can measure resistance, either in combination with another instrument or as a stand-alone instrument. Accuracy and sensitivity depends on the test conditions, sample rate, and meter resolution.

Very-low resistance values and very-high resistances are typically measured by different types of meters and probes. High Resistivity measurements are typically obtained using either a megohmmeter or an IR (insulation resistance) meter. Very low resistance values are measured by several different combinations of instruments and in some cases, very precise dedicated
Fabrico’s Lab has several meters that measure resistance, including those for very high-resistance values and for low-resistance values. We use an Agilent Technologies 34420A Nano-volt/Micro-ohm meter that has the resolution and accuracy we need for low-resistance measurements. We also use a Fluke 8846A general lab multimeter and an AEMC IR meter/Hipot instrument for very high resistance measurements.

**Two or four wires?**

Resistance or resistivity measurements require two or four wires. A two-wire resistance measurement is the most common method and is typically done with a handheld Multimeter (Figure 4). Today’s digital multimeters are fairly accurate for most applications.

The multimeter applies a very small DC current to an unknown resistance and measures the voltage drop across the resistance, displaying the results in Ohms. The leads and contacts have some resistance, which is included in the result. As long as the leads and contacts are lower in resistance than the specimen being measured, then you can ignore the lead or contact resistance and the measured resistance will be that of the specimen.

For better accuracy with a two-wire setup, a lab multimeter can measure the resistance of the leads and the contacts within a circuit with the specimen removed. The meter can then null this value while measuring the test specimen to get the actual value of the specimen. See Figure 5.

A four-wire resistance measurement is the most accurate way to measure very small resistances. The current and voltage are applied in two separate circuits, also called the source and the sense circuits. This is referred to as a Kelvin Bridge and special Kelvin clips are often used. Kelvin clips are typically gold plated and have the two positive wires electrically separated at the point of contact.
and the two negative wires electrically separated at the point of contact. The source circuit applies a known current to the test specimen. The sense circuit measures the voltage across the specimen. Given a known current from the source, the meter can then calculate and display resistance. This has the effect of eliminating most of the resistance in the leads and contacts. If a test fixture is used with a four-wire circuit, the resistance in the fixture may still need to be nulled. Semiconductor materials often require a specific measurement that involves a four-point probe with gold-plated pressure pins incrementally spaced along with a four-wire circuit.

Contact resistance can be found by measuring the same area test sample first by a two wire probe and then a four-wire Kelvin bridge and then subtracting the difference. The difference is equal to the contact resistance in a joint.

**Important Factors**

Sample preparation for electrical test procedures are spelled out in the respective test method. Any contamination, oxidation or surface irregularities can compromise the results of a test. Temperature has to be taken into account as well. Electrons move at different speeds at different temperatures. The temperature effect is different for different elements. Metals gain in resistivity as they heat. Semiconductors generally lose resistivity as temperature increases.

Composite materials and laminations present special challenges for resistivity testing. Humidity certainly has an effect, for surface resistivity measurements and depending on the hydroscopic tendency of the material, dimensional as well as the resistance values may be affected.

In some materials such as gaskets and adhesives, while the compound may be very conductive through the material, the relative isolation of the conductive suspended particles prevents linear resistance measurements. These materials are considered anisotropic. These adhesives are used extensively for flexible circuitry and in certain solar panel applications. For these materials, true volume resistance methods cannot be applied.

In a circuit or when several resistors or conductive materials are connected with in a single path back to ground or a meter, the measurement is referred to as a series resistance measurement. The resistance is calculated by totaling all the resistors. A solar cell is an example of a series circuit. In this case the units are expressed as Ω⋅cm².

**Examples of Resistivity Measurement**

Less than 25 years ago, when most electrical products were high voltage and bulky, resistance and conductance of materials didn't need to be very precise. Increased miniaturization and low power efficiency in today's electronic applications are driving resistivity measurements. You can't automatically assume that specification sheets provide the accurate information necessary to meet every application. A typical test can start by measuring the surface or bulk resistivity of a known insulator at a number of random locations to confirm that the supplier's sample is within the range specified in the datasheet and that the material is correct.

Resistance is a critical measurement to a solar-panel manufacturer. A solar panel is rated according to how much power it can produce. Each component in a solar panel circuit, starting from the photovoltaic collector through to the end terminals either contributes to the conductance of electrical current or the isolation of the current that carries that power. The total measurement of this in a completed panel is referred to as a series resistance measurement. Each component contributes to the cumulative effect of this resistance.
The higher the resistance in the circuit, the more energy the panel will dissipate and the less power it will produce. Series resistance in a circuit includes both the inherent "bulk" resistance of the conductors, plus the bus tape and the "contact" resistance between the components. This represents the low end of the resistance measurement. On the high end, the insulators, including the case and other parts of the panel that contain the conductive components of the solar panel, must also be measured to ensure they prevent current leakage and thus power loss. An insulator is often measured for its "surface resistivity."

Another application where resistivity measurement is critical is in the ESD (electrostatic discharge) containment. Certain electronics, transportation, and military/aerospace applications require a material to be conductive so that it will draw current produced by ESD away from critical low-power circuitry. A bulk or surface-resistance test lets you measure a material's ability to prevent circuit damage from ESD. In addition, the measurement might reveal a problem or a solution to a problem that can be solved by choosing a better-suited material, particularly in terms of a laminate or gasket choice for an electronic enclosure.

**For further reading**


ASTM D1000-10 Standard Test Methods for Pressure-Sensitive Adhesive-Coated Tapes Used for Electrical and Electronic Applications

ASTM D257-07 Standard Test Methods for DC Resistance or Conductance of Insulating Materials


"Electrical Conductivity and Resistivity," National Science Foundation.

**Clemens Bak** is the Fabrico Test Capabilities Lab Manager and has been with Fabrico since 1989. Clemens' background includes experience as a manufacturing engineer responsible for design and building production systems. In addition, he has worked as a machinist at Sonoco, Fruehauf, and Harley-Davidson. Clemens can be reached at cbak@fabrico.com.