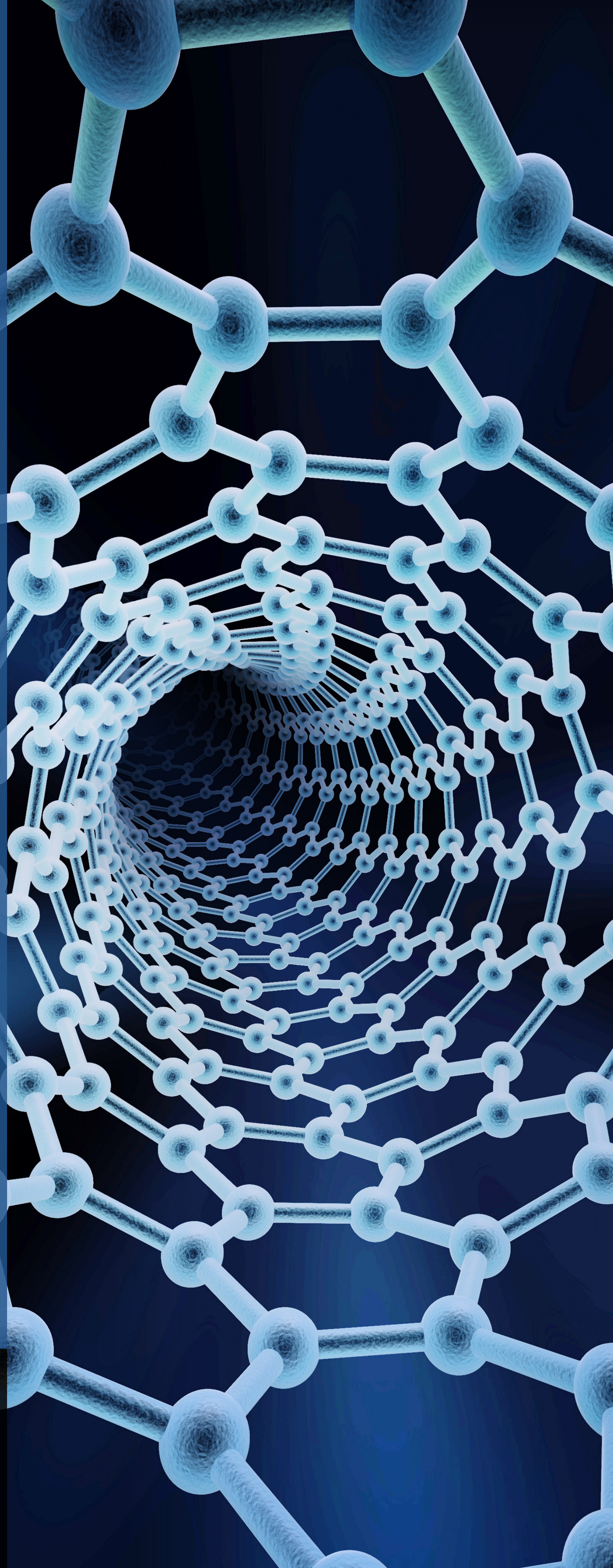
Advanced Materials

TERMS AND ACRONYMS



KEYSIGHT TECHNOLOGIES

Common Terms & Acronyms

Advanced materials discoveries are revolutionizing engineering across a variety of sectors, including aerospace and defense, and civil. The tunable physical, chemical, and biological properties of advanced materials often make them lighter, stronger, and more economical alternatives to traditional materials. Thanks to their unique properties, these materials enable technological innovation that benefits society. Below are some terms and definitions to help you navigate the continually advancing — and ever-so-promising — field of materials science.

AC impedance spectroscopy

AC impedance spectroscopy (sometimes called electrochemical impedance spectroscopy, or EIS) measures the impedance of an electrochemical system or material versus frequency. It is used to derive various material physical parameters such as carrier mobility, recombination time, and interface state profile.

ACMs – Advanced composite materials

Advanced composite materials are also called advanced polymer matrix composites. ACMs are materials characterized by remarkably high strength and high stiffness (high elastic modulus) compared to other materials.

Atomic polarization

Atomic polarization describes the phenomena that occurs when adjacent positive and negative ions in a material "stretch" under an applied electric field.

Biomaterials

Biomaterials are substances constructed to interact with biological systems for medical reasons, whether to treat, enhance, or replace damaged tissue. These materials can comprise plastic, ceramic, metal and even living cells. While biomaterials find application in many medical areas, they are commonly used for medical implants such as hearing loss devices, artificial joints, and heart stents.

Capacitor

A capacitor is a device that stores an electric charge. While capacitors vary in size, the basic configuration involves two conductors carrying equal but opposite charges separated by a dielectric. In electronic devices, capacitors are used to preserve the supply of power during battery charging.

CV – Capacitance-voltage measurement

Capacitance-voltage measurement is an **electrical property** measurement method that provides charge or carrier-related information for semiconductor materials. It is used to derive many key parameters, such as carrier density, doping profile, impurity distribution, and insulation layer thickness. The LCR meter is a standard instrument used for making CV measurements.

CNT – Carbon nanotube

Carbon nanotubes are cylindrical structures made of carbon — much like a sheet of graphene rolled into a cylinder. Like graphene, CNT has high electrical and thermal conductivity and a high Young's modulus. Unlike graphene, it has an adjustable bandgap, which makes it both resistive and highly conductive.

Charge pumping measurement

Charge pumping is an **electrical property** measurement method that measures trap density at a semiconductor / insulator interface. Unlike **CV measurements** that require large-diameter MOS capacitors, the device-under-test can be a small-geometry MOSFET. Since charge pumping currents are typically small, the instrument used to perform charge pumping measurements must be able to measure ultra-low current.

Coaxial probe measurement

Coaxial probe measurement is an **electromagnetic property** measurement technique that provides insight into a material's permittivity by immersing a probe into the liquid, semisolid, or powder material. Typically, the instrument of choice used for this method is an impedance analyzer or network analyzer.

Composite materials

Composite materials combine two or more elements, often with different properties. These materials are stronger in combination than they are by themselves. Various features work together to give the composite unique properties. However, one can easily tell the materials apart as they do not dissolve or blend into each other.

Conductivity / resistivity

Resistivity (ρ) and conductivity (σ) are fundamental material characteristics measuring a material's ability to conduct electrical current. Materials are categorized as conductors, semiconductors, or insulators according to their conductivity. The more conductive a material is, the larger the value of electric current that can flow through it. The resistivity of a material is the inverse of its conductivity ($\rho = \frac{1}{\sigma}$) . Also see **resistance** and **four-point probe measurement**.

CMC – Ceramic matrix composites

Ceramic matrix composites, also known as CMC, consist of ceramic fibers embedded in a ceramic matrix. CMC materials are used in aerospace and defense, transportation, and chemical industries where applications involve extreme thermal and mechanical requirements.

IV – Current–voltage measurement

A current-voltage measurement is typically called an "IV curve" where the measured current is plotted against a voltage stimulus. A current versus voltage plot provides important insight into the electrical current behavior of a material as the voltage stimulus varies. For active devices such as field-effect transistors, IV curves provide information on the device's conductivity, which varies with the voltage applied to the control terminal (e.g., gate) of the device. Equipment used to make IV measurements needs well-synchronized source and measurement (meter) points. A variation of the IV measurement is the **pulsed IV measurement**.

Dielectric constant

Dielectric constant is the relative permittivity or the absolute permittivity relative to the permittivity of free space.
See **permittivity**.

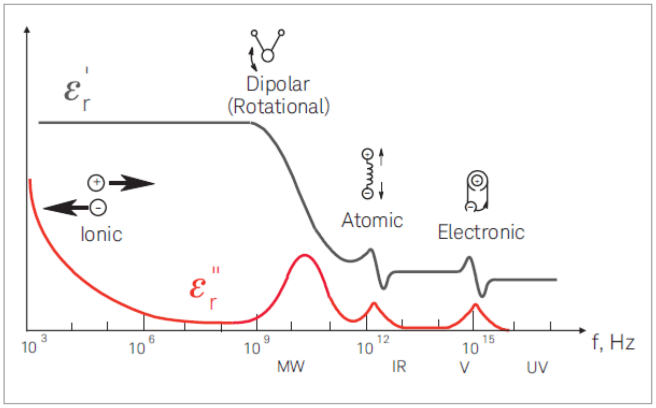
$$K^* = \varepsilon_r^* = \frac{\varepsilon^*}{\varepsilon_0}$$

Dielectric material

Dielectric material is an insulating (nonconducting) material that can be affected (or polarized) by an electric field. Electric charges in the dielectric material become polarized to compensate for the electric field such that the positive and negative charges move in opposite directions. A dielectric material can store energy when an electric field is applied. If a DC voltage source is placed across a parallel plate capacitor, more charge is stored when a dielectric material is between the plates than if no material (a vacuum) is between the plates. The dielectric material increases the storage capacity of the capacitor by neutralizing charges at the electrodes, which ordinarily would contribute to the external field.

Dielectric mechanisms

Dielectric mechanisms or polarization effects are effects that contribute to a material's overall permittivity. **Dipole orientation** and **ionic conduction** are two examples of dielectric mechanisms that interact strongly at microwave frequencies. The magnitude and "cutoff frequency" of a mechanism is unique for different materials.



Dipole orientation polarization

Dipole orientation polarization is a **dielectric mechanism** that exists when the rearrangement of electrons causes an imbalance in charge distribution, creating a permanent dipole moment. Water molecules, for example, are permanent dipoles that rotate to follow an alternating electric field. These mechanisms are quite lossy, which explains why food heats in a microwave oven.

Electrical properties

The electrical properties of a material define its ability to conduct electrical current and include such things as the material's resistivity, **conductivity**, and temperature coefficient resistance.

Electromagnetic wave propagation

Electromagnetic wave propagation is the traveling of electric and magnetic fields together, either at the speed of light (in free space) or slower than that (when the waves pass through materials). Many aspects of wave propagation depend on the permittivity and permeability of a material. Electromagnetic waves of various wavelengths exist. The wavelength of a signal is inversely proportional to its frequency, such that as the frequency increases, the wavelength decreases.

Electromagnetic properties

Electromagnetic properties of a material are characteristics that govern how it responds to electromagnetic radiation. A material's electromagnetic properties are typically defined in terms of its **dielectric constant** and magnetic **permeability**.

Electronic polarization

Electronic polarization is a **dielectric mechanism** that occurs in neutral atoms when an electric field displaces the nucleus with respect to the electrons that surround it.

Electronic substrates

Electronic substrates are materials that can serve as the base on which to build microscopic electronic components and connections, such as on a printed circuit board.

Four-point probe measurement

Four-point probe measurement is an **electrical property** measurement technique that measures the resistivity of a semiconductor material. For greater accuracy, the measurement equipment needs an accurate current source and the ability to measure ultralow signal levels. This method works for materials in the form of rods or thin layers. Also see **Van der Pauw measurement** for irregular-shaped materials.

Free space measurement

Free space measurement is an **electromagnetic property** measurement technique that provides insight into a material's permittivity and permeability by placing the material between two antennae in a non-contacting environment. Because of the non-contacting setup, the free-space method is ideal for applications requiring heating to very high temperatures or when the material is large or non-uniform. A network analyzer typically computes the material's electromagnetic properties from the reflected and transmitted signals.

Fringe effect

Fringe effect is a phenomenon that occurs when the electric field extends the area of overlap between two parallel plates. When the area of the parallel plate capacitance doubles, the area of the overlap doubles. The fringe effect, however, does not double.

GaN – Gallium nitride

Gallium nitride is a binary III/V direct bandgap, wide-bandgap semiconductor. Applications include semiconductor power devices, radio frequency (RF) components, and light-emitting diodes (LEDs). GaN is also prevalent in electrical grid and alternative energy devices, as well as in efficient power components used in high-energy vehicles, from electric trains to electric cars. See **Wide-bandgap** materials.

Graphene

Graphene is composed of a single flat sheet of pure carbon atoms arranged in a repeating hexagonal honeycomb lattice. As the lightest and strongest material known today, it has superior electrical and thermal conductivity, a high Young's modulus, and is non-permeable.

Hall effect measurement

Hall effect measurement is an **electrical property** measurement technique that involves applying a magnetic field to a conductor in a direction perpendicular to the current flow, in turn producing an electric field perpendicular to the magnetic field and current. This technique provides insight into majority carrier concentration (p or n) type and its mobility, μ.

High-loss materials

High-loss materials, also known as "lossy materials," have large values of **tan** δ (tan delta) and include water, food, and many natural materials. High-loss materials quickly absorb microwave energy and are not suitable for electronic components.

Inductance

Inductance is a characteristic in electrical conductors whereby conductor opposes any change in electric current that passes through it due to changing magnetic flux.

Inductance measurement

Inductance measurement is an **electromagnetic property** measurement technique that involves winding wire around a toroidal core and evaluating the inductance to the ends of the wire. The effective permeability of the material can be calculated from the inductance measured.

Interfacial or space charge polarization

Interfacial or space charge polarization occurs when, in the presence of a low-frequency electric field, the motion of migrating charges over a distance through a material is impeded. The charges can become trapped within the interfaces of a material. Motion may also be impeded when charges cannot be freely discharged or replaced at the electrodes. The field distortion caused by the accumulation of these charges increases the overall capacitance of a material.

Intramolecular forces

Intramolecular forces, or bonding forces, are the forces that exist within molecules and influence chemical properties.

Intermolecular forces

Intermolecular forces are the forces that exist between molecules and influence physical properties.

Ion-dipole force

Ion-dipole force results from the electrostatic attraction between an ion and a neutral molecule that has a dipole. This is particularly important for solutions of ionic compounds in polar liquids.

Ionic conductivity

Ionic conductivity is a current conduction mechanism involving the movement of ions from one point to another. It is most prevalent in moist materials and contributes to a material's measured loss.

Loss tangent

Loss tangent, or tan δ , expresses the relative "lossiness" of a material. It is the ratio of the imaginary part of the dielectric constant to the real part. Another term for loss tangent is dissipation factor, D or D_f, a measure of energy loss compared to energy stored. A material's quality factor, Q, is the reciprocal of its dissipation factor.

$$\tan\delta = \frac{\varepsilon_r''}{\varepsilon_r'} = D = \frac{1}{Q}$$

$$= \frac{\text{Energy lost per cycle}}{\text{Energy stored per cycle}}$$

Low-loss materials

Low-loss materials have small values of **tan** δ . Electronic applications such as insulators for cables, substrates, and dielectric resonators use low-loss materials. Their advantages are reduced signal attenuation and generated heat in the material.

MTJ – Magnetic tunnel junction

Magnetic tunnel junction is a new class of thin-film device. It is a tri-layer "sandwich" consisting of two layers of magnetic material separated by an ultrathin insulating film. Electrons can tunnel from one ferromagnet to the other if the insulating layer is thin enough (typically a few nanometers). MTJs exhibit a magnetoresistance effect called tunnel magnetoresistance. An external magnetic field can cause the direction of two magnetizations of ferromagnets to switch individually.

MMC – Metal matrix composites

Metal matrix composites are materials consisting of a group of materials, such as metals, alloys, or intermetallic compounds. An MMC contains at least two constituent parts, one being a metal and another being a different material, such as a ceramic or organic compound.

Nanofiber

Nanofibers are fibers with a diameter of 100 nanometers or less. Their controllable pore structures and high surface-to-volume ratio make them ideal for use in applications ranging from sensors and clothing to energy storage.

Nanostructured materials

Nanostructured materials contain structural elements, such as clusters, crystallites, or molecules, with dimensions in the 1- to 10-nanometer range. These chemical substances or materials are manufactured and used on a very small scale. They consist of particles with at least one dimension below 100 nanometers.

Parallel plate measurement

Parallel plate measurement is an **electromagnetic property** measurement technique that provides insight into a material's permittivity by placing the dielectric material between two electrodes to form a "capacitor" and computing measurements with an LCR meter or impedance analyzer.

Permeability

Permeability describes the interaction of a material with a magnetic field. It measures the ability of the material to allow magnetic lines of force to pass through it. If a direct current source is placed across an inductor, the inductance with the core material can be related to permeability. Permeability is a complex quantity, consisting of real (storage) and imaginary (loss) parts.

Permittivity

Permittivity describes the interaction of a material with an electric field and is a complex quantity, consisting of real (storage) and imaginary (loss) parts. It measures the obstruction generated by the material in the formation of an electric field.

$$\varepsilon_r^* = \frac{\varepsilon^*}{\varepsilon_0} = \varepsilon_r' - j\,\varepsilon_r'' = \left(\frac{\varepsilon'}{\varepsilon_0}\right) - j\left(\frac{\varepsilon''}{\varepsilon_0}\right)$$

Phantoms

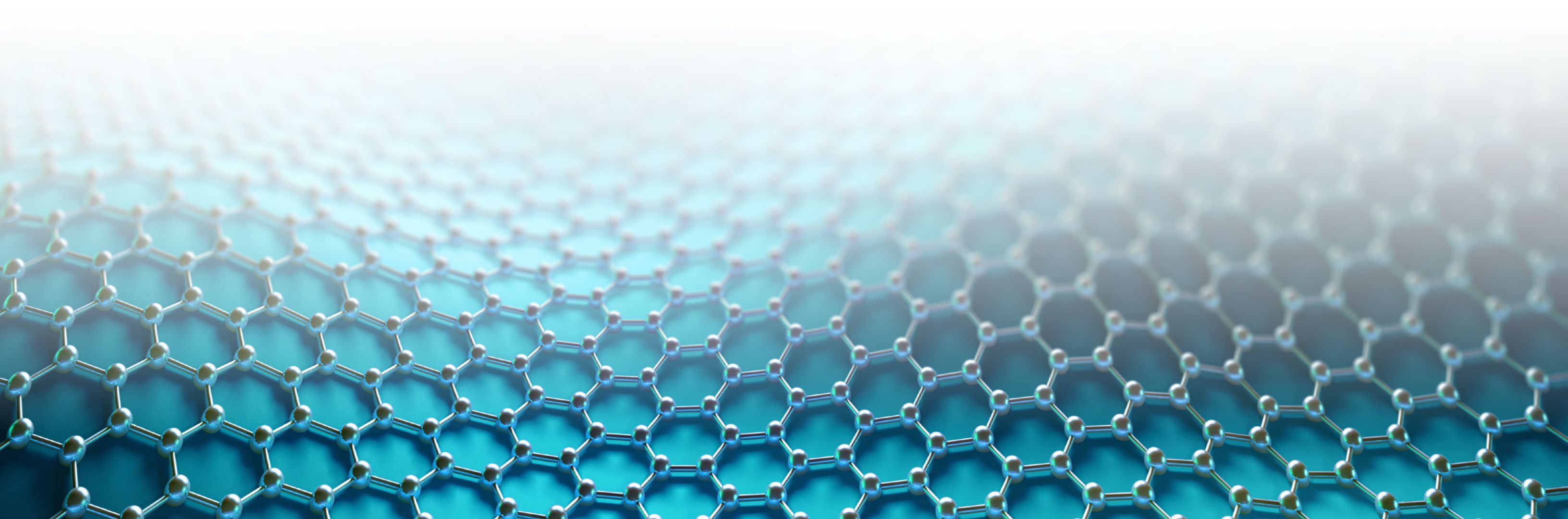
Phantoms — or, more specifically, imaging phantoms — are artificial structures developed to emulate the properties of human tissues. In wireless communications, specific absorption rate (SAR) testing on phantoms determine if emissions from wireless devices (e.g., mobile phones) are safe for humans. In medical research, phantoms help calibrate imaging devices such as magnetic resonance imaging (MRI) machines and microwave imagers, to ensure they are operating correctly.

Polymers

Polymer materials consist of long, repeating chains of molecules. The molecules have unique properties that depend on the type of molecules being bonded and how they are bonded. While some polymers bend and stretch, others are hard and tough. Depending on the polymer type, use cases range from food wraps and buckets to non-stick pan coatings and rugged insulation for electrical wires.

PMC – Polymer matrix composites

A polymer matrix composite, or PMC, is a composite material composed of a variety of short or continuous fibers connected by an organic polymer matrix.



PTFE – Polytetrafluoroethylene

PTFE is a versatile plastic fluoropolymer created through the free-radical polymerization of many tetrafluoroethylene molecules. PTFE materials are low-loss, have a low dielectric constant, and are often used for their high-gain capabilities at microwave frequencies. Other properties of PTFE that make it desirable across numerous applications include its chemical resistance, high thermal stability, high electrical resistance, and high insolubility. PTFE is best-known for its nonstick properties and is commonly used in cookware applications. Teflon, for example, is a well-known brand name of a PTFE-based formula.

Pulsed IV measurement

Pulsed IV measurement is an **electrical property** measurement technique. An **IV plot** shows how a material's conductivity varies with changes to the applied voltage. In smaller devices, the Joule self-heating effect becomes more pronounced and affects device characteristics. In pulsed IV measurements, using short pulsed signals with long duty cycles reduces Joule heating. The pulse width and period necessary to suppress Joule heating differs from one material to another, so the equipment used for pulsed IV measurements must allow precise control over the pulse width, period, leading / trailing edges, and voltage / current peak levels.

QSCV – Quasi-static CV measurement

QSCV measurement is an **electrical property** measurement technique used to evaluate the quantity of charge trapped in the interface states of metal-insulator-semiconductor structures. Also see **CV measurement**.

RAM – Radar-absorbing materials

Radar-absorbing materials are also known as RAM. RAM is a special polymer-based material that coats the surface of stealth military aircraft, making it harder for radar to detect. Another RAM application is in radar-absorbing structures like the pyramid-shaped foam absorber used to cover the walls of RF anechoic chambers. Pyramidal RAM such as this uses scattering and absorption techniques to attenuate electromagnetic signals in the chamber.

Relaxation time

Relaxation time, τ , is a parameter of interest when dealing with applications involving liquid or polar materials. For dipolar dielectrics, relaxation time describes the time required for dipoles to become oriented in an electric field (or the time required for thermal agitation to disorient the dipoles after removal of the electric field).

Resistance

Resistance (R) of a piece of conducting material is proportional to its **resistivity** and length (L), and inversely proportional to its cross-sectional area (A). ($R = \frac{L_\rho}{A}$)

Resonant cavity measurement

Resonant cavity measurement is an **electromagnetic property** measurement technique that provides insight into a material's permittivity by inserting the material into a resonator and computing measurements at specific frequencies with a network analyzer. This method is highly accurate and best for low-loss solid materials such as ceramic and **composite substrates**.

SiC – Silicon carbide

SiC is a hard semiconductor containing silicon and carbon. Commonly used as an abrasive, SiC finds its application in sandpaper, cutting tools, and ceramic plates in bulletproof vests. In electronic applications, SiC's **Wide-bandgap**, as well as its excellent thermal and electrical conductivities, make it suitable for use in semiconductor devices that operate at high temperatures, high power, and high frequencies.

Superconductor

Superconductor is a conductor that carries electric current with ease. It does not lose energy while conducting current, and no magnetic field can exist within it. There are two types of superconductors: Type I comprises basic conductive elements such as sulfur, and Type II comprises metallic compounds such as lead.

Temperature dependency measurement

Temperature dependency measurement is performed on a material with its temperature held at a specific value for a time before switching to a higher or lower temperature and then repeating the measurements and observation. The measurement provides insight into a material's characteristics because a change in thermal energy affects the kinetic and potential energy of the material's constituent atoms or molecules. A forced-air system typically helps reduce the time lapse from one temperature to another.

Time-domain voltage / current measurement

Time-domain voltage or current plot is an **electrical property** measurement technique that captures transient material behavior that occurs following continuous electrical stimulation over time. Factors such as interface traps, stray capacitance, or internal resistance can cause a transient response. The time-domain measurement also provides insight into a material's reliability.

Time-of-flight measurement

Time-of-flight measurement is an **electrical property** measurement technique that determines how long it takes minority carriers (primarily generated by light) to travel from one side of a sample to the other. Further calculation from this measurement provides minority carrier velocity and mobility information.

Transmission line measurement

Transmission line measurement is an **electromagnetic property** measurement technique provides insight into a material's permittivity and permeability by enclosing the material in a rectangular waveguide or coaxial airline and computing measurements with a network analyzer.

Van der Pauw measurement

Van der Pauw is an **electrical property** measurement technique used to determine a material's resistivity. This technique can be performed on irregularly shaped flat samples with uniform thickness and no isolated holes.

Wide-bandgap materials

Wide-bandgap semiconductors are semiconductors with higher breakdown voltages, lower on-resistances, and higher thermal conductivity. As transistors, they provide faster switching speeds than conventional power devices. Such properties are essential in today's automotive and energy industries, which often require device operation at increasingly higher voltages, frequencies, and temperatures.

Creating a better tomorrow begins today, with research breakthroughs in advanced materials that enable stronger, more durable, safer, and more sustainable devices and methodologies. Accurate characterization of material properties is essential to creating next-generation technologies and products.

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