Performance Differences of Common Resistive Materials

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Surface mount and thru hole resistors utilize many different types of materials for their resistive elements. These different materials will perform differently with respect to many characteristics and may have different capabilities depending on if the part is thru-hole or surface mount. This article will discuss some important performance parameters and characteristics of common resistor materials for both axial leaded and surface mountable resistors.

Temperature Coefficient of Common Resistive Materials		
Materials	**Axial Leaded**	**Surface Mount**
Carbon Comp	-400 / +500 to -1400 / +2000 ppm	± 400 to -1300 ppm
Carbon Film	± 400 to -1500 ppm	± 350 to 1000 ppm (MELF)
Nichrome Metal Film (Thin Film SMD)	± 2 to 100 ppm	± 2 to 100 ppm
Metal Oxide	± 200 to 400 ppm	± 200 to 400 ppm
Metal Glaze (Thick Film SMD)	± 50 to 200 ppm	± 25 to 1000 ppm
Tantalum Nitride (Thin Film)	NA	± 10 to 100 ppm
Alloy wire (Wirewounds)	± 10 ppm to ± 400, -80 / +900 ppm	± 10 to 100 ppm

Temperature Coefficient

The change in resistance value a resistor experiences over a given change in temperature is measured by the temperature coefficient of resistance, or TCR. For applications that must perform in a wide variety of temperature levels and environments, TCR is important to maintain the stability and reliability of the circuit. For example, if an application experiences change in temperature of 100C, which is not uncommon in power supply, industrial, or automotive applications, a resistor with a TCR of 400 ppm may shift by as much as 4% over this span, where a resistor with a TCR of 50 ppm may shift by no more than 0.5%.

There are many power and control applications that are not temperature sensitive, either because of circuit or application tolerances, or because they reside in a controlled environment. For those applications, low cost materials such as carbon film or carbon composition (for lower power) and wirewounds (for higher power) are common choices. Surface mount wirewounds have a much more limited resistance value range and are more expensive than the many thru-hole wirewound resistor options. For electronics that have plenty of design margin but require higher pulse energy handling and lower inductance, carbon composition is the material and technology of choice.

Metal oxide material provides slightly higher power capability than carbon films and better TCR. Metal Glaze technology for axial resistors is generally reserved for high voltage applications and higher resistance values.

For surface mount resistors, this type of material is generally referred to as thick film. Many common chip resistor types are made from this thick film material. Thick film chip resistors have good TCR for most of their resistance range but have poorer TCR generally at the highest and lowest resistance values. For designs that require tolerances of 1% and tighter and TCR of 100 ppm or better, metal film provides the best balance of precision and cost.

Surface mount wirewounds can also be designed with materials providing low TCR and tight tolerance and can have excellent overall stability. Surface mount metal film resistors are generally either nichrome or tantalum nitride thin film resistors. Both thin film resistor materials provide a very high precision and electrically stable element. Nichrome material is generally less expensive and has the capability to provide better TCR and tolerance than tantalum nitride. Tantalum nitride however provides a resistive element that is impervious to moisture due to its self-passivating characteristic.

Power Handling Capability of Common Resistive Materials		
Materials	**Axial Leaded**	**Surface Mount**
Carbon Comp	1/4W to 1W	1/4W to 1/2W
Carbon Film	1/8W to 2W	1/4W to 1W (MELF)
Nichrome Metal Film (Thin Film SMD)	1/8W to 2W	1/20W to 2W
Metal Oxide	1/2W to 7W	NA
Metal Glaze (Thick Film SMD)	1/4W to 10W	1/20W to 3.5W
Tantalum Nitride (Thin Film)	NA	1/20W through 2/5W
Metal Alloy wire (Wirewounds)	1/2W to 2000W	1/5W through 15W

Power Handling Capability

Some common resistive materials have highly variable power handling capability depending on their design and whether they are surface mount, thru hole, or chassis mount. Metal alloy wire used in wirewound resistors will generally only handle up to 4W or 5W in surface mount form. Thru hole wirewounds may be found up to 50W. Higher power chassis mount or tubular wire element resistors may handle up to 2000W.

Surface mount resistors with solid metal plate alloy elements may handle up to 15W depending on chip size. Thick film elements in leaded or thru hole form are typically designed for higher voltage and can be sized to handle up to 10W. Surface mount thick film resistors are typically limited to around 2W, although thick film on aluminum nitride substrates may handle up to 3.5W due to the superior heat dissipation of aluminum nitride.

Carbon composition, carbon film, tantalum nitride, and metal film elements are generally only able to handle up to 2W of power regardless of whether it is a surface mount or thru hole package. Metal oxide resistive elements are generally used for higher power and higher pulse applications and therefore may be rated up to 7W. However, if the application requires a power rating above 5W, the choices become quite limited.

Test Performance of Common Resistive Materials			
Materials	**Load Life**	**Short Time Overload**	**Biased Humidity / Damp Heat**
Carbon Comp	± 10%	2%	10%
Carbon Film	1% to 3%	0.25% to 0.75%	1.5% to 5%
Nichrome Metal Film (Thin Film SMD)	0.15% to 1%	0.1% to 0.25%	0.1% to 1.5%
Metal Oxide	2.5% to 5%	0.75% to 2%	2.5% to 5%
Metal Glaze (Thick Film SMD)	1% to 3%	1% to 2%	1% to 5%
Tantalum Nitride (Thin Film)	0.1% to 0.5%	0.1% to 0.5%	0.1% to 1.5%
Metal Alloy wire (Wirewounds)	1% to 5%	1% to 2%	1% to 5%

Performance Comparison

From an electrical and environmental performance standpoint, most materials behave the same and will have similar characteristics regardless of mounting type. The material with the poorest overall stability is carbon composition. The doped carbon slug element exhibits large resistance shifts due to moisture, aging, load life, and temperature cycling. However, carbon composition elements withstand very high energy pulses and exhibit virtually zero inductance.

Metal oxide materials, while better than carbon composition in terms of environmental and electrical performance, generally are not capable of the same stability as metal film elements. Metal oxide materials will handle higher temperature, higher power, and pulses better than metal film elements. Carbon film materials generally have performance stability better than metal oxides and are typically the least expensive thru hole technology to manufacture. On the downside, carbon film elements have lower continuous power capability and will typically have poorer pulse handling performance than metal oxide elements.

Nichrome metal film elements have exceptional electrical and environmental stability and as such are commonly chosen for precision circuit requirements. Nichrome metal film elements however are only available in lower power ratings and may be susceptible to corrosion in high humidity environments. Tantalum nitride thin film materials, while not as capable of providing high precision elements, have similar stability properties as nichrome and add robustness to high moisture environments. The disadvantage is that tantalum nitride elements are more difficult to manufacture and are therefore more expensive.

Metal glaze thick film materials are abundant in surface mount form and have good but not great stability and reliability characteristics. Metal glaze thick film elements are typically inexpensive and inherently impervious to moisture due to their glasslike nature in their final state.

Wirewound materials performance varies depending on the part design. For inexpensive ceramic housed wirewounds, the performance, stability, and precision is not very good. But for high precision wirewounds, environmental and electrical stability can be as good as all but the best metal film and tantalum nitride options available.

Summary

Resistor technologies such as carbon composition are generally used for power applications that require both high energy pulse handling and low inductance and don't have significant stability requirements. Carbon film resistors are widely used for a range of applications that require low cost 5% resistors and can accept middling stability and temperature performance.

Metal glaze or thick film technology provides an ideal blend of electrical performance and stability at low cost. Metal oxide technology provides higher continuous power and pulse power capability at the expense of electrical and environmental stability. Nichrome and tantalum nitride thin film materials provide exceptional stability and reliability with high precision but are limited to lower power ratings and are more expensive than other film types.

Metal alloy wirewound and wire element resistors may be used for a range of applications from inexpensive designs with minimal stability and precision requirements to high precision power monitoring and controls. In the end, the precision, stability, and cost depend on the resistor design and package type.