

Thick Film Materials for Strain Gage Applications

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Abstract

Thick film materials have been used for many years in various electronic sensor applications. Temperature, pressure, position, and flow are some of the properties that can be measured using circuits built from thick film microelectronics. Cermet thick film materials are ideally suited to these applications due to their robust nature, precise tolerances and resistance to mechanical, thermal and chemical stresses. These sensors are used in automotive, industrial, aerospace, medical, and other applications where harsh environments and critical properties are required. As more and more of the world is being controlled by computer technology, sensors that connect the physical world to the electronic world are needed. There is an expanding interest in using thick film materials for strain gage hybrids. Strain gages can be used in automotive applications for sensing pressure, industrial applications for measuring displacement and even in civil applications where they are used to measure mechanical stress.

This paper will discuss the actual design of various strain gage devices using thick film materials. The basic concept is that when the thick film resistor is flexed, it shifts in resistance. Important parameters of the thick film resistor are the gage factor, the amount of resistance shift compared to the strain, and the hysteresis of the resistor, which is how close the resistance comes back to the original value. The variation in resistance changes the voltage output of the strain gage device (such as a Wheatstone bridge). This modification in voltage is what allows the circuit to work.

Heraeus Incorporated Thick Film Materials Division has a full line of materials for manufacturing strain gage circuits. The paper will list comparisons of different material sets and technologies that will help the designer select a specific technology. The paper will also report on results from various material and substrate combinations.

Key Words: Strain gage, conductors, thick film resistors, dielectrics, and alumina.

Introduction

When external forces are applied to a stationary object, stress and strain are the results. Strain is

the amount of deformation per unit length of an object when a load is applied. Strain can be compressive or tensile. All strain gages are designed to convert mechanical motion into an

electronic signal. As you deflect the resistive element on a gage circuit, the resistance changes, which changes the voltage output of the circuit, which will give the gage factor, which will be discussed later in this paper. The use of strain gages is found in many applications. Thick film resistor strain gages are used in many automotive applications. They are also used in trade industries such as aviation and building applications. Load cells are another application for strain gages. They are found in many industrial applications, including pointing sticks for laptop computers. These were early thick film strain gage circuits.

In order to measure strain with a resistance strain gage it must be connected to an electric circuit. There are many different types of these circuits. These gages usually employ four strain gage elements connected to form a Wheatstone bridge. A Wheatstone bridge is a divided circuit used to measure static or dynamic electrical resistance. The output voltage of a Wheatstone bridge is expressed in millivolts per volt input.

Figure 1 shows a typical divided Wheatstone Bridge Design.

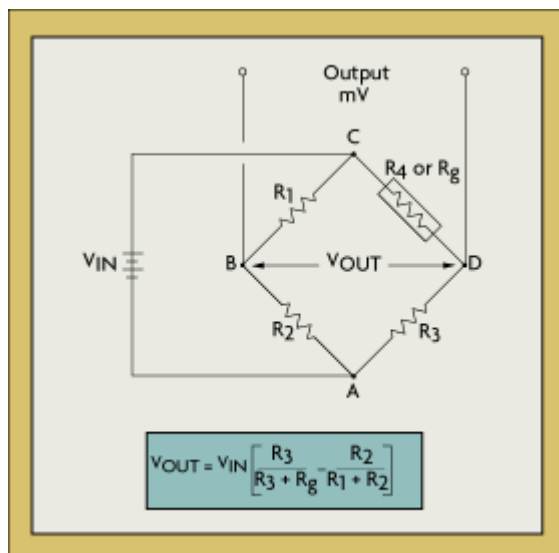


Figure 1

In this type of circuit, if all four resistance values are equal, R_1 - R_4 , and a voltage is applied from points A and C, V_{IN} , the output from points B and D will show no potential difference. If R_4 is changed to a different value, not the same as the other 3 resistors, the voltage output will change. The resistor that is strained is called the R_g resistor element.

The number of resistor elements that can be connected to a bridge depends on the application. Some designs also have some resistors in compression and some in tension. For strain measurements on rotating machines (engines, turbines, etc.) the Chevron Bridge is used. This circuit switches between changing one resistor to two. Figure 2 shows this circuit design. This design allows the circuit to compensate for changes in bridge arm resistance by switching from one resistor being changed to two resistors being changed.

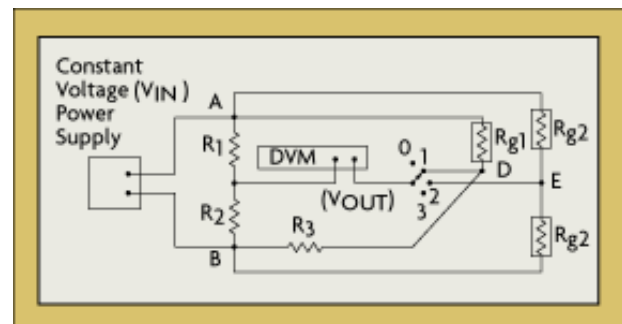


Figure 2

Another circuit design is called the Four Wire Ohm Design. The main advantage of this design is that the conductivity of the attached lead wires does not affect strain measurement values. Figure 3 shows this design.

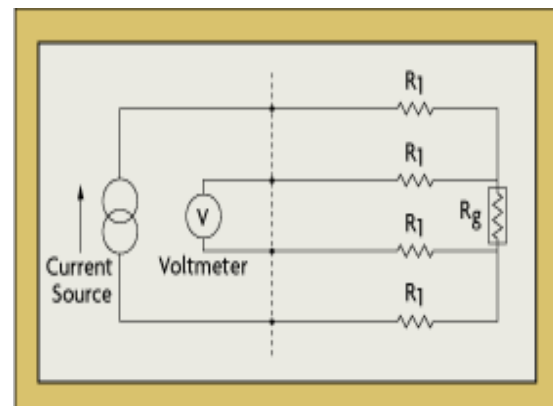


Figure 3

The last type of circuit design to be shown is the Constant Current Design. In this design, current is used to change the bridge resistor and can help the output be more linear. This can be useful when dynamic strain is being measured. Figure 4 shows this design.

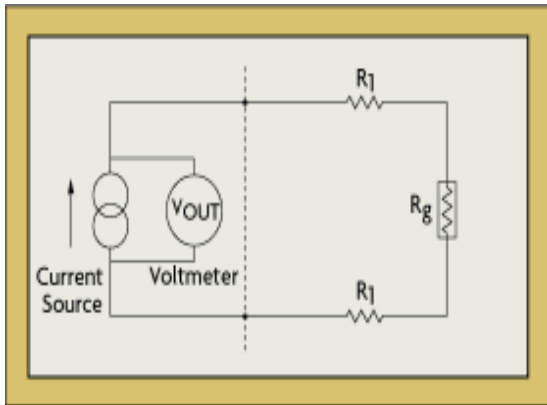


Figure 4

Most strain gages use some sort of shielding or guarding for the lead wires. This is to prevent noise errors to negate the R_g value. This can be accomplished by twisting lead wires and shielding the lead wires themselves. Some alternate lead wire configurations are shown in Figure 5.

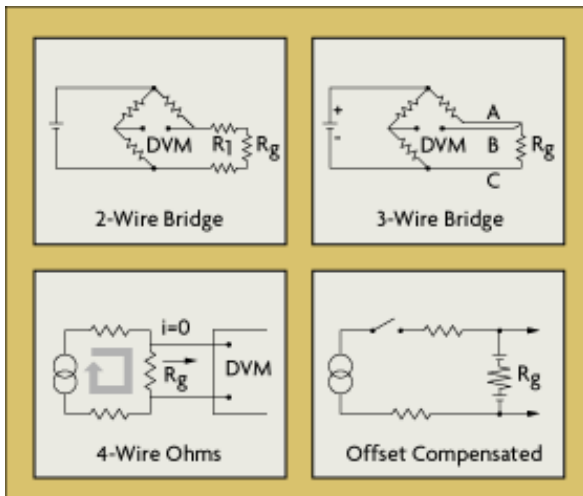


Figure 5

Heraeus TFD Materials for Strain Gage Applications.

All thick film resistor materials show some resistance when stressed. How much the resistance changes from the initial, non-stressed state to the position after it is deflected is called the gage factor (GF). Most thick film resistors have a gage factor of between 3 and 15. It is the GF that determines the strain sensitivity of the sensor. The higher the GF the more the resistance of the R_g changes during deflection. When the circuit is built on a cantilever beam design, this allows for easy flexing of the resistors. All strain gages need to be flexed in

some way to work, usually when they are in tension (during deflection.) It is important that the resistor R_g returns to its original value after deflection to ensure a stable sensor. Heraeus TFD resistors have shown their ability to return to the original value after deflection. Figure 6 shows the test circuit that Heraeus TFD uses to test for R_g . Depending on the customer's needs, the resistors can be printed directly on alumina, on dielectric on alumina, or on dielectric on steel. As will be shown later the choice of the termination types will significantly change the GF of the same resistor material.

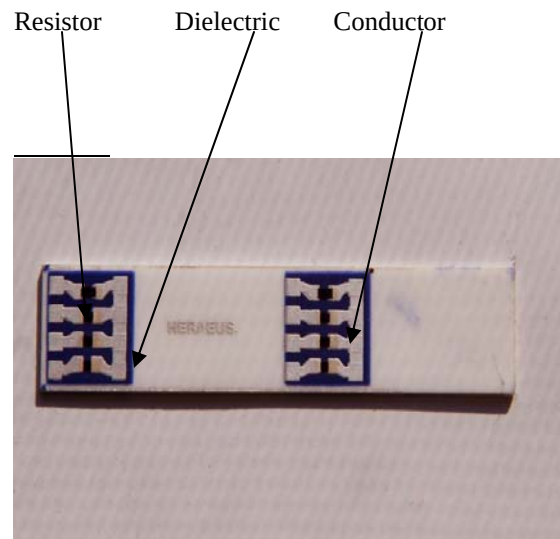


Figure 6

This test pattern is printed with Heraeus TFD resistor, conductor and dielectric products. Leads are attached to the conductor. It is then stressed with a deflection of 10 mils. The resistance is measured before and after flexing. The actual change of resistance is very small. You can then calculate the GF from this resistance difference. There are other strains that occur during this deflection, such as shear straining, Poisson straining, and bending strain. For most thick film applications these are very small and don't change the GF measurement.

Heraeus TFD makes materials for both ceramic substrate strain gages and steel substrates (430 type steel). Steel substrates are usually used in automotive applications and ceramic substrates in commercial applications. As mentioned before thick film resistors, conductors and dielectrics are needed to make these circuits. All products should be standard screen printable pastes, and processed using standard procedures.

For Ceramic Circuits

- Some circuit designs on ceramic use a base layer of dielectric and some are printed directly on alumina. Using a base layer of dielectric has been shown to give higher GF numbers. For a circuit on alumina IP9117S is recommended. This is a standard 850° C firing material.
- Standard silver bearing conductors like C1076SD (Pt/Ag), C8717 (Ag) and C4740S (Pt/Ag) are recommended. For gold bearing conductors C5789, C5756, and C5729 are recommended.
- Most applications use a resistor value of 10-20Kohm per square. For ceramic R8241 resistor is recommended directly on alumina, R8241DG on dielectric and gold, and R8241HGF, which is a special blend of resistor paste that gives a gage factor of 13 or higher. This resistor will be discussed later. The other two mentioned resistor pastes will provide a gage factor of from 9-11.
- Standard resistor overglazes are recommended, such as IP9035A.

For steel circuits

- A base layer of dielectric of SD1000 is recommended. This dielectric is expansion matched to 430 steel. Three layers of dielectric are recommended..
- Either C1076SD or C8717 are recommended for silver bearing conductors. Gold is usually not used on the steel substrate as they are mostly used in lower cost automotive circuits.
- The resistor most commonly used is R8241DN. This product is matched to the TCE of the dielectric.
- Overglazes are typically not used, but standard resistor overglazes can be used if necessary.

Other information

It is important that the proper resistor choice be used on the proper dielectric. As you change from IP9117S to SD1000 the resistor values shift. It is typically noticed that a resistance shift in an Rg resistor will also change the gage factor. Changing conductor types will also have an effect on resistance, but not as much as changing dielectrics. Tests were done on various conductors, and two different dielectrics, IP9117S and SD1000. The resistor value used was kept constant, R8241DG. This resistor is nominally 10Kohm when calibrated on IP9117S and using a Pd/Ag termination. The fired thickness of the resistor was kept constant. Resistance and gage factor were measured. Parts were also tested directly on alumina. Table 1 shows the results.

Table1: Gage Factor of R8241DG with Various Conductors and Dielectrics

Combination	Resistance	GF
C5789	12.0Kohm	14.4
C1076SD	8.1Kohm	13.7
C8717	7.3Kohm	13.8
C5789	3.5Kohm	11.7
C1076SD	2.1Kohm	10.1
C8717	1.8Kohm	9.4
C5789	42.2Kohm	17.1
C1076SD	41.5Kohm	16.7
C8717	39.1Kohm	15.1

C5789 is a gold conductor. C1076SD is a Pt/Ag conductor. C8717 is a pure silver conductor.

The first 3 combinations use IP9117S as the dielectric. The next three combinations use SD1000 as the dielectric. The last 3 are fired on alumina.

As you can see from the data the most drastic shifts occur when going from dielectric to alumina. The resistance value goes up on alumina and the gage factors shift as well. Some circuit designs may be able to use the higher resistance on alumina with the higher factors. The shifts going from IP9117S to SD1000 are smaller but still significant. These GF resistors can also be blended to different values.

During this testing there was much work done to try to determine why the change from dielectric to alumina was so large. The one thing that was noticed was that the R8241 DG resistor was originally calibrated on IP9117S. The theory was

that the glass from the dielectric was reacting with the glass in the resistor. As previously mentioned most of the thick film resistor values used to make these circuits at in the 10-20Kohm range. It was decided to look at a higher value resistor to look at the GF. R8251DG, which is a 100Kohm resistance value, was tested for GF.

Test Results

The R8251DG was fired on SD1000 dielectric and C1076SD conductor. The resistance was 65Kohm and the GF was around 12.5. This seemed rather low as a R8241DG at this value would have a much higher GF. The formulas for the 2 resistors were compared. It was noticed that the higher value R8251DG had two different glass frits in the formula and the R8241DG had only one glass frit.

A paste was made of the R8251DG with only the one glass frit found in the R8241DG. This ink was processed as before. The resistance value was now 34Kohm and the GF was 14.1. This new ink was blended with R8241DG to a theoretical value of 20Kohms. The resulting paste was 21Kohm and had a GF of 14.2. This became product number R8242HGF as mentioned earlier. It was shown that resistance range and GF can be changed by changing the frit type and content of the resistor pastes used.

Summary

Strain gages circuits are used in many applications. Thick film products have proven to be a good alternative to thin film strain gage circuits and semiconductor strain gage circuits.

There are many different circuit designs for these applications. Thick film materials can be used in all these designs. The choice of the various combinations of resistor, dielectric and conductor will determine the final resistor gage factor.

The types of frit and the amount of frit can determine the gage factor of various resistors. Future work will be done on optimizing gage factors by changing the composition of the resistor.

Acknowledgments

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References

- 1.) Omega.com for the circuit pictures.