The Performance of a Flammable Gas Sensing Pellistor Bead With Respect to the Material Properties of the Support Arms

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Abstract

The pellistor bead is used for the detection of combustible gases within an oxygen-based atmosphere. In its simplest form a platinum wire coil is encapsulated within a porous alumina bead – which has been doped with a precious metal such as palladium or rhodium – and is suspended between two metallic support arms. This paper looks at the performance of this device with respect to the material properties of these support arms. A three-dimensional finite element model was constructed using ANSYS software. It shows how the efficiency of this device can be improved by careful choice of the materials used for the support arms. In many cases gas sensors employing pellistor beads have to be portable. Any increase in the pellistor's efficiency would result in either longer battery-lifetime or in the reduced mass of the complete sensing unit.

Introduction

Catalytic gas sensors, such as the pellistor bead, operate by the catalytic oxidation of combustible gases such as methane (CH_4) or hydrogen (H_2) and are commonly used towards the prevention of explosive accidents [6]. The device that will be investigated in this paper consists of platinum wire coil supported between two cylindrical support arms (Figure 1). The platinum wire itself has a diameter of **12.5μm**. The **5-turn** coil has a radius of **130μm** with an average spacing of **50μm** between consecutive turns. The support arms have a height of **5,000μm** and a centre-to-centre separation of **7,500μm**. After deposition, a porous alumina bead doped with a palladium catalyst encapsulates the coil (Figure 2). The radius of this spherical bead is approximately **300μm**.

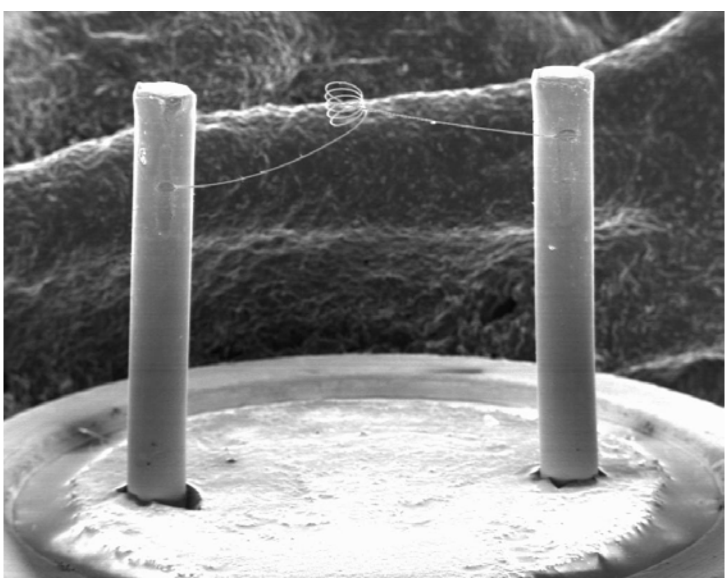

Figure 1 - Scanning Electron Microscope Photograph Of The Platinum Wire Coil Suspended Between Two Support Arms

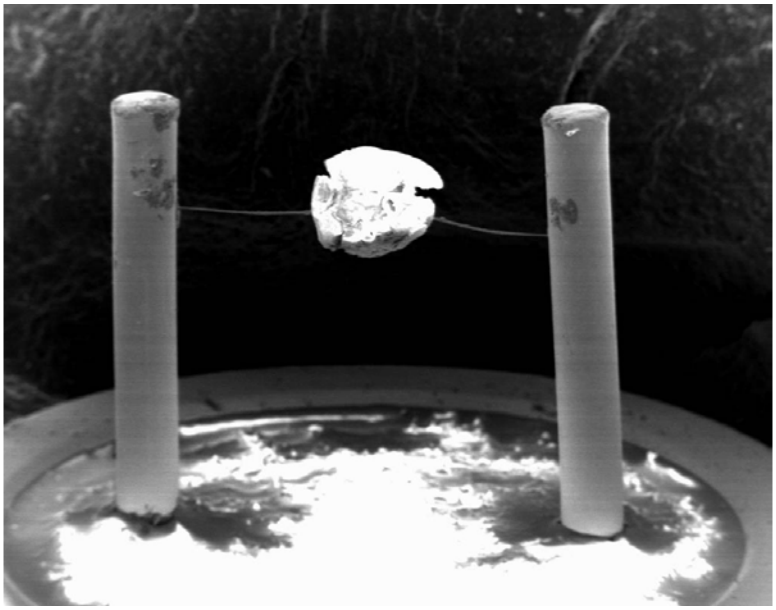
Figure 2 - Scanning Electron Microscope Photograph Of The Pellistor Bead

Principle of Operation

During operation, a voltage is applied between the support arms of the device to raise the temperature of the catalyst doped into the porous alumina bead above the "activation temperature" of any combustible gas that may be present in the surrounding environment. In the presence of such an inflammable gas, the precious metal catalyst supports combustion further raising the temperature of the doped porous alumina bead and consequently that of the platinum wire heating-coil. As the resistivity of metals increase linearly with temperature then any further increases in temperature due to catalytic combustion may then be measured as a change in resistance of the sensing device. Consequently, this change in resistance is then a measurement proportional to the concentration of the inflammable gas that is present.

In order to eliminate ambient temperature variations in the atmosphere being monitored, resistance changes are measured relative to a reference element within a Wheatstone bridge configuration. The reference element is usually an identical pellistor bead where the porous alumina bead has not been doped with a catalytic material. As such, this reference element will not support catalytic combustion when an inflammable gas is present in the atmosphere.

In many cases catalytic gas sensors need to be portable with their own power supply. Thus there is a demand for devices with minimal power consumption. Current researchers are investigating the manufacture of catalytic sensors by micromachining [1,4] and by design optimisation [2,3]. This paper, on the other hand, looks at the effect of the materials used to support these catalytic devices.

Procedure

A three-dimension model of the pellistor – using the dimensions listed above - was created using ANSYS finite element software. The model consisted of three distinct parts:

1. **The support arms:** The supports used to suspend the pellistor bead were modelled by generating two cylinders. (Figure 3).

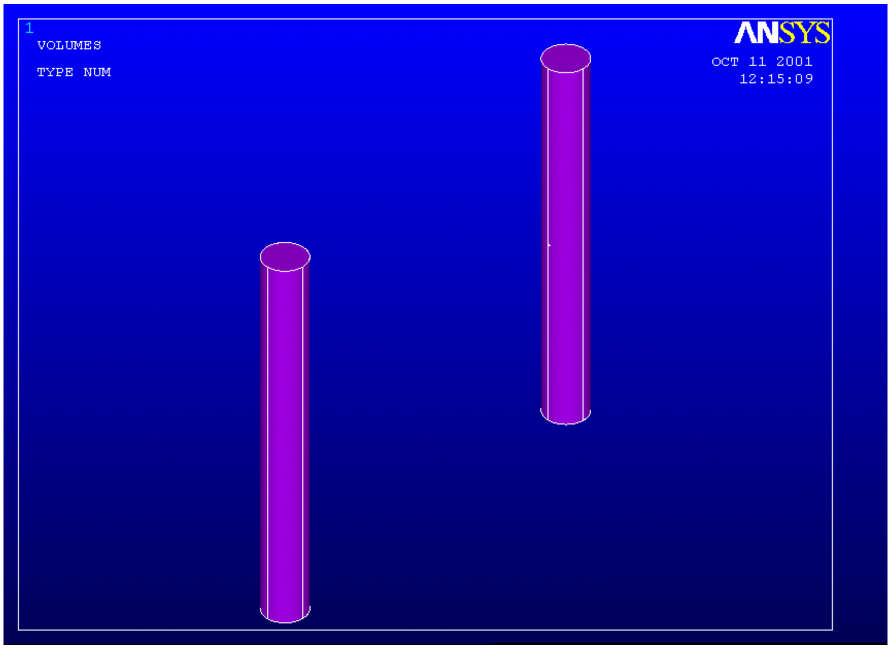

Figure 3 - The Metallic Support Arms For The Pellistor Bead

2. **The wire coil:** The heating coil was modelled by first generating fifty-six equally spaced central keypoints along its length. Afterwards, lines joining the adjacent keypoints together were defined. In the coiled region line fillets with a radius equal to that of the coil were generated. Next, all the resultant lines were added together. At one of the end points, a circle with a radius equal to that of the wire was introduced on a plane normal to that of the summed line. Finally, this circle was dragged along the newly created line to obtain the required three-dimensional volume (Figure 4).

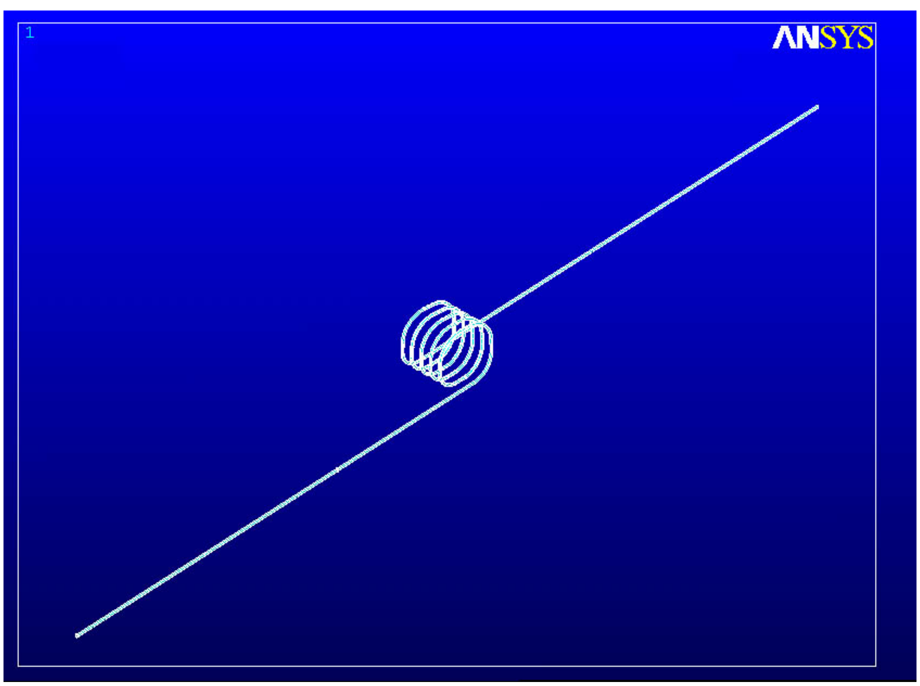

Figure 4 - The Platinum Heating Coil

3. **The catalytic bead:** The bead encapsulating the coil was modelled by simply generating a sphere (Figure 5)

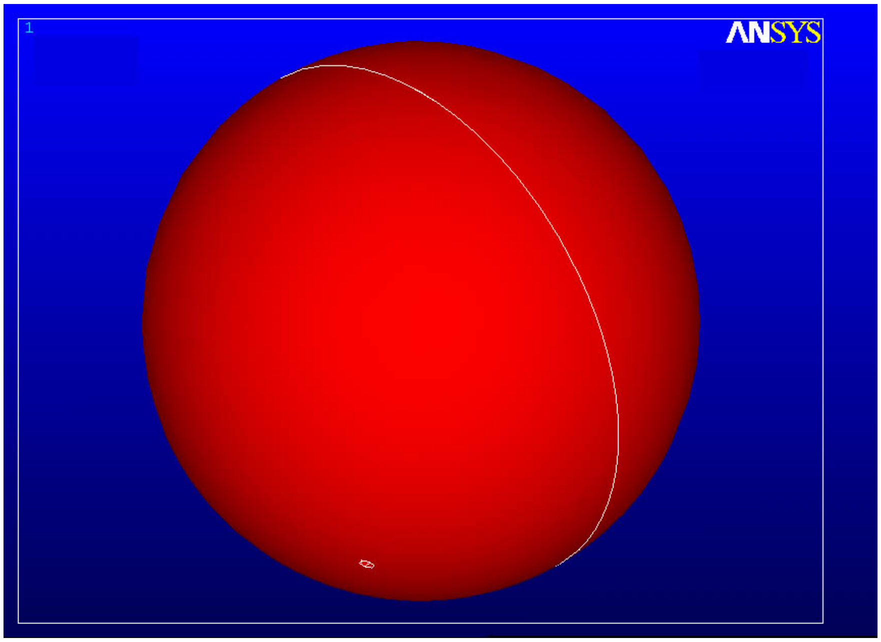

Figure 5 - The Porous Alumina Bead

The complete structure was then constructed by overlapping the four volumes defined above. The support arms and the regions where the wire intersected the arms were added to reproduce the "*original support arms*". The two lengths of wire at each end of the coil were added to the coil itself to produce the full platinum heating element and the bead now contained a hollow region that made full contact with the coil. (Figure 6).

As a three-dimensional model had been created the element SOLID69 (3D Thermal-Electric Solid) was chosen to mesh the support arms and the wire coil whilst the element SOLID70 (3D Thermal Solid) was chosen to mesh the bead. The following boundary conditions were applied: A voltage of **0V** was applied to the base of one of the support arms whilst a voltage between **0V** and **2V** was applied to the base of the other. Heat losses were assumed to be through natural convection over the surface area of the device and a convection coefficient of **30W/m^2** was assumed.

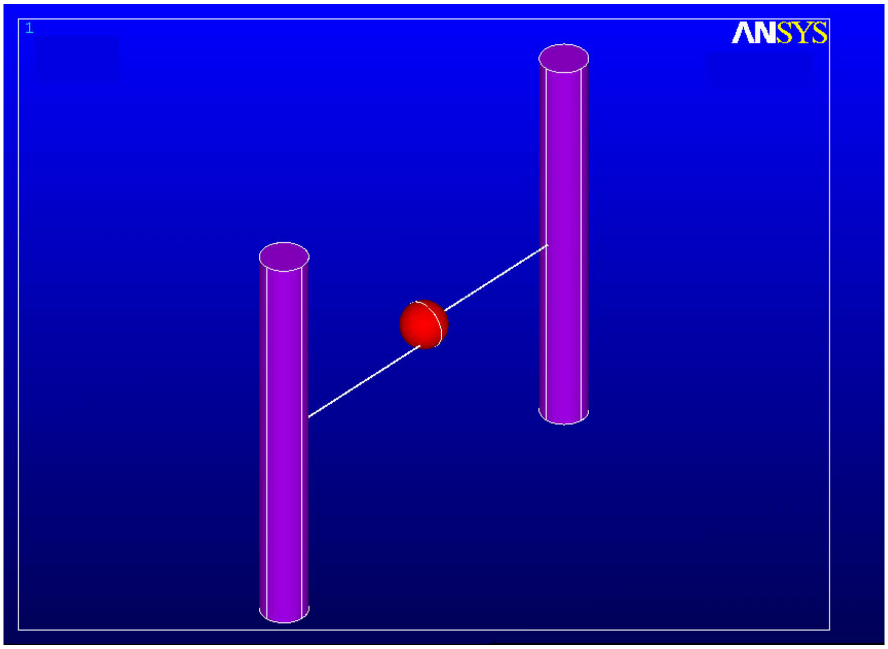

Figure 6 - The Complete Pellistor Generated in Three-dimensions

Analysis Results & Discussion

Comparison of Modelled Results to Actual Devices

Present commercial devices consist of a platinum wire coil heating element and a porous alumina sensing bead doped with a palladium catalyst. The support arms used to support the pellistor are composed of an Iron/Nickel alloy (*50% Iron by weight*). Figures 7 and 8 show the thermal and electrical properties as a function of temperature - as used by the model described above [5].

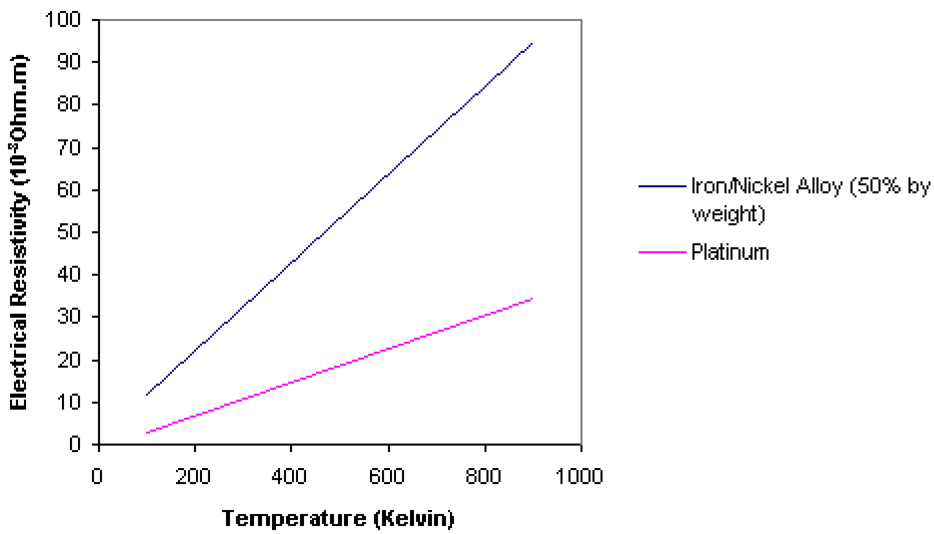

Figure 7 - Electrical Properties Of The Materials Used To Construct Commercial Pellistors

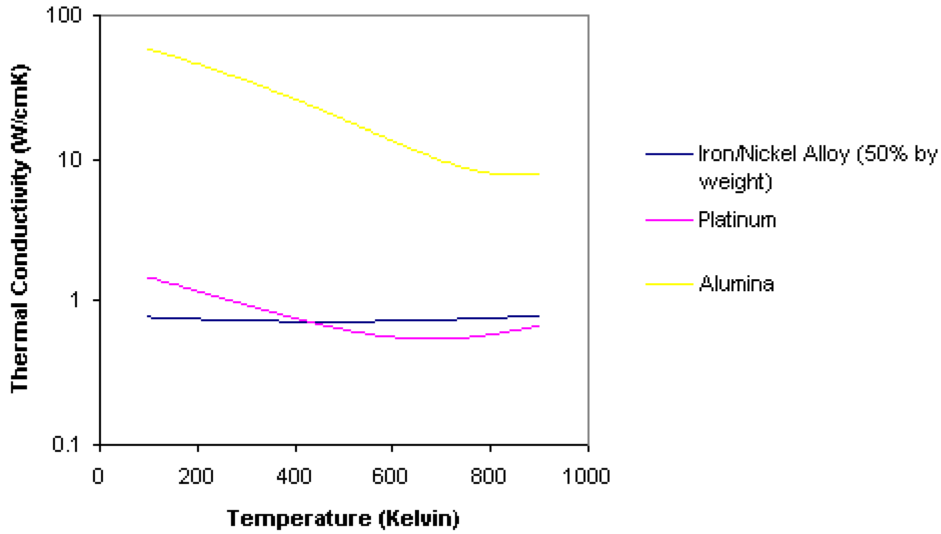

Figure 8 - Thermal Properties Of The Materials Used To Construct Commercial Pellistors

Using this finite element model, figure 9 show the average surface temperature of the bead versus the power applied to the pellistor. The average surface temperature was determined by calculating the mean temperature of the nodes on the surface of the bead. The current flowing through the device was found by summing all the current density vectors together and then dividing by the mean cross-sectional of the electrically conducting areas. The power supplied to the device is simply this current multiplied by the potential difference across the bases of the support arm. For comparison figure 9 also depicts the performance of a "real" device. A thermal profile generated by ANSYS is shown in figure 10.

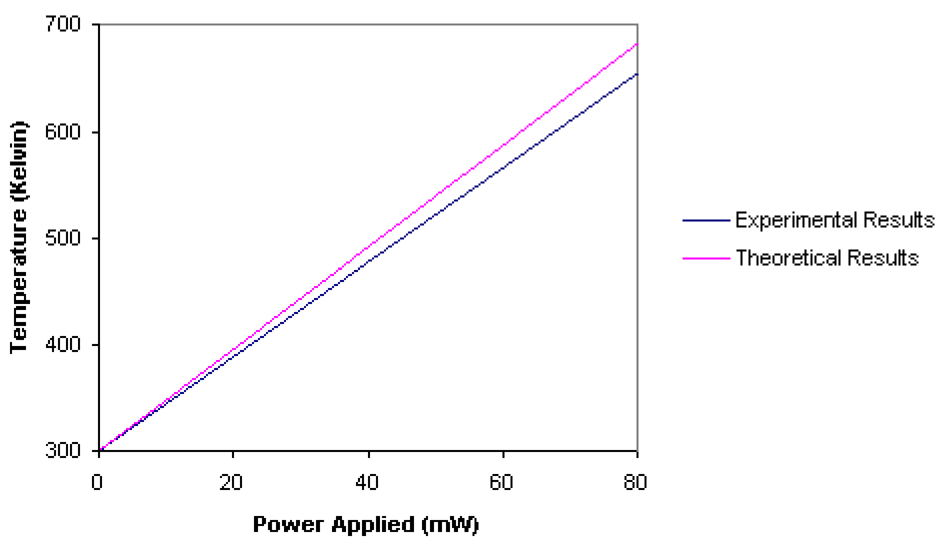

Figure 9 - Comparison Between Experimental and Modelled Results

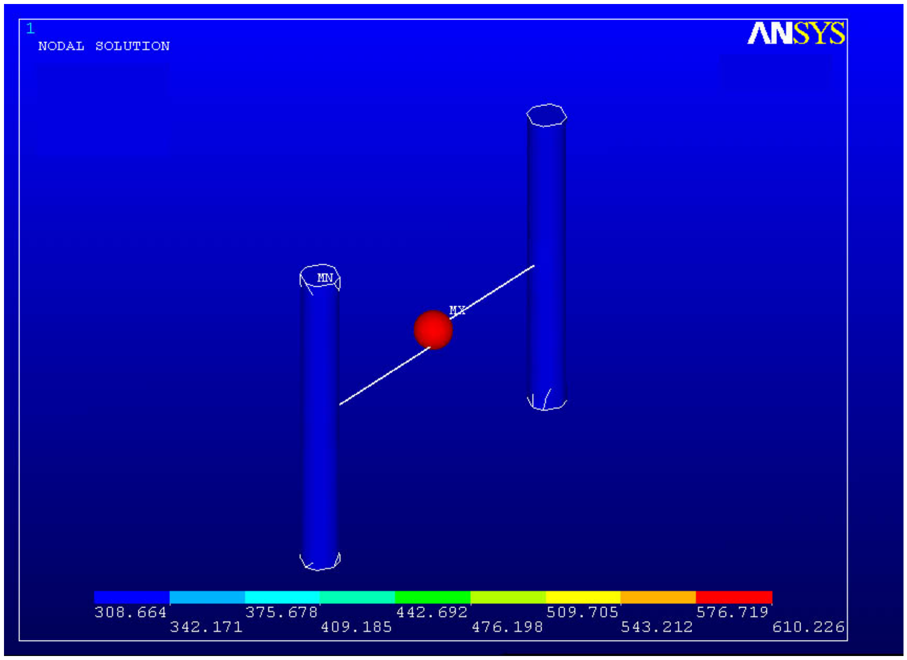

Figure 10 - The Thermal Profile Of A Pellistor Generated Using An Input Power Of 70mw (Temperatures Are In Kelvin)

Between the experimental and modelled data, an error of approximately 20% exists between the two sets of data. There are several reasons that may explain this discrepancy:

1. In the model, an assumption was made that the bead was perfectly spherical. In reality, the bead tends to be more oblong with a non-uniform surface (Figure 2). However since the exact bead profile varies form one device to the next this seemed a reasonable assumption to make.

2. Again, in the model a further assumption was made that the coil itself was perfectly circular with uniform spacing between adjacent turns. However, figure 1 shows that the spring profile tends to be "*compressed*" along one end. Again the exact profile tend to vary from one device to another so the "*simplified*" symmetrical model was used in the theoretical calculations.

3. The main source of heat loss from the finite element model was natural convection. In the real world Raleigh convection would also play an important part in this process. However, to model Raleigh convection would also require precise data on the surrounding environment and this would be difficult to define in real-life operating conditions. For this reason convection losses from the surface was omitted from the model. (In obtaining the experimental data the surrounding atmosphere was kept as stationary as possible to minimise this loss.)

4. The model takes no account of heat loss due to radiation. As radiation losses increase with the fourth power of the temperature, radiation losses would become more significant at high temperatures. However, even assuming the bead has a relative emisstivity of 1, then at 800K - and with the dimensions of the bead - this loss would only for 5% of the discrepancy at the most.

5. In real life the support arms would be mounted on ceramic pellistor "*header*". (A glass cylinder 10,000µm in diameter and 5,000µm thick). This would behave like a heat sink to any heat that was conducted from the bead, across the wires and through the support arms. The model attempted to accommodate for this conduction loss by applying boundary conditions to set the temperature of the nodes on the base of the pellistor equal to that of the surrounding atmosphere, 293K.

Comparison of Pellistors Characteristics With Respect to the Material Properties of the Support Arms

The model thus far has been solved using the material properties of an Iron/Nickel alloy (*50% Iron by weight*) to represent the support arms of the bead. An investigation was carried out to determine whether or not using other materials for the support arms of the device would have a significant effect on the performance of the gas sensor. The characteristics of the materials chosen to model are shown in Figures 11 and 12 [5].

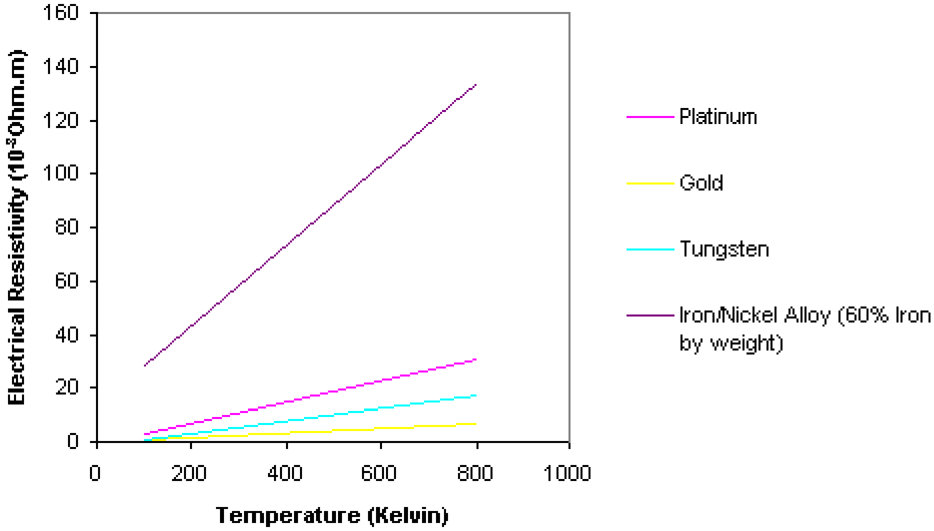

Figure 11 - Electric Properties Of Other Possible Support Arm Materials

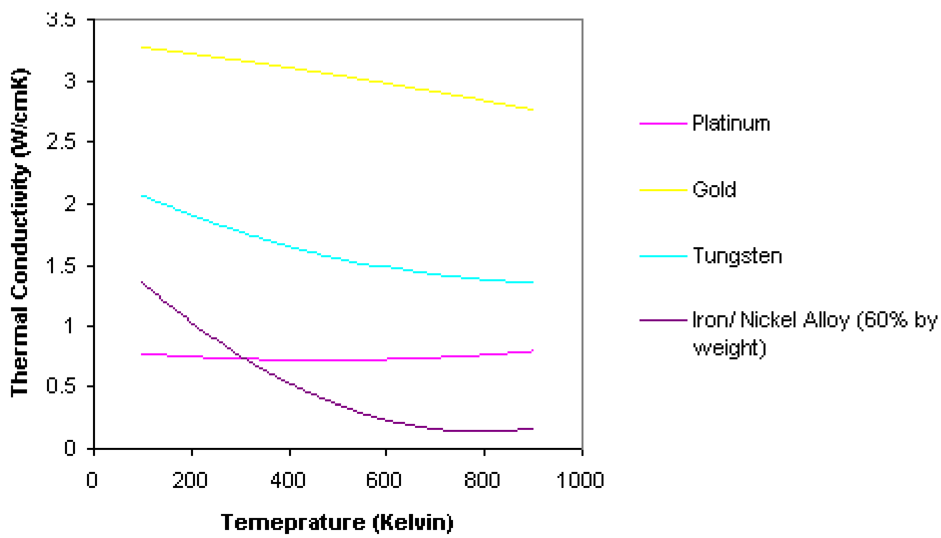

Figure 12 - Thermal Properties Of Other Possible Support Arm Materials

For these other materials, figure 13 shows the average temperature of the bead with these other materials subtract the average temperature of the bead with an Iron/Nickel alloy (*50% Iron by weight*) versus the applied power. Comparing the results in figure 13 to the material properties in figures 11 and 12 shows that in order to maximise the heating efficiency of the device it is necessary to minimise both the thermal conductivity and the electrical resistivity of the material of which the support arms are composed of. Even although this may be what one intuitively would expect, what is surprising is the power saving.

Switching from the Iron/Nickel alloy (*50% Iron by weight*) to platinum represents an increase in efficiency of almost 5% in efficiency. In a highly competitive market such a saving would be advantageous to any manufacturer.

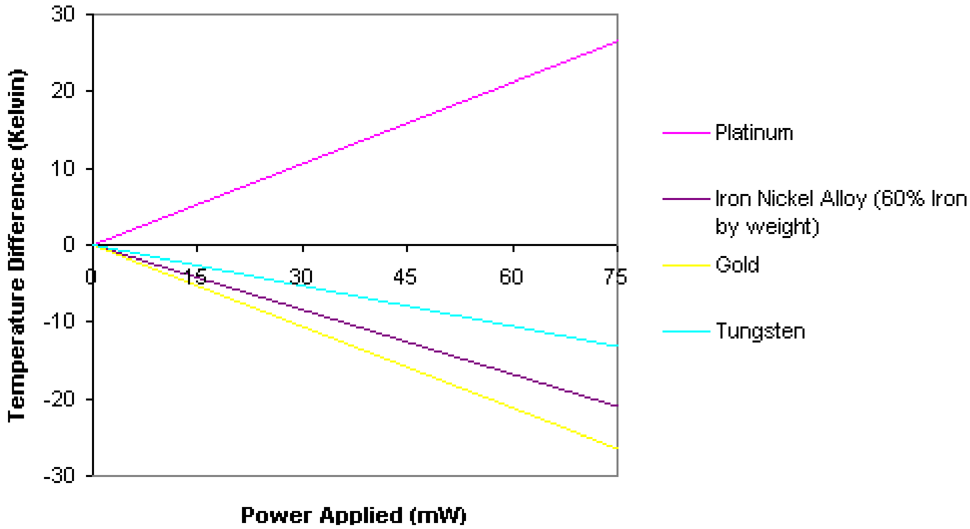

Figure 13 - Comparison Between The Operating Temperature For A Range Of Materials

Conclusion

The pellistor bead is used for the detection of combustible gases within an oxygen-based atmosphere. A platinum wire coil is encapsulated within a porous alumina bead that is consequently doped with a precious metal catalyst such as palladium or rhodium. This sensing device is suspended between two metallic support arms to ensure thermal isolation.

In this effort, a method was developed to model the thermal mechanisms of a pellistor bead. The analysis showed that the choice of material supporting the bead had a notable effect on the performance of the device. The power consumption of traditional devices, which are constructed using an Iron/Nickel alloy (*50% Iron by weight*), may be reduced by as much as 5% by constructing these arms from platinum instead.

As well as offering a saving in terms of the battery lifetime and/or the mass of a portable unit, this *effective* thermal mass reduction could also be used towards implementing pellistor beads within neural networks for individual concentration measurements within multiple gas environments. Alternatively, it may also be used towards a temperature modulated pellistor bead that can eliminate errors caused by transient temperature changes of the environment by implementation of a phase locked loop.

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