DESIGN AND ANALYSIS OF TO-8 AND TO-16 POLYETHERETHERKETONE PACKAGES FOR GAS SENSORS

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Abstract— With the advent of MEMS technology, solid state sensors have become more and more common in sensor modules used to detect various gases. Two simple conventional packages (headers) for gas sensors are the TO-8 and TO-16 packages. Due to their miniature size the dimensions become difficult to manufacture which in turn raises the cost of fabrication of these package headers increasing cost of the gas sensor component as a whole. Presently, Nickel is used as the packaging material for most gas sensors. To substitute Nickel as the packaging material, alternate materials and their respective performances were inspected. Certain aspects that play a role in the selection of packaging material of the sensor are; temperature resistance, vibration, natural frequency, ultraviolet ray resistance, overall strength (during fabrication), corrosion (application dependent gases) as well as cost. On the basis of material properties and performance analysis, Polyetheretherketone (PEEK) was found suitable for the aforementioned requirements for a wide range of applications.

Keywords— Composite Plastic, Finite Element Simulation, Gas Sensor, Packaging Material, Polyetheretherketone.

I. INTRODUCTION

The TO-8 and TO-16 gas sensors are manufactured by various methods of fabrication which involve several mechanical loads such as impact loads, shear loads, bending loads as well as the endurance limit and for this reason, certain mechanical properties must be incorporated into the packaging material to withstand the mentioned loads. Varying temperatures affect the sensor outputs and gas sensors may be subjected to extreme temperature conditions ranging over hundred degrees above and below ambient temperature. To overcome these difficulties, the sensor packaging material should be able to operate over the same span of temperature. When the sensor is placed in contact with a hot sample gas such as from the exhaust of a fuel based system, it is subjected to corrosion which will not only result in erroneous readings but also damage the packaging and eventually, the sensor. To avoid such conditions, the material chosen should be resistant to corrosion by hot gases. In addition to being exposed to these types of gases, the sensor is often subjected to vibrations during use. To ensure that the sensor is not severely affected by these vibrations, the natural vibration frequency of the sensor geometry should be greater than the excitation frequency that it is subjected to. Generally, plastics decay with exposed to ultra violet (UV) rays, which can compromise the material's performance. Thus, the material chosen must be resistant to the ill effects of UV radiation. Nickel is predominantly used as sensor packaging material and performs adequately under the aforementioned conditions but the fabrication cost of this sensor is very high. To reduce cost, plastics have been used to replace the traditional metal packaging but do not perform at higher temperatures. Hence, to economically replace the packaging material and simultaneously meet performance requirements Carbon Reinforced Polyetheretherketone serves as a viable alternative. To affirm this claim, finite element simulations were conducted and the results were evaluated.

II. SELECTION OF MATERIAL

Certain aspects in the packaging material designare temperature resistance, vibration response, natural frequency of the material, ultraviolet ray resistance, overall strength (during fabrication), corrosion (application dependent gases) as well as cost. When alternate metals are looked into, the cost of fabrication using these materials was found to be high, more or less at par with Nickel. It also involved various processes [1] like drop coating and annealing. Coatings of silicon are required too for improved temperature distribution and the power consumed in the fabrication of these materials is high. Ceramics, though being temperature and corrosion resistant, are brittle and have low impact strength and hence cannot be manufactured to the sensor dimensions with the existing fabrication techniques. Plastics like High Density Polyethylene (HDPE), though economical, cannot be used due to its low temperature resistance. Asbestos satisfies all the desired properties but is poses a major health hazard as it is a known carcinogen [2].

Polyetheretherketone (PEEK) [4], has enhanced properties like excellent UV resistance, sufficient strength, resistant to humidity [5], resistant to oxidation and a wide range of operating temperature (-123^{o}C to 199^{o}C). It is also possible to compound formulations based on PEEK and the incorporation of carbon fibers is now a well-established method for preparing injection molding materials. These compounds are generally referred to as micro-composites. We find that Carbon Reinforced Polyetheretherketone (CRPEEK) [3] caters to the

requirements of the sensor packaging material all while being economical and safe.
Chemical composition: **(O-(C6H4)-O-(C6H4)-C (O)-(C6H4))n**

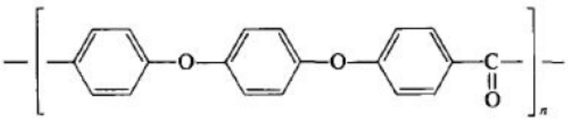


Figure 1: Molecular Structure of PEEK

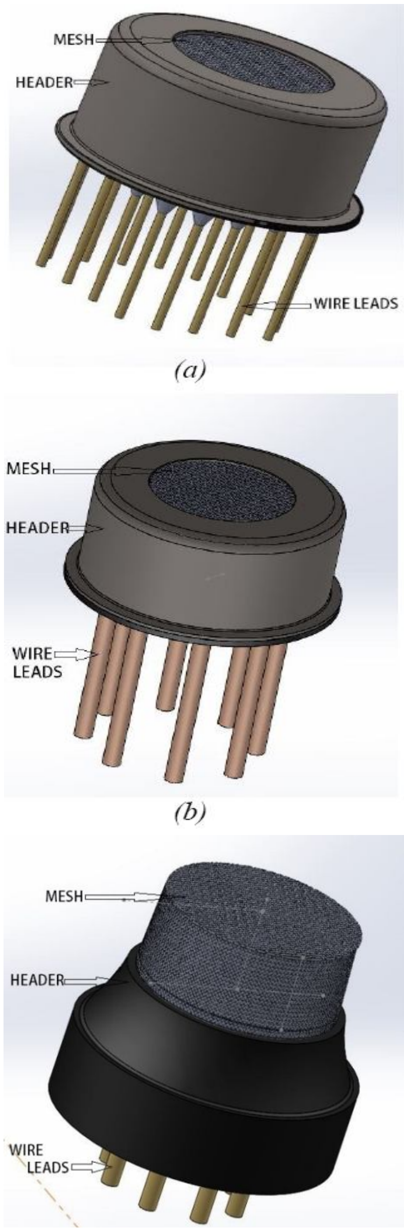
PEEK is an aromatic polymer with glass transition temperature approximately 142^{o}C and 199^{o}C when reinforced with carbon and with a melting point of 346°C. This implies a high temperature performance in the range of 370° to 400°C. PEEK being thermoplastic in nature can be converted into a range of component shapes and sizes by the full spectrum of fabrication technologies (extrusion, injection molding, etc.). PEEK, as a thermoplastic, undergoes the widest conceivable range of processing methods to produce engineering components and as a composite material, provides the widest mechanical property spectrum with modulus in the range 3-150 GNm^{-2} and strength in the range 100-2000 MNm^{-2} at ambient temperature. [6]
Application specific requirements are imposed on the properties which dictate the compositional form for PEEK, e.g. unreinforced, biaxial film or short fibre reinforced micro-composite which in turn decides the fabrication method as well as the cost. The remainder of the paper shows the design and analysis of the sensor in varying physical parameters. Table 1. shows theproperties of PEEK.

Table 1: Mechanical and Thermal Properties of PEEK [7]

PROPERTY	VALUE	UNIT
Young's Modulus	3.95	GPa
Tensile Strength	103	MPa
Compression Strength	130	MPa
Endurance Limit	41.2	MPa
Bulk Modulus	5.749	GPa
Fracture Toughness	4.296	MPa.m$^{1/2}$
Hardness	285	MPa
Modulus of Rupture	116	MPa
Shear Modulus	1.425	GPa
Poisson Ratio	0.3779	-
Ductility	1.5	-
Melting Temperature	619	K
Specific Heat Capacity	1501	J/kgK
Maximum Service Temperature	533	K
Minimum Service Temperature	150	K
Glass Transition Temperature	472	K
Thermal Conductivity	0.26	W/m.K
Thermal Expansion	72	10^{-6}/K

III. MECHANICAL DESIGN

To make sure the design can be used widely we maintained the dimensions of the currently existing standard TO-8 and TO-16 sensors to ensure uniformity and avoid changes. A tolerance of 0.05mm was given to the sensor dimensions on the positive and negative scale. To ensure the plastic had the aforementioned mechanical properties, minimum thickness of 1mm was maintained throughout the sensor. The tapered support between the wire leads and the sensing cap was filled with epoxy. Since PEEK has good chemical resistance, epoxy does not corrode or damage the packaging material. Wire leads for both TO-8 and TO-16 sensor are made up of Cobalt and are connected to the sensing unit PCB. The sensor filter which filters out the gas entering the sensor is made up of two materials. The filter membrane is made up of Polytetrafluoroethylene (PTFE) and the filter substrate is made up of Polyethylene Terephthalate (PET).



(c)

Figure 2: a) TO-16 PEEK Packaged Sensor b) TO-8 PEEK Packaged Sensor c) TO-8 PEEK Packaged (omnidirectional) Sensor

IV. MECHANICAL ANALYSIS

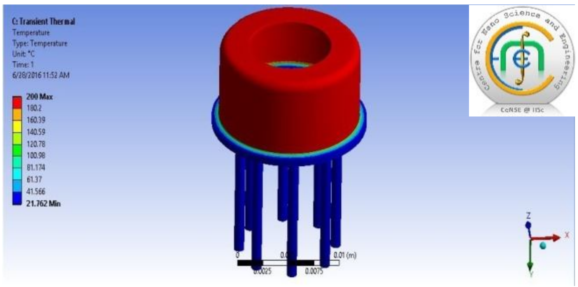


Figure 3: Thermal Analysis of TO-8 PEEK Packaged Sensor

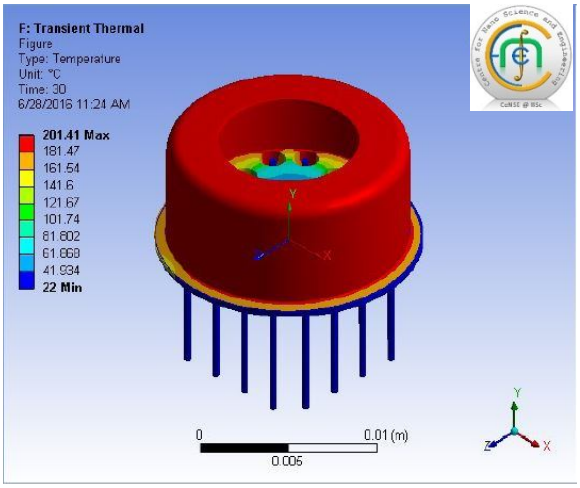


Figure 4: Thermal Analysis of TO-16 PEEK Packaged Sensor

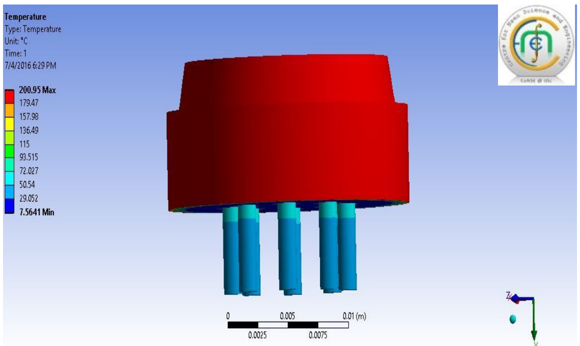


Figure 5: Thermal Analysis of TO-16 PEEK Packaged Sensor (Omnidirectional)

On conducting a transient thermal analysis on the proposed TO-8 and TO-16 packaging material, it can be see that even though the sensor cap is maintained at 200 degrees Celsius, only a fraction of the heat reaches the leads of the sensor.

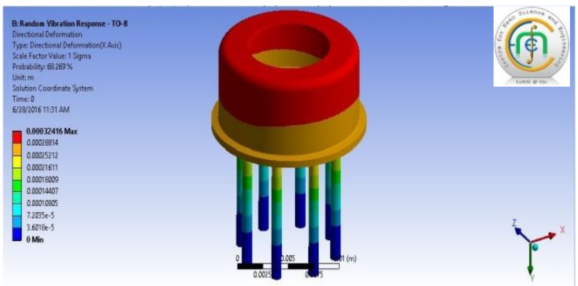


Figure 6: Vibration Deformation for TO-8 PEEK Packaged Sensor

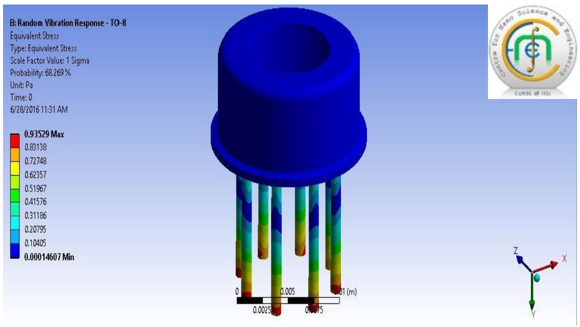


Figure 7: Equivalent stress in TO-8 PEEK Packaged Sensor

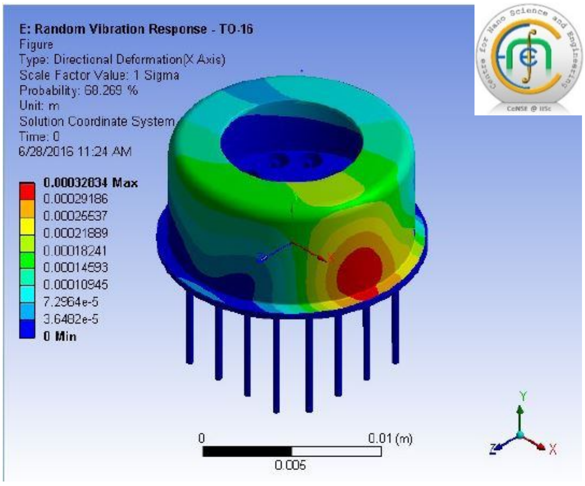


Figure 8: Vibration Deformation for TO-16 PEEK Packaged Sensor

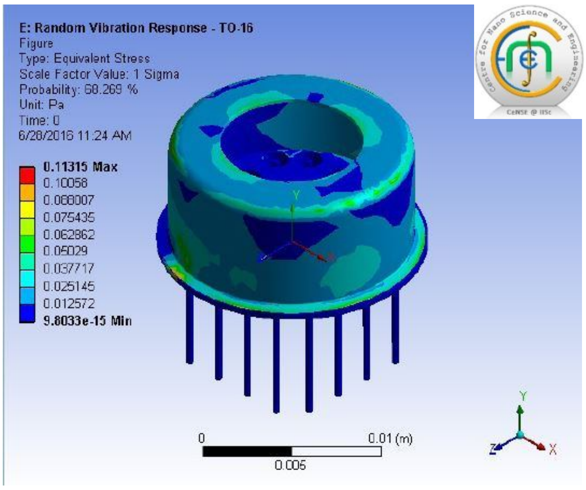


Figure 9: Equivalent stress in TO-16 PEEK Packaged Sensor

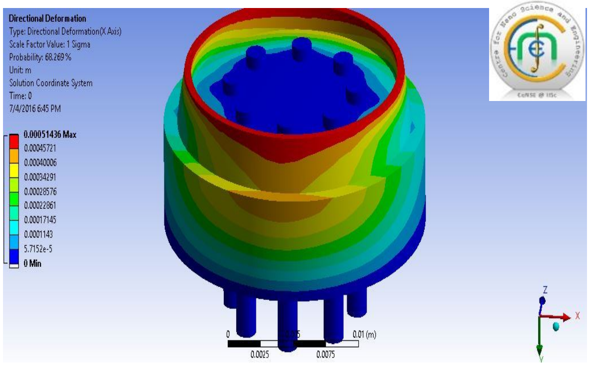


Figure 10: Random Vibration Deformation for TO-8 PEEK Packaged Sensor (Omnidirectional)

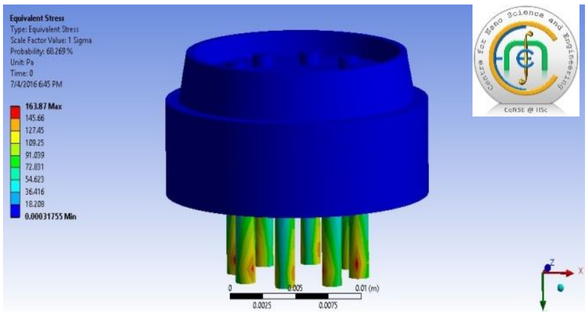


Figure 11: Equivalent stress in TO-8 PEEK Packaged Sensor (Omnidirectional)

On conducting a random vibration analysis along the z-axis and the x-axis from a frequency of 16Hz to 22Hz with an acceleration of 2m/s2, it can be seen that for the TO-8 and TO-16 sensor the maximum displacement is approximately 0.3mm and for TO-8 omnidirectional flow sensor it is 0.5mm. The frequency range and the acceleration was decided upon the vibration of the exhaust pipe of an automobile while using a damper [8], which was generally found to be around 18Hz with an acceleration of 2m/s2. The ends of the leads and the base of the cap were selected as the fixed supports. The deformation is graphically visible in Fig.6, Fig.7, and Fig.8. On conducting the equivalent stress analysis, it can be seen that maximum stress is on the ends of the leads which are generally connected to the PCB. The stress was found to be 0.11315 N/m2 in TO-16 PEEK packaged unidirectional flow sensor, 0.93529 N/m^2in TO-8 PEEK packaged unidirectional flow sensor and 163.187 N/m^2in omnidirectional TO-8 PEEK packaged sensor. TO-16 omnidirectional flow PEEK packaged sensor cannot be used as the dimensions become very large while maintaining its required strength.

V. COMPARISON OF SENSOR DESIGNS

Table 3. Comparison between unidirectional PEEK packaged sensor, omnidirectional PEEK packaged sensor and currently used Nickel packaged sensor

Parameter	New sensor design- one directional flow	New sensor design- Omnidirectional flow	Currently used sensor
Material	PEEK	PEEK	Nickel
Deformation (due to vibration)	0.3 mm	0.5mm	0.26 mm
Equivalent stress	Approx. 0.95 N/m^2	Approx. 163 N/m^2	Approx. 1.29 N/m^2
Cost	Low	Low	High
Thermal response	Does not conduct heat to wire leads	Does not conduct heat to wire leads	Conducts heat to wire leads

VI. RESULTS AND CONCLUSION

For a sensor to perform within a range of error, the ambient conditions must be controlled to ensure there is no damage to the sensor as well as the packaging material. The results from the various analysis were evaluated against the tolerable conditions and conclusions were drawn.

For the Thermal Analysis of the TO-8 and TO-16 sensor shown in Fig. 3, Fig. 4 and Fig.5, we can see that the low value of thermal conductivity of PEEK is beneficial due to the fact that it thermally insulates the Nickel leads from any rise in temperature. This result is promising as it results in an accurate output from the sensor.

For the vibration analysis of the TO-8 and TO-16 sensor it can be observed from Figs. 6, 8, and 10that the maximum displacement for both the sensors is approximately 0.3-0.5 mm or 300-500 μm. This maximum displacement is minute in comparison to the dimensions of the sensor, which established that the sensor performs well under random vibrations like the ones seen on the tailpipe of automobiles. From the stress analysis we can determine where the welds or the solder needs to be reinforced to ensure safe operation of the sensor. TO-16 omnidirectional flow PEEK packaged sensor cannot be used as the dimensions become very large while maintaining its required strength. Hence, we use the appropriate sensor design according to application involved.

REFERENCES

[1] D Brianda, A Kraussb, B van der Schoota, U Weimarb, N Barsanb, W Göpelb, N.F de Rooija, *Design and fabrication of high-temperature micro-hotplates for drop-coated gas sensors*, Institute of Micro Technology.

[2] A.M. PYE, "*A review of asbestos substitute materials in industrial application*", September 28 1978, Fulmer Research Institute, Stoke Pages (Gt. Britain).

[3] Frederic Neil Cogswell, *Thermoplastic Aromatic Polymer Composites*, 1992, Butterworth-Heinmann Ltd.

[4] J. Blumm, A. Lindemann, A. Schopper, "*Influence of the CNT content on the thermophysical properties of PEEK-CNT composites*", Proceedings of The 29th Japan Symposium on Thermophysical Properties, October 8–10, 2008, Tokyo.

[5] R. Selzer and K. Friedrich, 29February 1996; revised 12 November 1996, *Mechanical properties and failure behaviour of carbon fibre-reinforced polymer composites under the influence of moisture*, Institute for Composite Materials Ltd, University of Kaiserslautern, Germany.

[6] D.P. Jones, D.C. Leach and D.R. Moore, 1985, *Mechanical properties of poly(ether-ether-ketone) for engineering applications*, Imperial Chemical Industries plc, Petrochemicals and Plastics Division, PO Box 90, Wilton, Middlesbrough, Cleveland, TS6 & JE, UK.

[7] "*Mechanical and Thermal Properties of PEEK*". Retrieved from http://www.azom.com/properties.aspx?ArticleID=1882 and http://www.goodfellow.com/E/Polyetheretherketone.html?referrer=AZOMDOTCOM&id=1656.

[8] "*Optimal Automobile Muffler Vibration and Noise Analysis*" Sujit Kumar Jha (Engineering Department, Ibra College Technology, Sultanate of Oman) and Ajay Sharma (Department of Mechanical and Automation Engineering, ASET, Amity University, Noida, India)

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