# Thermal Response Analysis of a Low Thermal Drift Three-axis Accelerometer for High Temperature Environments

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**Abstract:** In this paper, thermal response analysis of a temperature controlled three-axis accelerometer for high temperature environments with integrated micro-heaters and temperature sensors is investigated with finite element method (FEM) program, ANSYS and infrared thermal measurement systems. And availability to application fields from a viewpoint about short thermal response time is discussed. In this paper, the time of three-axis accelerometer for high temperatures becoming 300°C by integrated micro-heaters and temperature sensors to reduce thermal drift characteristics was analyzed as a thermal response time of this device. The simulated thermal response time (time until SOI piezoresistors actually becomes 300°C) of three-axis accelerometer for high temperatures with ANSYS is about 0.6s, and measured result with infrared temperature measurement systems is about 0.64s. Experimental results using infrared thermal measurement systems agreed well with these theoretical results.
**Keywords:** Thermal Response, FEM, Constant temperature control, SOI, Accelerometer

## 1 INTRODUCTION

Various types of silicon micromachined sensors for high temperature environments using micro electro mechanical systems (MEMS) technology and silicon on insulator (SOI) technology are realized, and the operating characteristics under high temperature environments (300°C or more) are reported [1-3]. Applying SOI technology to a working sensor under high temperature environments is one of means to raise environment-proof of the sensors [4].

Recently, research in that feature a portable size combined with very high sensitivity, low thermal drift and short response times is increasing. Especially, when these sensors are actually applied to application fields where atmospheric temperature is varied suddenly such as aerospace, it is considered that characteristic for thermal response time is most important in the other thermal characteristics. We have investigated silicon micromachined three-axis accelero meters for high temperature environments with very low thermal drift over R.T. to 300°C [5-7]. In order to stabilize the characteristics of a three-axis accelerometer over a wide temperature range, the constant temperature control was performed to SOI piezoresistors on the accelerometer using integrated micro-heaters and temperature sensors with the SOI layer [5]. By constant temperature control, the sensing parts of three-axis accelerometer can be kept at a constant operation temperature (the maximum of operation temperature is 300°C).

In this paper, thermal response time of the fabricated temperature controlled three-axis accelerometer for high temperatures with integrated microheaters and temperature sensors is analyzed using finite element method (FEM) program, ANSYS and infrared thermal measurement systems. The finite-element model has five layer (Aluminum /$SiO_2$/ Silicon/$SiO_2$/Silicon) structures so that it may become the same structure with the actual accelerometer device. The validity of finite-element modeling is confirmed by infrared temperature measurement systems in temperature range of R.T to 300°C with resolution time of 45ms. The results of finite-element modeling agreed well with the experimental results using infrared temperature measurement systems.

## 2 FEA MODELING FOR THERMAL RESPONSE ANALYSIS OF THREE-AXIS ACCELEROMETER

The three-axis accelerometer for high temperatures has been reported as shown in Figure 1 [5]. It has a center support and surrounding mass structure [8],[9]. Four folded beams are formed between the center support and the surrounding mass [10]. The SOI piezoresistors to detect acceleration is formed at the edges and center connection points of the beams. The four piezoresistors on one folded beam are connected to form a wheatstone bridge. The piezoresistors are enclosed with the integrated micro-heaters. The whole resistance of four wheatstone bridges is used as the temperature sensor, because it is insensitive to acceleration input while it is proportional to temperature. The die size of the accelerometer is 6.5mm × 6.5mm. The length of each beam structure is 2mm, the width is 50μm, and the thickness is 15μm.

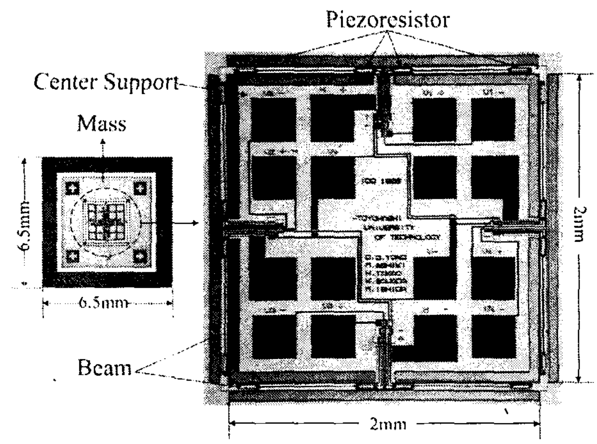


Figure 1. Photograph of the fabricated three-axis accelero- meter for high temperature environments with temperature control elements [5].

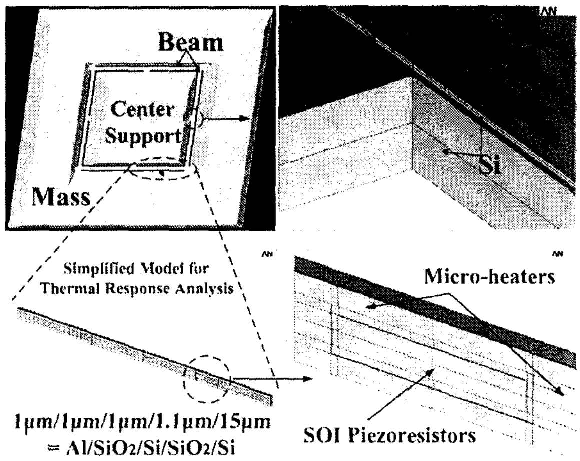


Figure 2. FEA model for thermal response analysis of three-axis accelerometer for high temperatures (Five layer structure).

In this paper, we considered a multi-layered beam structure shown in Figure 2 so that it may become the same structure with the actual accelerometer device. The FEA model for thermal response analysis is simplified as shown Figure 2. The length of simplified beam structure 1mm, the width is 50μm, and the thickness is 15μm. The model includes convection heat transfer coefficient to be used as an input for□the boundary conditions of the entire device. Table 1 lists the material properties corresponding to each material and the thickness of each layer. When the thermal response analysis is performed, the steady state and transient analysis are necessary because sometimes thermal distribution of device changes rapidly, in other cases it changes slowly or not at all. The simulated thermal response time with ANSYS is shown in Figure 3. From the results of FEM simulation as shown in Figure 3, when atmospheric temperature is 26°C and temperature of SOI piezoresistors become 300°C, the thermal response time (time until SOI piezoresistors actually becomes 300°C) is about 0.6s. The thermal response time is average value of each node on SOI piezoresistors in FEA model. In additional, the cause of increased offset voltage about the previous fabricated device [5],[6] is considered that the generated different thermal distribution to SOI piezoresistors due to different thermal radiation of connected beam portion to device.

Table 1. Material properties and thickness of beam structure

| Properties | Al | Silicon (Bulk) | $SiO_2$ |
|---|---|---|---|
| Young's modulus (GPa) | 69 | 162 | 70 |
| Poisson's ratio | 0.29 | 0.29 | 0.29 |
| Density (kg/m$^3$) | 2692 | 2660 | 2328 |
| Thermal Expansion Coefficient (ppm /°C) | 25 | 2.6 | 0.4 |
| Thermal Conductivity (w/m·°C) | 237 | 149 | 1.4 |
| Specific Heat (J/kg·°C) | 896 | 712 | 920 |
| Thickness (μm) | 1 | 1 (15) | 1.1 |

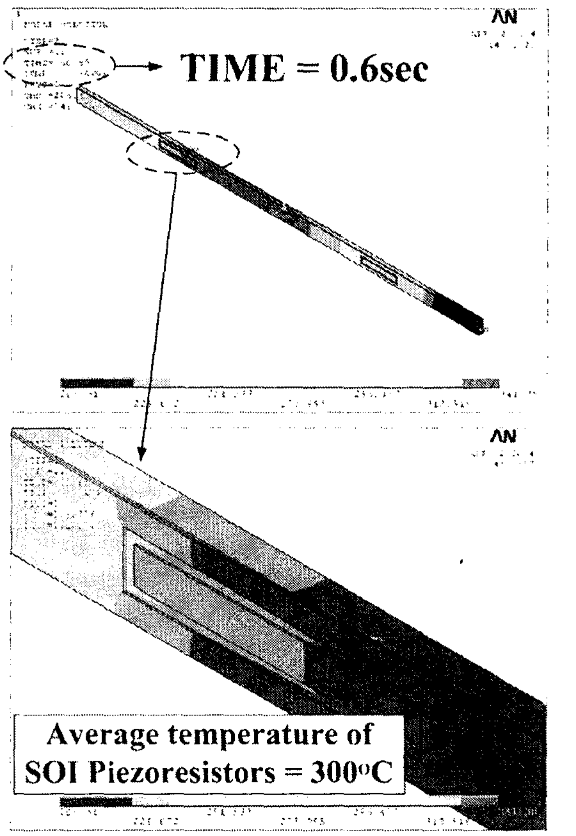


Figure 3. Thermal response time and thermal distribution of simplified model for thermal response analysis with ANSYS.

## 3 ANALYSIS OF THERMAL RESPONSE TIME USING INFRARED THERMAL MEASURE- MENT SYSTEMS

Infrared thermal measurement is a method or technique by providing a comprehensive two dimensional thermal map. The infrared camera captures part of the radiated energy. Temperature resolution of used infrared thermal measurement systems can be as fine as 0.1°C. Spatial resolution, the ability to measure temperatures on small areas, can be as fine as 80μm. The validity of finite-element modeling is confirmed by infrared temperature measurement systems in temperature range of R.T to 300°C with resolution time of 45ms. When atmospheric temperature was room temperature, thermal response time (time until SOI piezoresistors actually becomes 300°C) was measured with infrared temperature measurement systems in temperature range of R.T to 300°C. Figure 4 shows the measured thermal distribution with infrared temperature measurement systems. Figure 4(a) shows the thermal distribution of device without power supply to integrated micro-heaters, and Figure 4(b) shows it with power supply to integrated micro-heaters. The amount of radiated energy depends on relative efficiency of thermal radiation in the device structures. As shown in Figure 4(b), the thermal radiation of mass side is larger so that it may understand from simulated results using FEM simulation. From this result, it is also confirmed that the cause of increased offset voltage about the previous fabricated device is the different thermal distribution of each SOI piezoresistors.

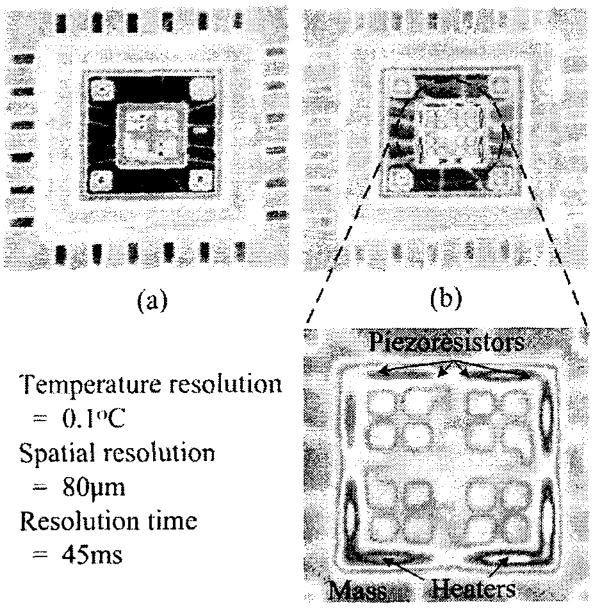


Figure 4. Measured thermal distribution of device using infrared thermal measurement systems: it is measured without power supply (a), and with power supply (b) to integrated micro-heaters.

Figure 5 shows the comparison results of simulated and measured thermal rises. As shown in Figure 5, the measured thermal response time (time until SOI piezoresistors actually becomes 300°C) of three-axis accelerometer for high temperatures is about 0.64s. The results of finite-element modeling agreed well with the experimental results using infrared temperature measurement systems. It is considered that the measured 0.64s response time is sufficient to use this device in application fields where atmospheric temperature is varied suddenly such as aerospace.

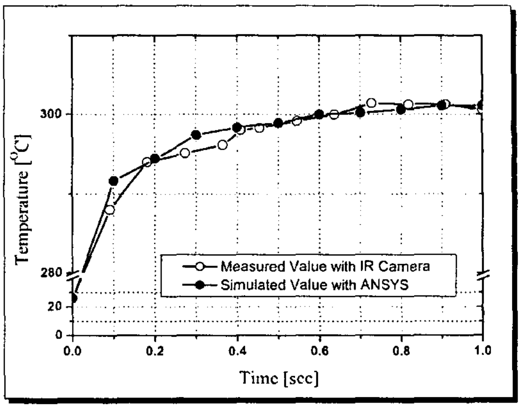


Figure 5. Measured and simulated transient thermal rises. Simulated results by finite-element modeling agreed well with the experimental results using infrared temperature measurement systems.

## 4 CONCLUSIONS

In this paper, the thermal response time (time until SOI piezoresistors actually becomes 300°C) of the constant temperature control type three-axis accelerometer for high temperature are analyzed to ensure availability to application fields from a viewpoint about short thermal response. The simulated thermal response time of three-axis accelerometer for high temperatures with FEM simulation, ANSYS is about 0.6s, and measured result with infrared temperature measurement systems is about 0.64s. This thermal response time is measured using power supply that temperature of SOI piezoresistors becomes 300°C without constant temperature control system. It is considered that the thermal response time becomes short than 0.64s if the constant temperature control system is performed to device with more power supply to integrated micro-heaters. It is considered that the measured response time is sufficient to use the temperature controlled three-axis accelerometer for high temperatures in application fields where atmospheric temperature is varied suddenly such as aerospace. If the FEA model is used to design device for high temperatures, it is possible to realize advanced micromachined device with consideration about relative efficiency of thermal radiation in the device structures.


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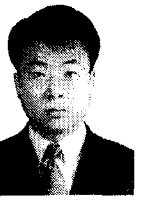

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