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Thermal-stress modeling of an optical microphone at high temperature

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Abstract

To help determine the capability range of a MEMS optical microphone design in harsh conditions computer simulations were carried out. Thermal stress modeling was performed up to temperatures of 1000 °C. Particular concern was over stress and strain profiles due to the coefficient of thermal expansion mismatch between the polysilicon device and alumina packaging. Preliminary results with simplified models indicate acceptable levels of deformation within the device.

ACKNOWLEDGMENTS

Thanks are due to Murat Okandan for supplying the initial microphone designs, as well as his discussion about there parameters and modes of operation. Also, many thanks go out to Mike Baker for his instructions on how best to approach the modeling of the microphone in ANSYS. No doubt it would have proved even more difficult an interface than it already was without his advice.

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FIGURES

NOMENCLATURE

MEMS	Micro electromechanical system
°C	Degrees Celsius
um	Micron
CTE	Coefficient of thermal expansion
Pa	Pascal
MPa	Megapascal
GPa	Gigapascal
DOE	Department of Energy
SNL	Sandia National Laboratories

1. INTRODUCTION

In order to determine the envelope of conditions in which a device can reasonably perform it is first necessary to ensure the device itself will not be physically damaged in such a way that renders it inoperable. In this case we discuss the reaction of a MEMS optical microphone, designated as RS646, to high temperatures. Simulations were to be performed up to at least 1000°C, a temperature deemed high enough to encapsulate future performance parameters at this time.

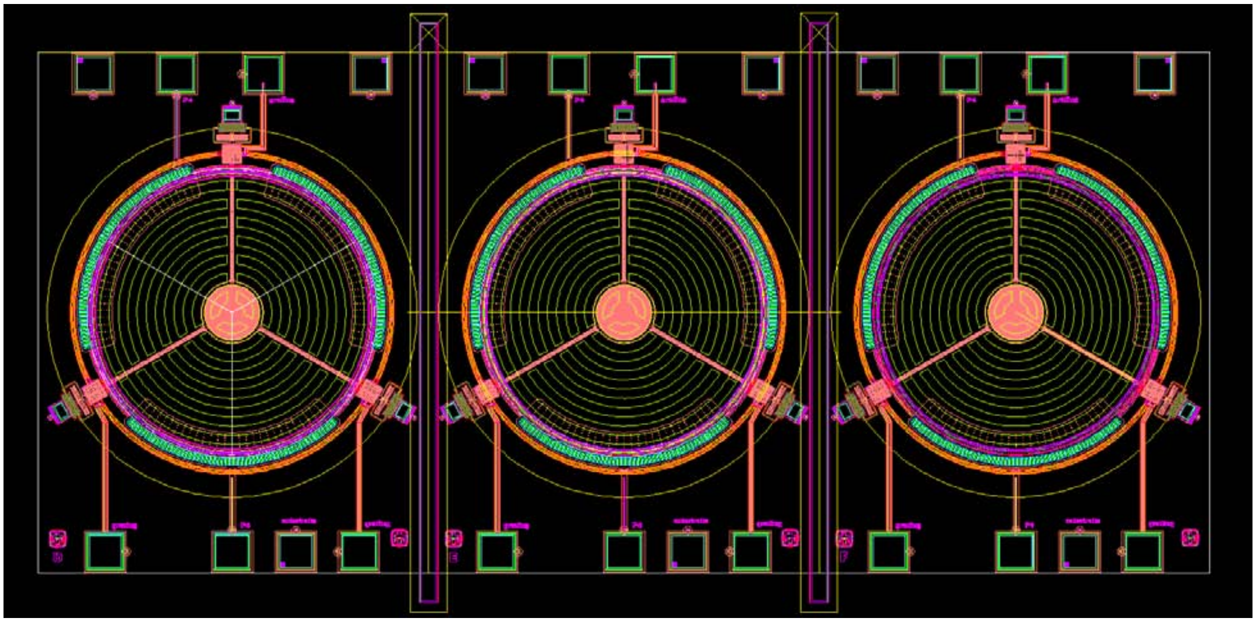

Figure 1. AutoCAD diagram of three of the RS646 MEMS optical microphones.

There were several areas of concern that might lead to unacceptable stresses, strains, deformations or other failures of the device. First, the expansion of the primarily polysilicon design itself could deform in unforeseen ways. Although the coefficient of thermal expansion (CTE) was the same throughout, the geometry might cause troublesome at temperatures this high, as it had not been previously tested up to this point.

Secondly, the interaction between the oxide and nitride substrate layers below the first polysilicon device layer could cause stress due to slight CTE mismatches. This effect was expected to be minimal because of the small difference in CTE, as well as the sizeable backside bosch etch that would allow for expansion.

Of primary concern were the strains that might be imposed from the packaging. The relatively large size of the package when compared to the die was seen as possibly problematic, as even small offsets in CTE could lead to large deformations at that scale. The intended use of alumina, having a CTE similar to the polysilicon at lower temperatures, was seen to mitigate some of this risk, although it was difficult to tell how it would react at higher temperatures.

2. MODELING

All modeling and simulations for this work were carried out utilizing ANSYS 12.0 Workbench and the accompanying Mechanical APDL.

To avoid the difficulties associated with importing the complex geometry directly from AutoCAD to the ANSYS program a simplified version was generated within the ANSYS Design Modeler. This was done to avoid an overcomplicated finite element mesh, allowing for greater focus on the areas of interest and circumventing excessive amounts of computation time.

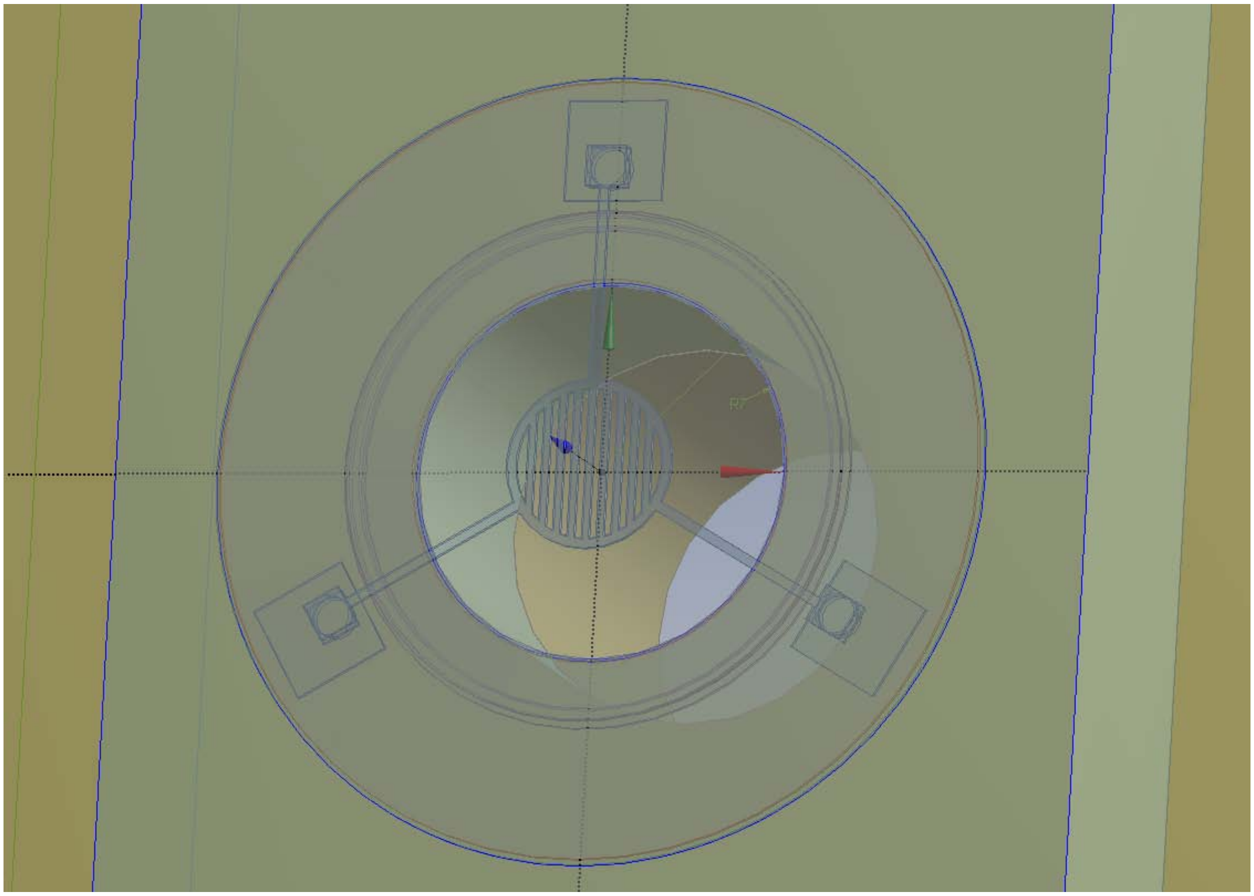

Figure 2. Simplified model generated in ANSYS Design Modeler.

For this model a microphone diaphragm diameter of 1000 um was utilized, with a backside etch diameter of 750 um, with the nitride and oxide layers at a diameter of 1600 um. The polysilicon die was modeled at 2000 um wide by 2800 um long, and at a depth of 650 um consistent with fabrication techniques. Alumina packaging was set at 5000 um by 5000 um, with a depth of 1000 um.

Several simplifications were made on the design. The number of interferometry gratings was reduced to a nominal amount, although this was not expected to affect results significantly. Most notably though was the three spring supports of the grating were modeled as fully clamped. This was deemed an acceptable place to start, as it represents a worst case scenario from the perspective of thermal stress, and thus was a good baseline. Furthermore the alumina packaging was fully constrained to the polysilicon die, which would also return the highest possible strains before proper adhesives were incorporated.

Another design change was also modeled, to be tested concurrently. Instead of simply clamping the diaphragm to the substrate a simply supported method was also tried. This was done in an effort to reduce stresses on the diaphragm if need be, allowing it to float separate from the effects of the packaging.

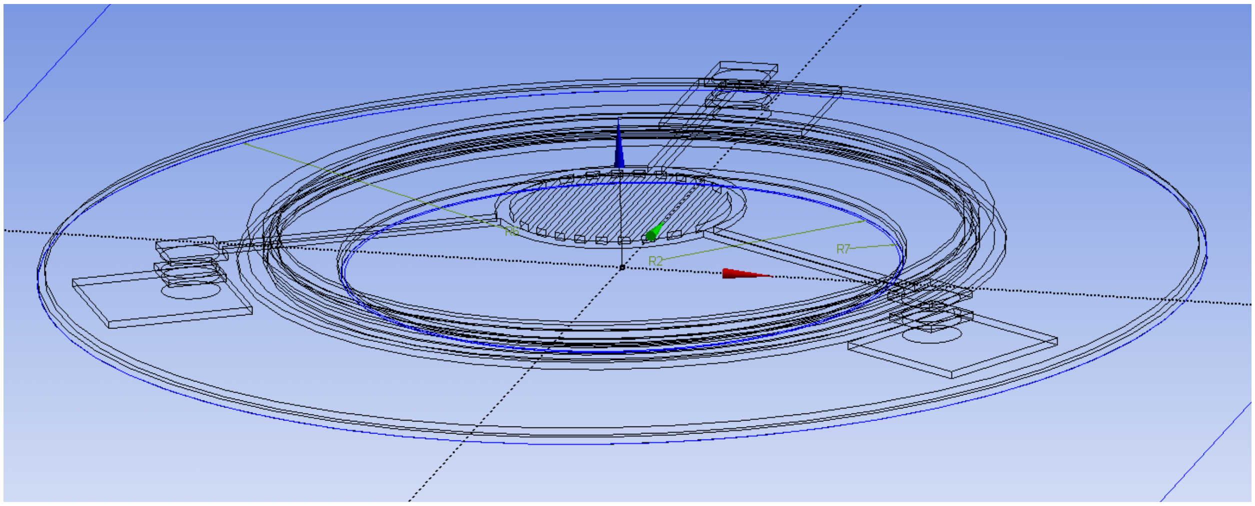

Figure 3. Simply supported diaphragm version of the microphone model.

There were concerns over the sizing of the overall mesh as well. A very fine resolution was desired for geometry of the MEMS device itself, but such a scheme could not be held constant over the entirely of the packaging. Due to its large nature the computational complexities could have proved prohibitive. Thus a submodeling approach was utilized for the smaller scale parts. The element size of the device was constrained to a 10 um maximum edge length while using a tetrahedral method. Package and die were modeled using a sweep method with maximum element size of 250 um. This allowed for acceptable resolution of the microphone mesh while retaining enough of the deformation of the packaging as well.

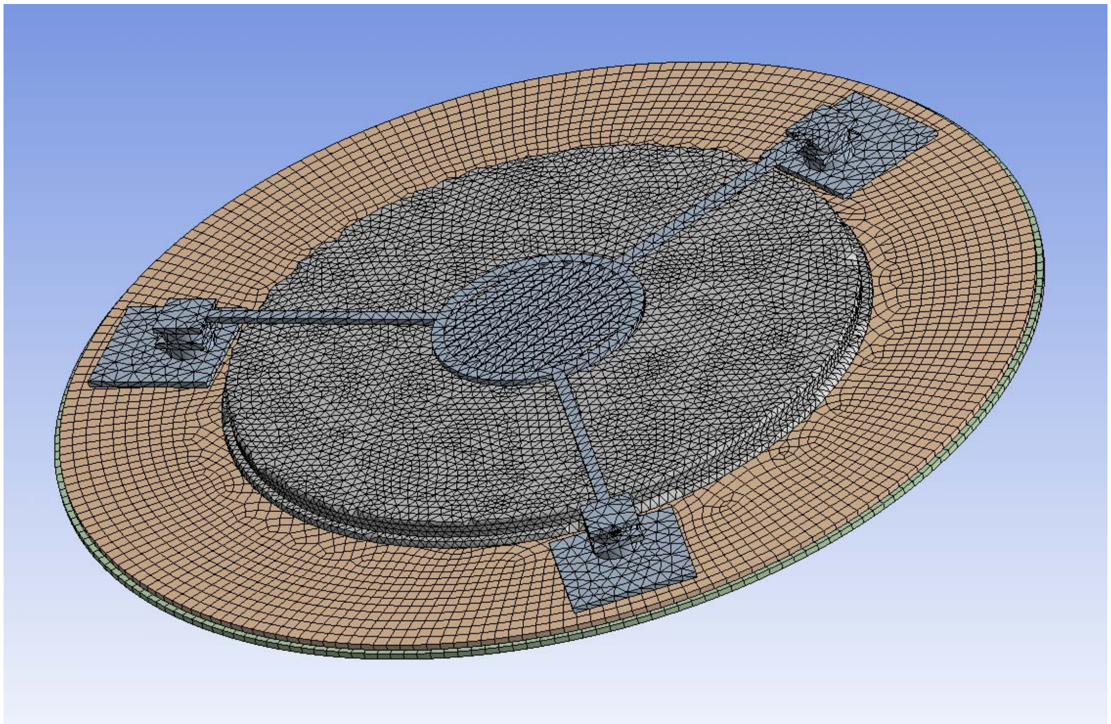

Figure 4. Zoomed in diagram displaying resolution of microphone element mesh.

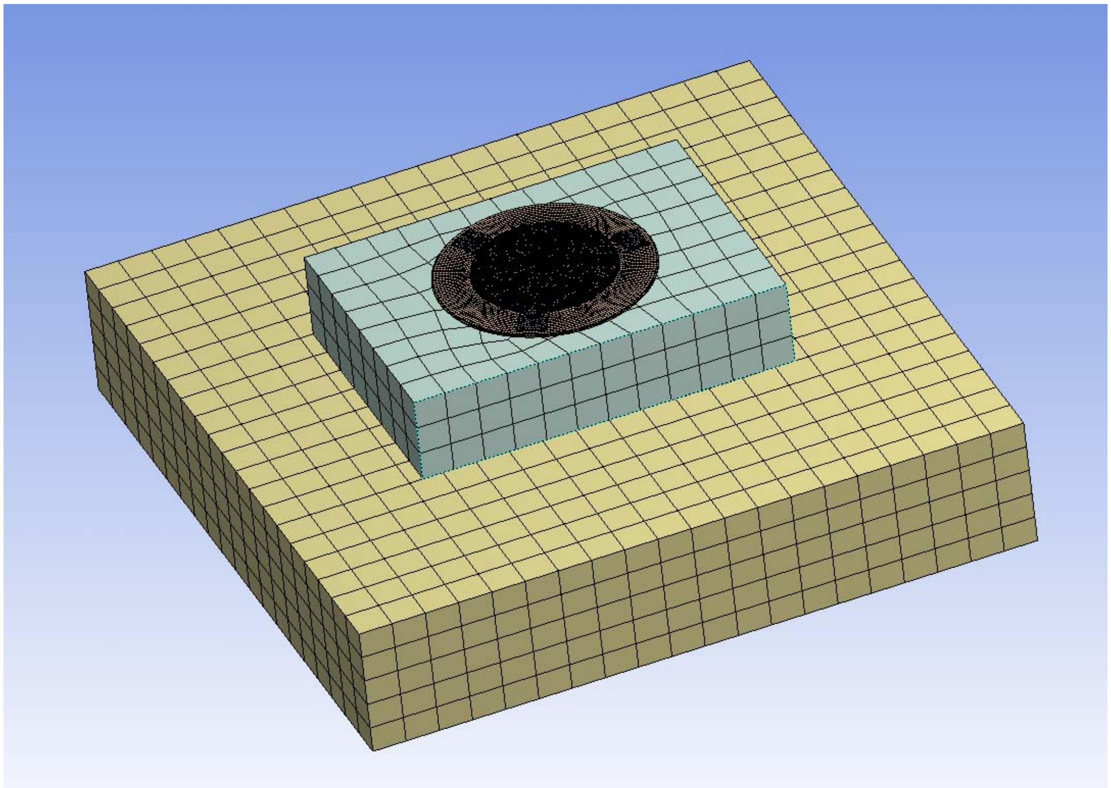

Figure 5. Overall mesh of the full package, displaying element size difference.

3. ANSYS RESULTS AND CONCLUSIONS

ANSYS computations were performed for overall equivalent von-Mises stress, equivalent von-Mises elastic strain, directional deformation, and total deformation of the model.

For the clamped model, stress tests showed maximum values at the corners of the alumina and polysilicon interfaces, on the order of 1.74 GPa. These results were extremely localized to these corner points, and indeed the majority of stress at that interface was on the order of 773 MPa. The highest stress seen on the device was at the oxide layer, at a level of 387 MPa. Highest values within the polysilicon layers of the microphone remained below 100 Pa.

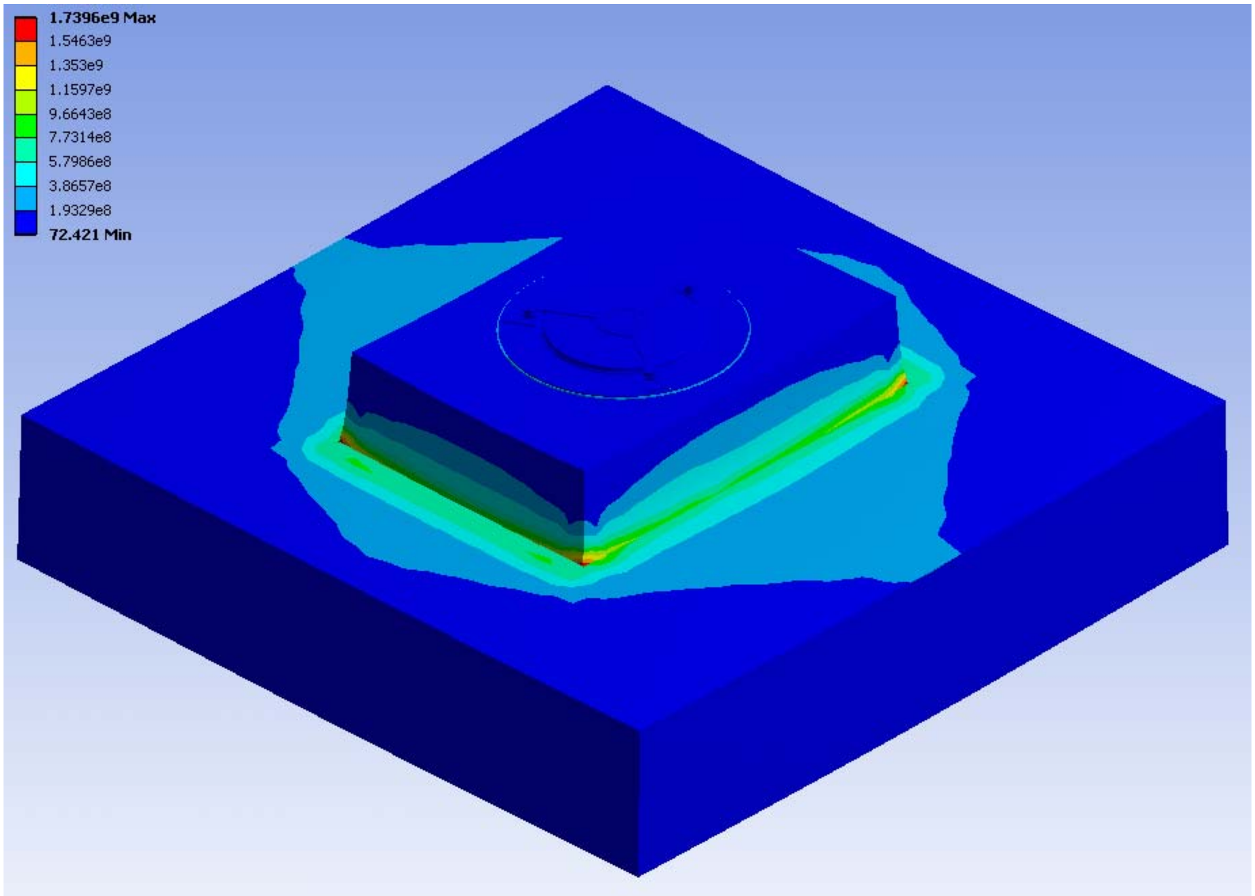

Figure 6. Overall stress results of clamped diaphragm model.

Results of the strain computations showed different results. Strain values throughout the packaging remained below 0.0073, except at the corners of high stress, where strain reached 0.0145. Maximum points of strain occurred at the interface between the polysilicon layers of the device and the underlying nitride layer. These peaked at a level of 0.0654 intermittently around the clamped diaphragm interface. Although throughout the bulk of the polysilicon strain held at levels similar to those of the packaging.

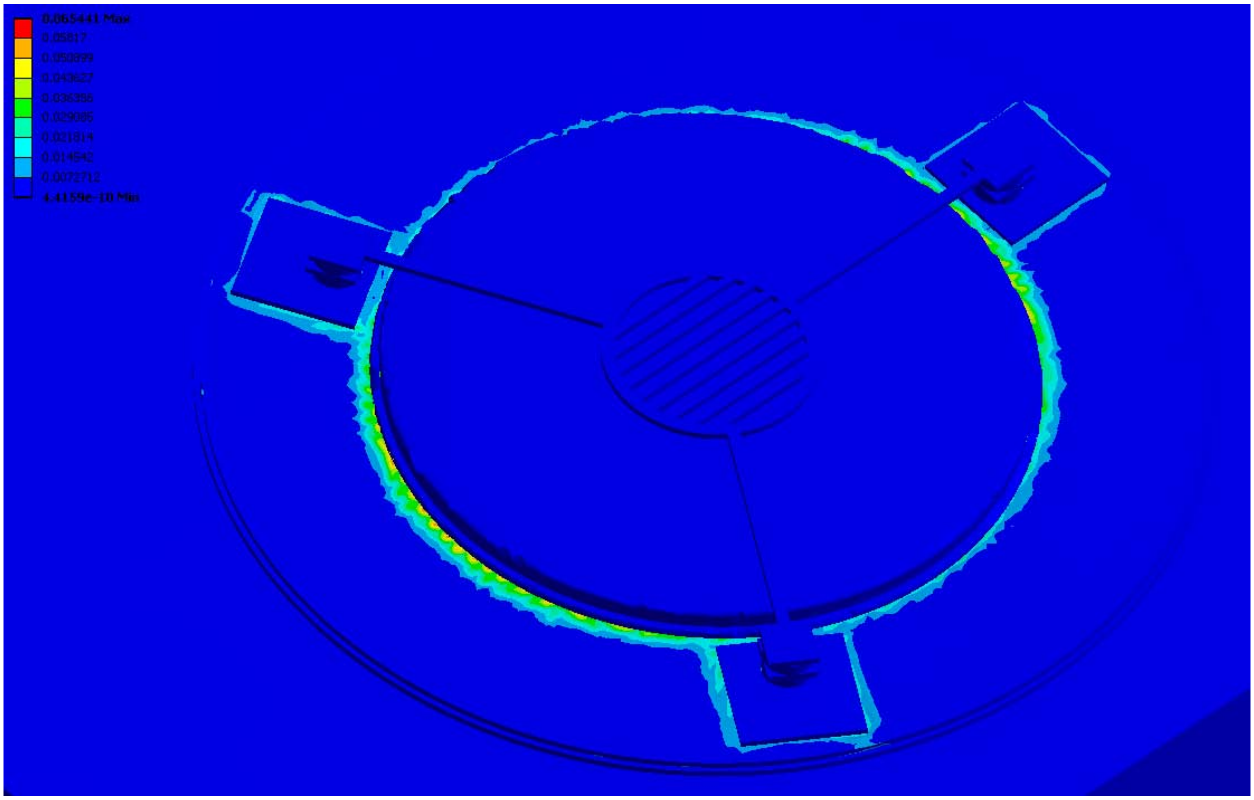

Figure 7. Zoomed in strain profile of clamped diaphragm model.

As to be expected, due to the scaling differences, the maximum total deformations occurred at the outside corners of the alumina level. These were on the order of 30 um at most, and there distance from the device makes them relatively inconsequential from a performance perspective. At the outside edges of the oxide and nitride layers deformation reached peaks of 3.41 um. Within the polysilicon layers however maximum total deformations remained at submicron levels.

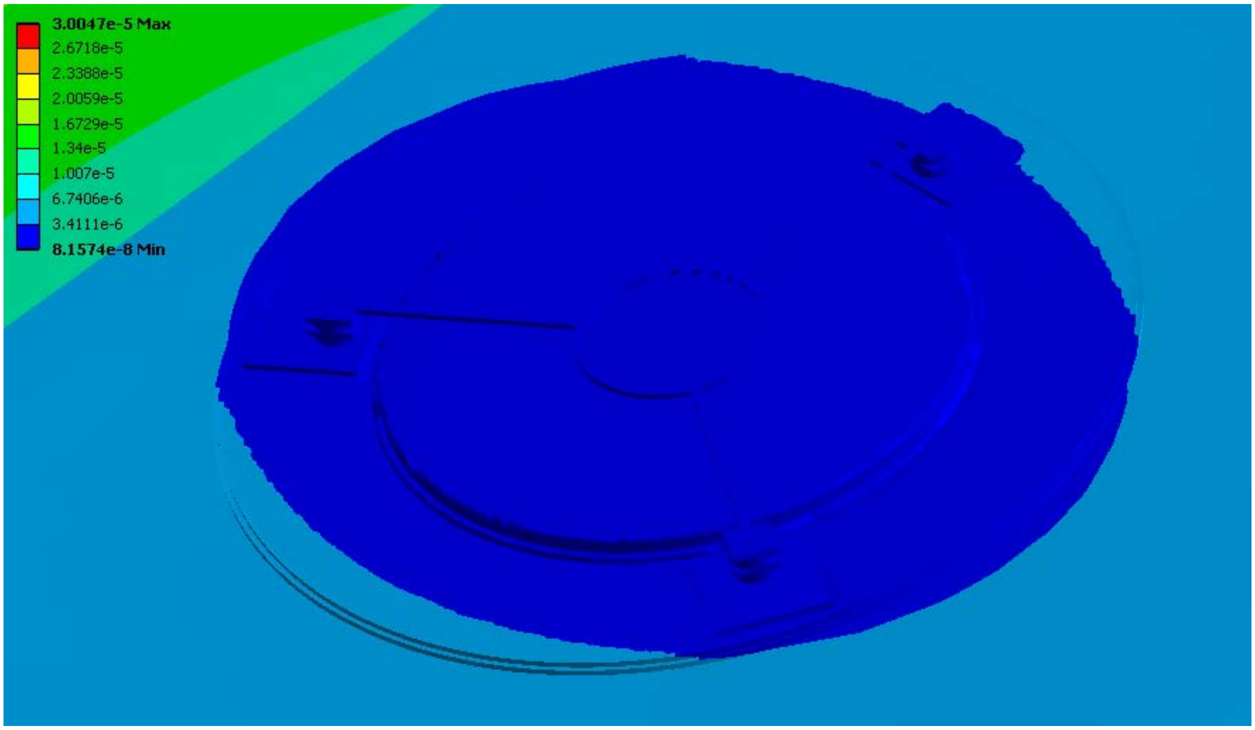

Figure 8. Total deformation values of the device.

For the simply supported model these values were almost wholly congruous. (See Appendix A for further image results) There was possible problem that was not initially predicted, although it is easily remedied. At low levels of support overlap, that is how far the diaphragm lies in its supports, it is possible for gaps to appear between the different layers. Because the total deformations are still so low this is unlikely to be a problem, and can be fixed by simply ensuring a few micron overlap, but should be noted.

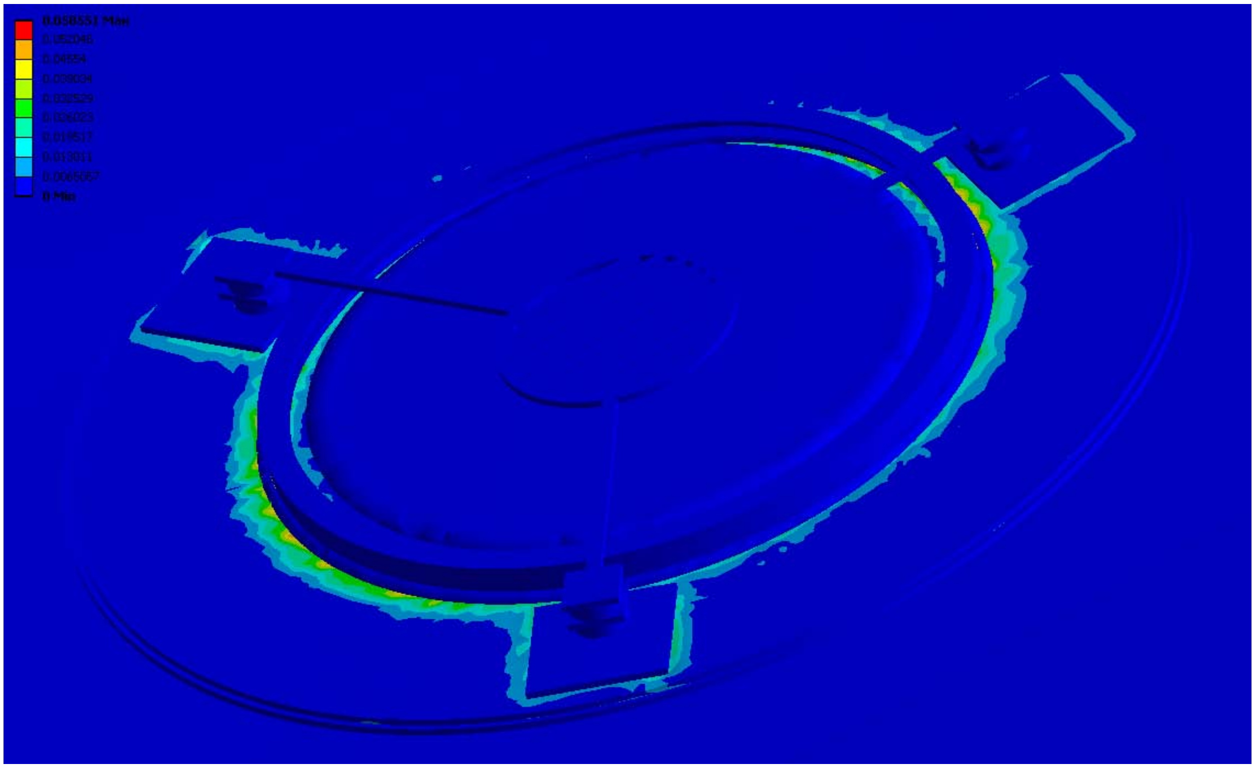

Figure 9. Strain results of simply supported model, with gap between layers exaggerated.

These results indicate that there should be no foreseeable problems with this current design scheme up to temperatures of 1000 °C. The values of stress, strain, and deformation are all under acceptable levels.

Further investigation could be done into refining the overall geometry of the device to more closely match AutoCAD design, although this was done as a worst case scenario. Improvements to the spring modeling as well as the packaging interface would most likely only serve to reduce the calculated levels further.

4. REFERENCES

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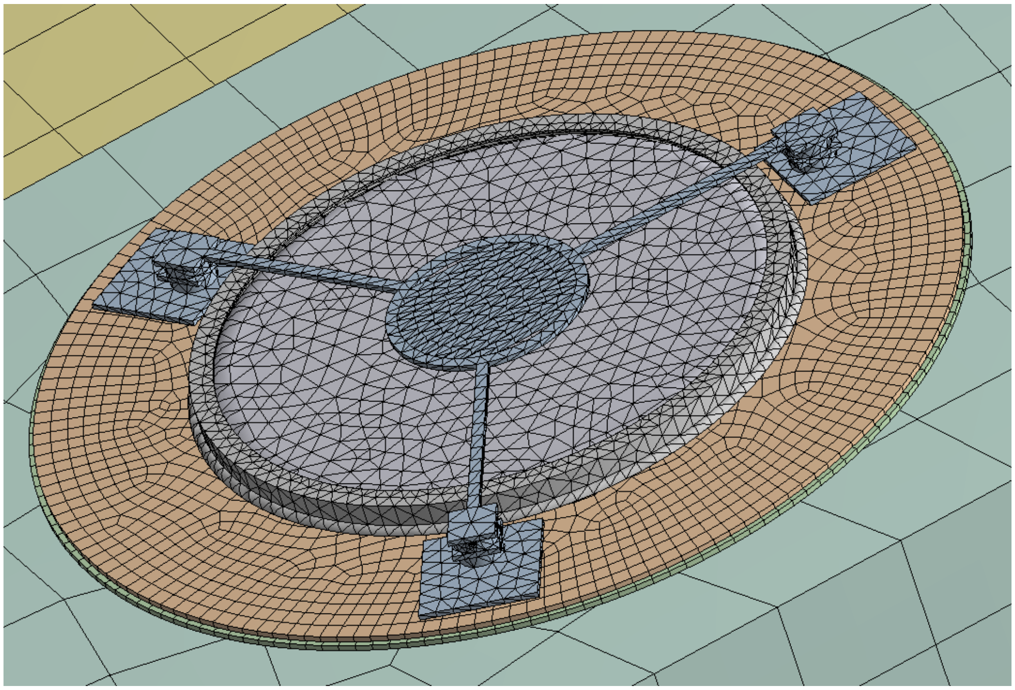
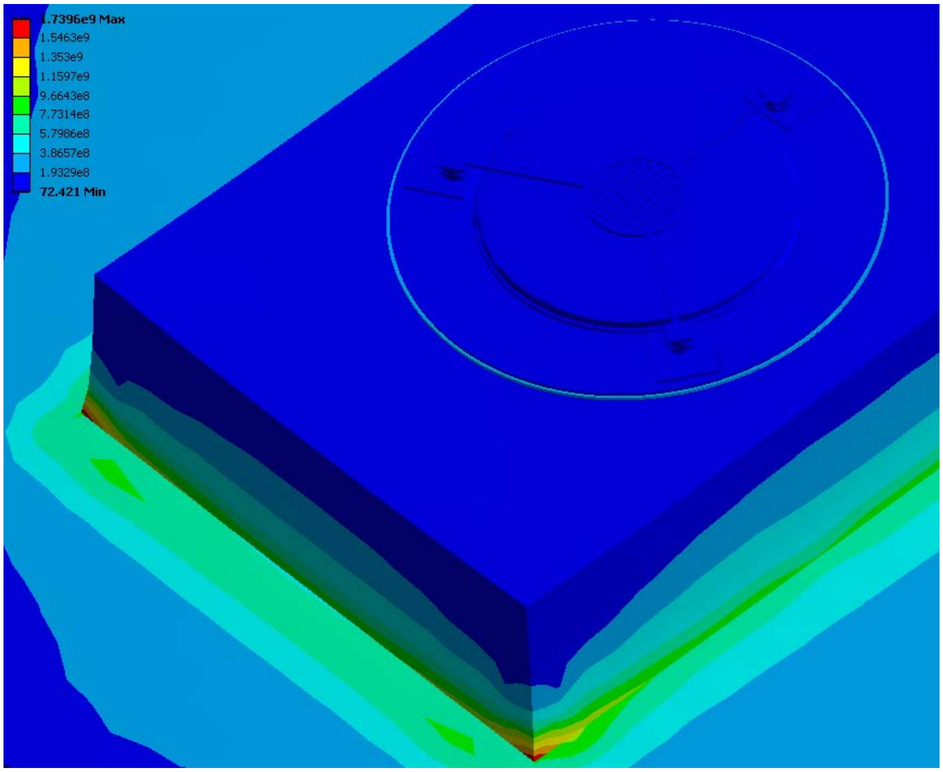
2. Hall, Neal A; Okandan, Murat; Littrell, Robert. *Micromachined accelerometers with optical interferometric read-out and integrated electrostatic actuation.* Journal of Microelectromechanical Systems, Vol 17, No 1, 2008

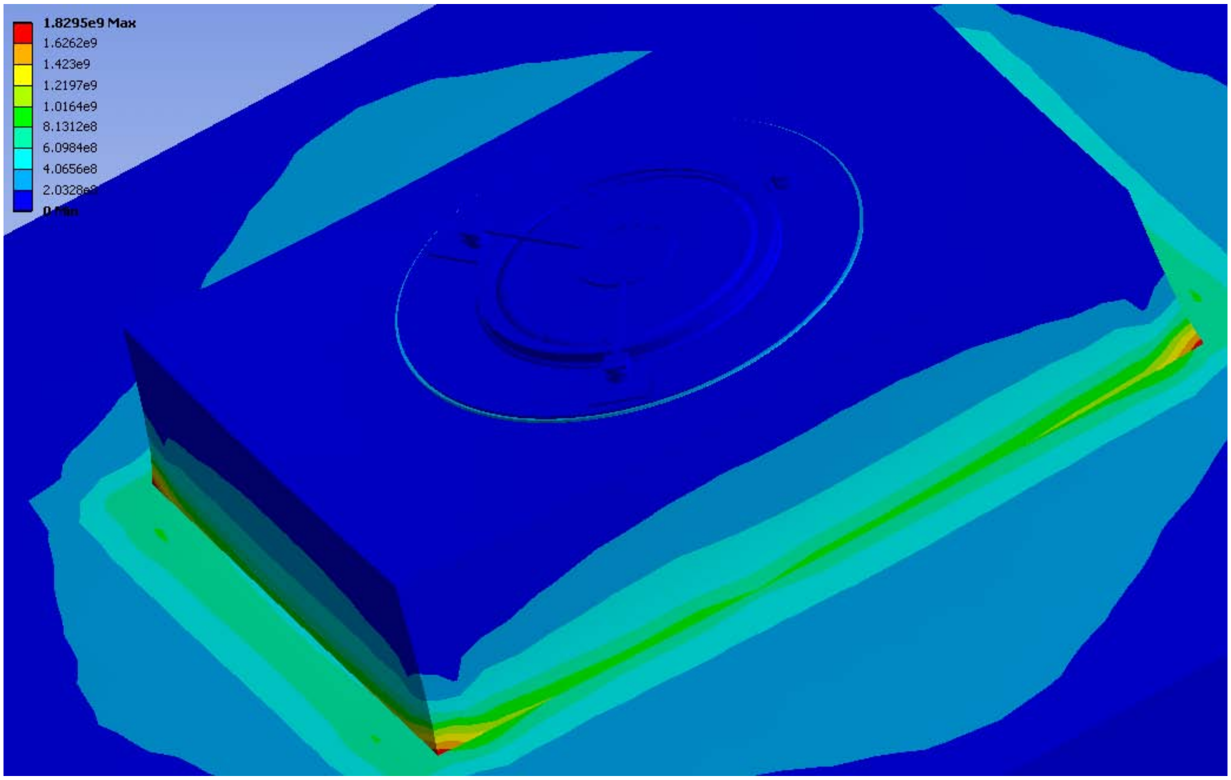
APPENDIX A: FURTHER ANSYS RESULTS IMAGES



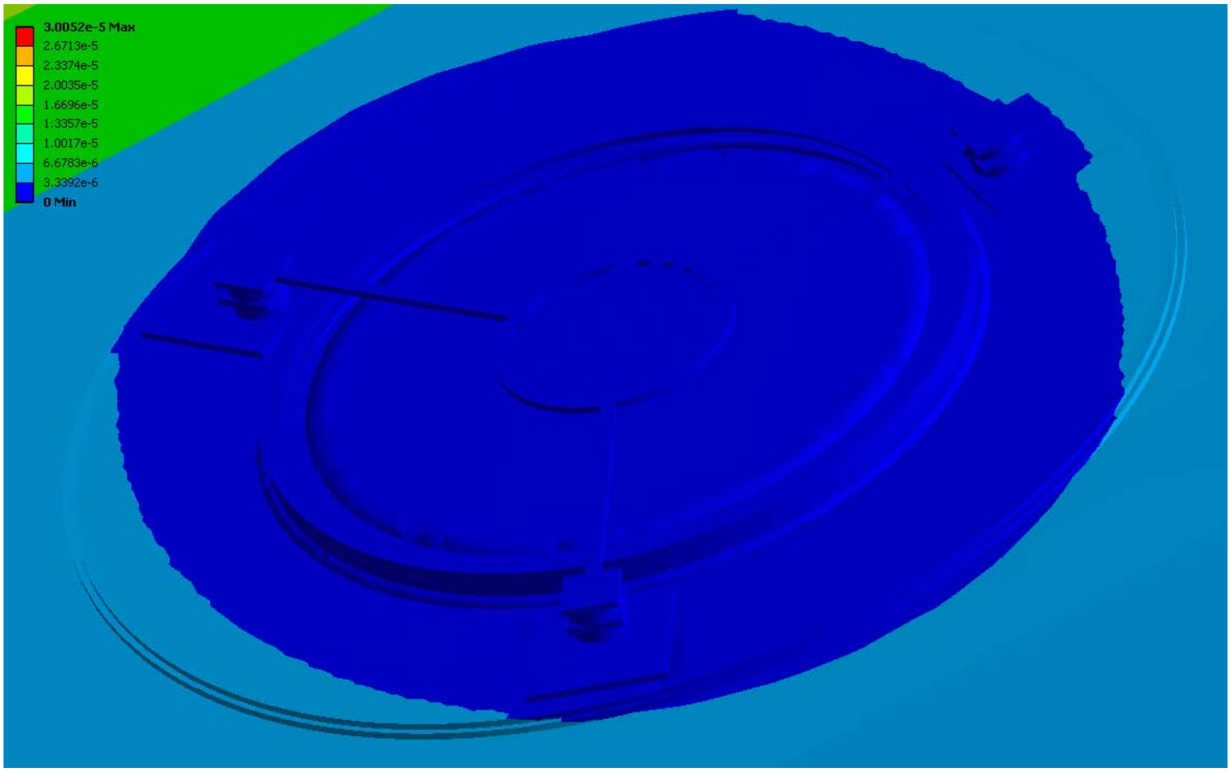
A1. Finite element mesh for simply support model.



A2. Zoomed in stress results for clamped model.



A3. Overall stress results for simply supported model.



A4. Total deformation of simply supported device.

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