


Wide-field Imaging System and Rapid Direction of Optical Zoom (WOZ)
(Contract Number N00014-10-C-0194)

Quarterly Technical Report #2
16 Sep 2010 - 15 Dec 2010

Submitted by
Kratos Defense and Security Solutions

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Quarterly Technical Report #2 (QTR-2)

# Wide-field Imaging System and Rapid Direction of Optical Zoom (WOZ) QTR-2

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# Abstract

This report covers technical progress on the Wide-field Imaging System and Rapid Direction of Optical Zoom (WOZ) contract for the period 16 Sep 2010 - 15 Dec 2010. A report covering financial status for this period is provided separately. During this period, subcontracts were awarded by the prime to both team mates, Advanced Optical Systems, Inc. and NeXolve, Inc. The multiphysics design tool is under development and successfully demonstrated communications between all of the software packages. A method and fixture for characterizing the piezoelectric properties of the materials has been fabricated and initial test results are promising. Finally, an initial sample of the material to confirm test film design is suitable has been undergone initial testing. It does not show the strong bimorph behavior seen in previous films but NeXolve has developed a hypothesis to explain the behavior. The period concluded with a Technical Interchange Meeting held on 6 Dec 2010.

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## Summary

In June 2010, Digital Fusion Solutions (DFS, a wholly-owned subsidiary of Kratos Defense and Security Solutions, Inc.) was awarded a contract for the development of optical quality flexible membrane mirrors. This report covers technical progress on the Wide-field Imaging System and Rapid Direction of Optical Zoom (WOZ) contract for the period 16 Sep 2010 - 15 Dec 2010. A report covering financial status for this period is provided separately. During this period, subcontracts were awarded by the prime to both team mates, Advanced Optical Systems, Inc. and NeXolve, Inc. The multiphysics design tool is under development and successfully demonstrated communications between all of the software packages. A method and fixture for characterizing the piezoelectric properties of the materials has been fabricated and initial test results are promising. Finally, an initial sample of the material to confirm test film design is suitable has been undergone initial testing. It does not show the strong bimorph behavior seen in previous films but NeXolve has developed a hypothesis to explain the behavior. The period concluded with a Technical Interchange Meeting held on 6 Dec 2010.

## Introduction

DFS has teamed with Advanced Optical Systems, Inc (AOS) and NeXolve, Inc. to develop a breadboard system for demonstrating non-mechanical zoom using flexible thin films. The project consists of three major task area, which are Material Characterization, Diagnostic System Development, and Imaging System Development. DFS is responsible for leading the modeling effort, AOS is responsible for leading the optical design effort, and NeXolve is responsible for fabrication of the films. In addition, each member of the team supports the others in their areas of responsibility.

Material Characterization phase will involve two components: development of modeling tools and measurement of material properties for use in the tools. This phase is currently ongoing and will be discussed thoroughly in the next section. The Diagnostic System Development phase will apply the tools and knowledge developed in the first phase to build algorithms for modeling and testing one-dimensional films with multiple actuators. These models will then be compared to experimental results and modified as needed. The Imaging System Development phase will conclude the effort by building a sensor system with variable zoom based on optical quality PVDF films.

## Methods, Assumptions, and Procedures

The modeling tools are based on interaction between three commercial software packages: SolidWorks, COMSOL Multiphysics, and ZEMAX optical design. The multiphysics design tool is nearing completion. We have demonstrated the ability to create a model in SolidWorks, import the model into COMSOL, and then interactively update the model with either package. COMSOL can then perform the electrostatic and mechanical modeling to calculate the deformation resulting from the applied voltages. Finally, the deformed surface can be exported to ZEMAX via MatLab. From ZEMAX, various analyses can be conducted to determine important parameters such as focal point, aberrations, and wavefront distortion. Defining the specific analytical results to extract from ZEMAX to support the optimization remains to be determined.

Figure 1 shows the deformation calculated using a model of an evaluation film (in the same configuration as supplied by NeXolve as described in the first quarterly report) with a *z*-gradient in the $d_{31}$ piezoelectric coefficient. This model gives a response of the same order of magnitude to the response seen in a film supplied by NeXolve under a previous contract, 0.9 mm in this case. This figure also shows the mesh used in the COMSOL computation. In order to capture the solution near the edges of the aluminum electrodes, the mesh had to be very fine. On the other hand, the much larger mesh near the ends of the film did not degrade the accuracy of the solution.

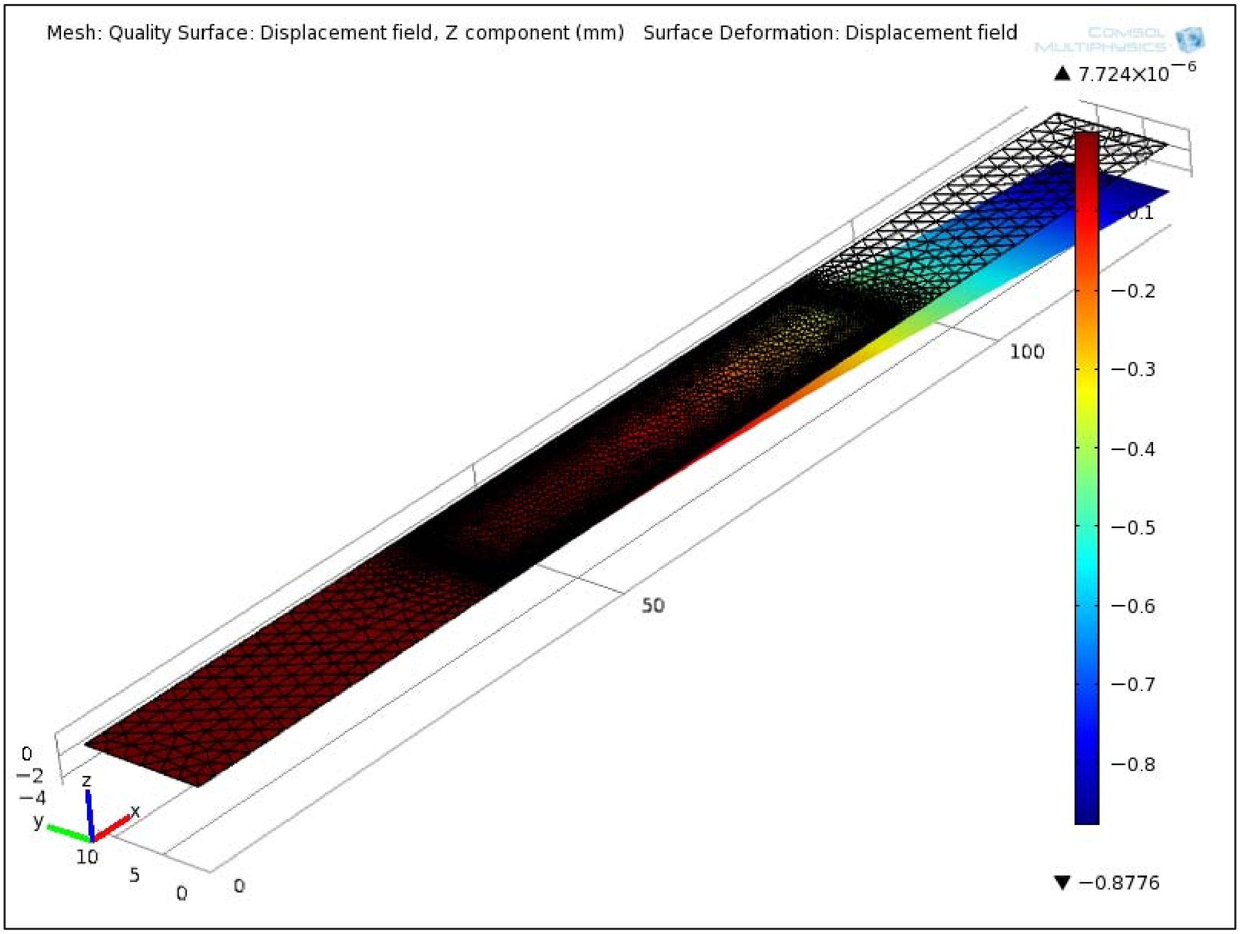

**Figure 1. Deformation of film based on gradient model with hypothetical gradient**

The film surface was imported into ZEMAX to calculate the optical properties and begin to identify the important characteristics to extract from ZEMAX for determining the quality of the surface. For this step in the process, the ZEMAX model consisted of a collimated light source illuminating the film and several planes for evaluating spot diagrams and the irradiance.

Another important model was examining the impact of the spaces between the electrodes. For this study, we modeled the 50 mm long electrode consisting of 5 segments. The total electrode length was held constant at 50 mm, and the electrode spacing was varied from 5 mm to 0.05 mm. The results are presented in Figure 2, which shows second derivative of the displacement (i.e. the curvature). Some smoothing of the derivative has been done, but some numerical artifacts remain. These artifacts are principally seen as blocky sections with rapid changes in the curvature. An algorithm for removing these artifacts has been developed but was not implemented or tested in time for this report. The important features to note are the reduction in curvature in the spaces between the actuators (quilting) and the reduction in the peak value of curvature. If the actuator spacings are limited to 0.1 mm, then there is no observable quilting. However, the narrow spacing will limit the voltage difference that can be applied between two segments to prevent arcing. NeXolve is investigating how to use photolithographic methods to achieve the narrow spacings and how to apply a dielectric layer to avoid arcing between segments.

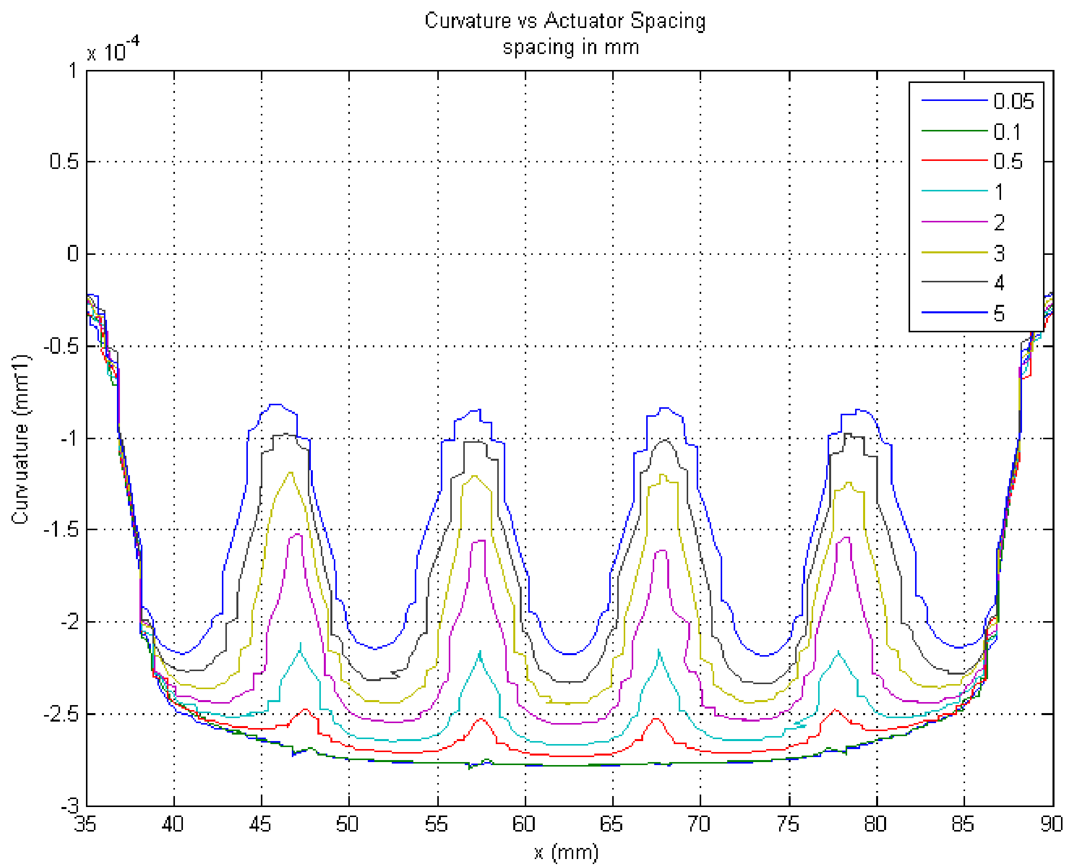


**Figure 2. Curvature along centerline of film. Legend shows spacing between segments (in mm).**

We performed an initial round of testing on samples provided by NeXolve to evaluate the design of the samples for test purposes. Our testing of the samples has shown they do not have the strong bimorph response demonstrated by samples provided by NeXolve on a previous contract. NeXolve attributes the decrease in bimorph response to improvements in processing in order to increase the magnitude of the total piezoelectric response. These changes have likely resulted in a decrease in the gradient and increase in the average value of the *d* coefficients. We have identified one method that should substantially increase the gradient. That method involves placing a thermal gradient across the thickness of the film after the film has been polled. NeXolve expects the thermal gradient will result in partial decrease of the crystallinity on warmer side, which will result in a decrease in the piezoelectric response, thus creating a strong gradient.

A method for testing the freely hanging films was developed using a computer controlled camera to capture images of the film edge-on. The experimental layout is shown in Figure 3. The purpose of the magnifying lens is to enable the camera to focus at a shorter range than the minimum focal distance of the camera lens.

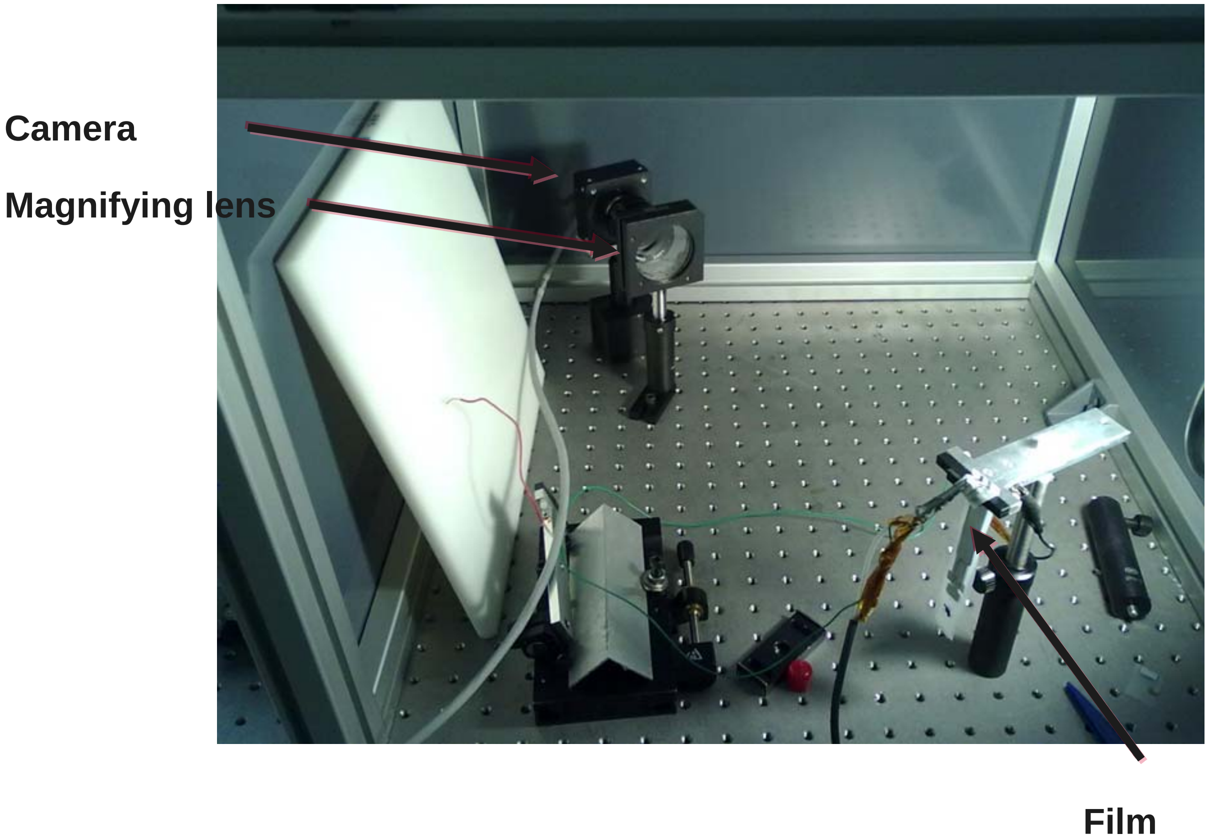


**Figure 3. Set up for measuring deflection of film**

## Results and Discussion

The multiphysics design tool is integrating well and will enable an empirical approach to understanding the behavior of the films. Using the example from above, a sample calculation was performed and exercised the tool from the SolidWorks design environment through plotting a spot diagram in ZEMAX. All that remains is to extract the significant values from ZEMAX for use in optimizing the shape of the film by varying on the applied voltages.

The experimental work has shown that the film samples will work for performing the material characterization. Since the deflection of the films as provided by NeXolve was so small, two films were bonded with the polling directions opposite one another. This formed a bimorph, such that an applied voltage would cause one film to lengthen and one film to shorten. As expected, the film deformation is approximately quadratic and the curvature (coefficient of $x^2$) is roughly linear with applied voltage.

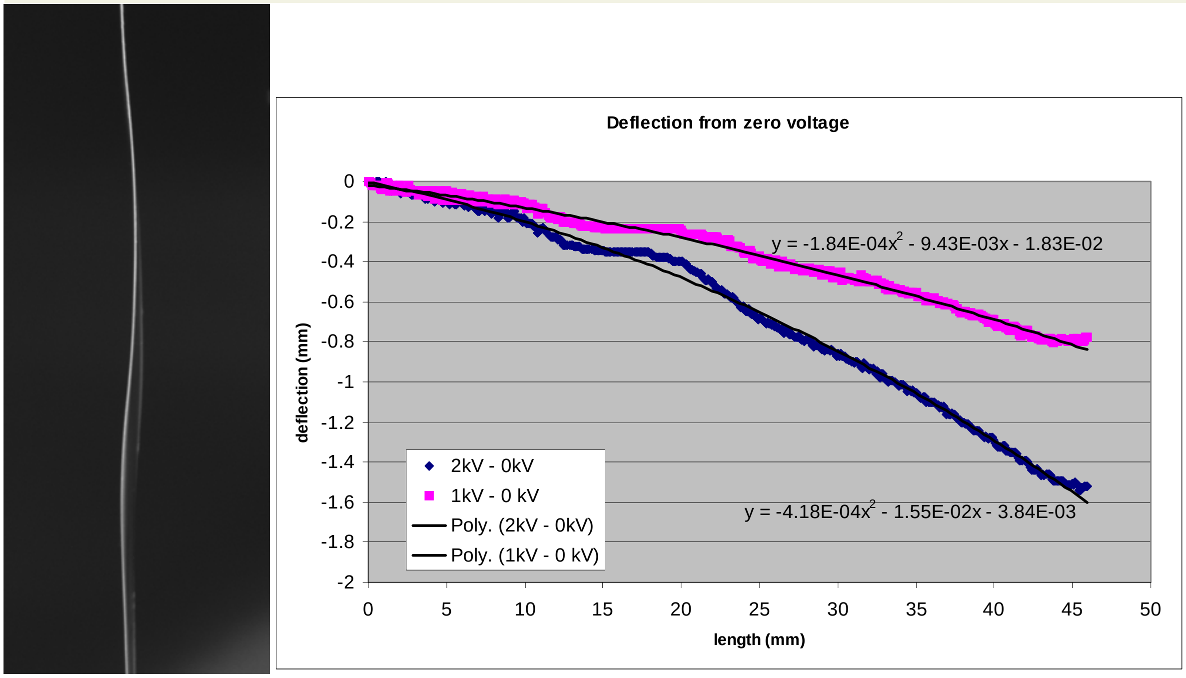


**Figure 4. (left) Image of film viewed edge-on. (right) Deflection of bimorph film relative to zero volts applied.**

# Conclusions

The multiphysics design tool is progressing according to plan. The experimental work is behind schedule, and more focused attention will be given to that part of the effort.