CAD Modeling of Scratch Drive Actuation

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ABSTRACT

Assembled MEMS structures provide a unique design opportunity by overcoming the inherent planarity of MEMS devices, allowing for added flexibility and new application areas. However, external assembly of these devices is frequently problematic. Force and displacement controls are often imprecise at the microscale resulting in damage to the device. In contrast, self-assembling MEMS structures can avoid external manipulation and therefore can be less likely to suffer damage. Self-assembly, though, requires the added complexity of integrated actuation.

One type of integrated actuation is driven by scratch drives. Scratch drive actuation is an electrostatic phenomenon that results when a suspended plate with an attached bushing is attracted to a flat plate. The attraction causes snap-down and zippering, pushing the bushing forward. When the charge is released, the plates separate, but the bushing remains in position, causing a horizontal displacement. This process can be repeated to generate forward motion.

This paper demonstrates a new CAD capability, the modeling of scratch drive actuation. Modeling any type of self-assembly necessarily involves extensive contact analysis capabilities. In the case of scratch drives, a full actuation cycle – consisting of pull-in, zippering, and release – must be modeled. This capability will be demonstrated by considering a polysilicon scratch drive actuator that was developed by researchers at the University of Tokyo. Their findings show that the distances the scratch drives travel in each step are approximately 0.1 µm and depend on the peak voltage, suspended plate length, and bushing height. Now, with CAD advances, such as fully coupled electro-mechanical contact analysis and post contact analysis, these devices can be simulated accurately prior to fabrication. This paper describes the simulation methodology and provides a comparison with measured results.

Keywords: MEMS, CAD, simulation, actuators, electrostatic

1 INTRODUCTION

Recent advances in CAD for MEMS tools have started to enable users to model devices not previously possible. While modeling of electromechanical phenomena, including actuation, have been possible for some time, only through further advances have these software tools been able to model more complex behavior, such as scratch drive actuation.

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This paper looks at a simple scratch drive actuator (SDA), consisting of a plate, bushing, multiple dielectric layers, and a substrate (Figure 1), simulated in IntelliSuite™.

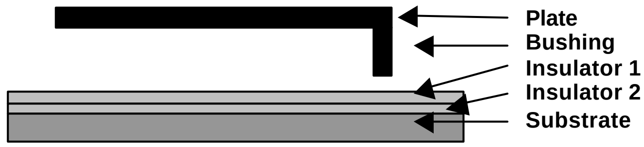

Figure 1 Schematic view of a representative SDA

To drive the SDA, a step voltage load is applied between the substrate and the plate. This results in the unsupported end of the plate snapping to the insulators, pushing the bushing outwards (Figure 2). When the voltage is released, the SDA is moved forward by the bushing.

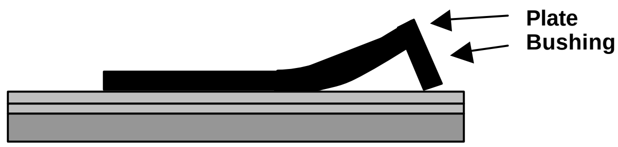

Figure 2 Schematic view of the SDA under the applied load

Prior work has been done to characterize SDAs by plate dimension, bushing height, and voltage bias [1, 2]. CAD analysis for multiple dielectric layers [3], true contact analysis [3], and micro-assembly [4] has also been discussed previously, but was significant in the analysis of this device.

This paper looks at the analysis of the two-step process of SDA motion. First, analysis is performed for the downward motion which pushes the bushing forward. Second, the voltage is released, enabling the device to move forward so that it is even, once again, with the bushing. The first step requires true electromechanical contact analysis, including zippering. The second step requires the ability to release the structure, while allowing the stresses created by the applied voltage load to pull the structure forward. Results are compared with those previously determined for similar geometry SDAs [2].

2 INTELLISUITEÔ MODELING

IntelliSuite enables modeling of SDAs by allowing for post-assembly analysis. This allows users to model phases of device movement such as pull-in and zippering from the voltage application then release and forward motion when the voltage load is removed.

2.1 Scratch Drive Model

For this analysis, a sample model scratch drive was created and analyzed within the IntelliSuite design environment. Shown in Figure 3, the SDA is comprised of a plate, bushing, and two support arms. The support arms hold the structure over the initial air gap. The base is comprised of a substrate with two dielectric layers.

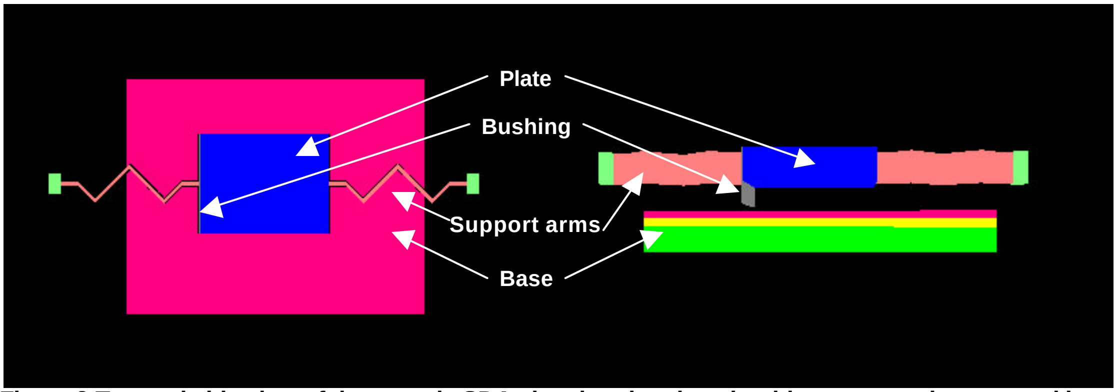

Figure 3 Top and side view of the sample SDA showing the plate, bushing, support beams, and base

3.2 Materials

The sample SDA plate, bushing, and support arms are constructed of polysilicon deposited at 600 °C by low-pressure chemical vapor deposition (LPCVD). The base is a silicon substrate with a layer of silicon oxide grown at 1100 °C. The upper dielectric layer is silicon nitride deposited at 800 °C by LPCVD. Material properties for these processes were determined using MEMaterial®, an extensive thin-film material database included within IntelliSuite.

3.3 Geometry

The sample SDA consists of a 46 by 60 µm plate, 1.5 µm thick, and a 1.0 µm tall bushing. The oxide layer is 0.35 µm and the nitride layer 0.3 µm thick. The support beams are 70 µm long and 20 µm in total width. This is shown in Figure 4.

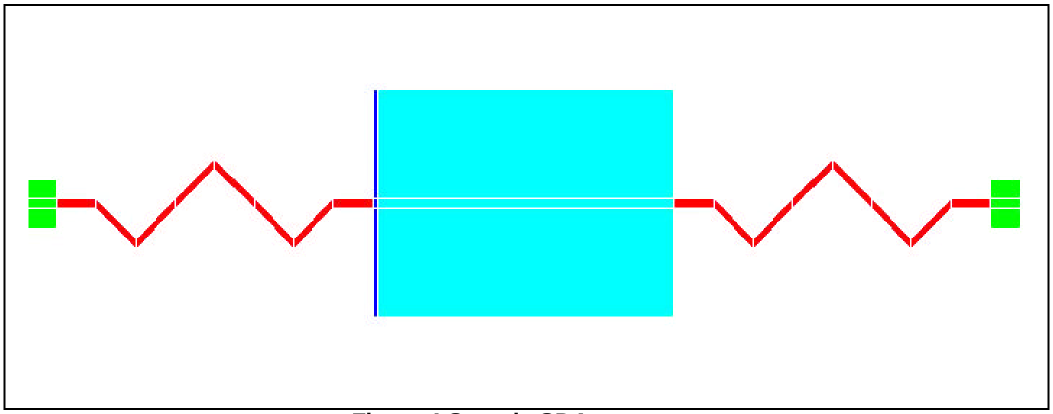
Figure 4 Sample SDA geometry

4 STEP 1: MOVEMENT UNDER APPLIED VOLTAGE LOAD

To activate the SDA, a step voltage of 140 V is applied between the plate and the substrate. This results in a downward displacement of the plate, bushing, and support arms. The long, flexible support arms prevent the SDA from floating freely, while allowing it to deform. As shown in Figure 5, the bushing bends outwards as the plate zippers to the substrate.

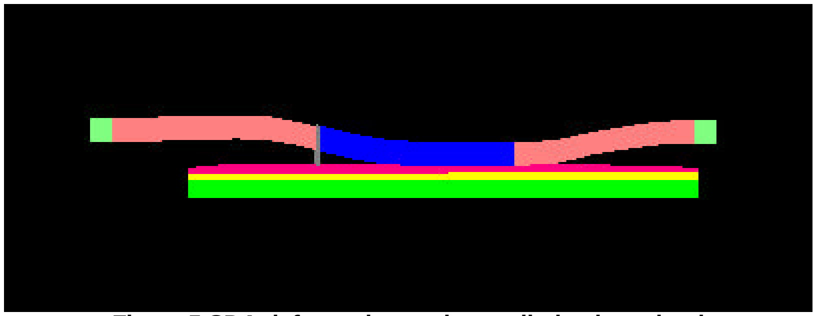

Figure 5 SDA deformation under applied voltage load

Figure 6 shows a top view with the numerical values for the resulting z-displacement. The right side of the plate has completely contacted the base, while the left is supported by the substrate. The support arms show similar deformation.

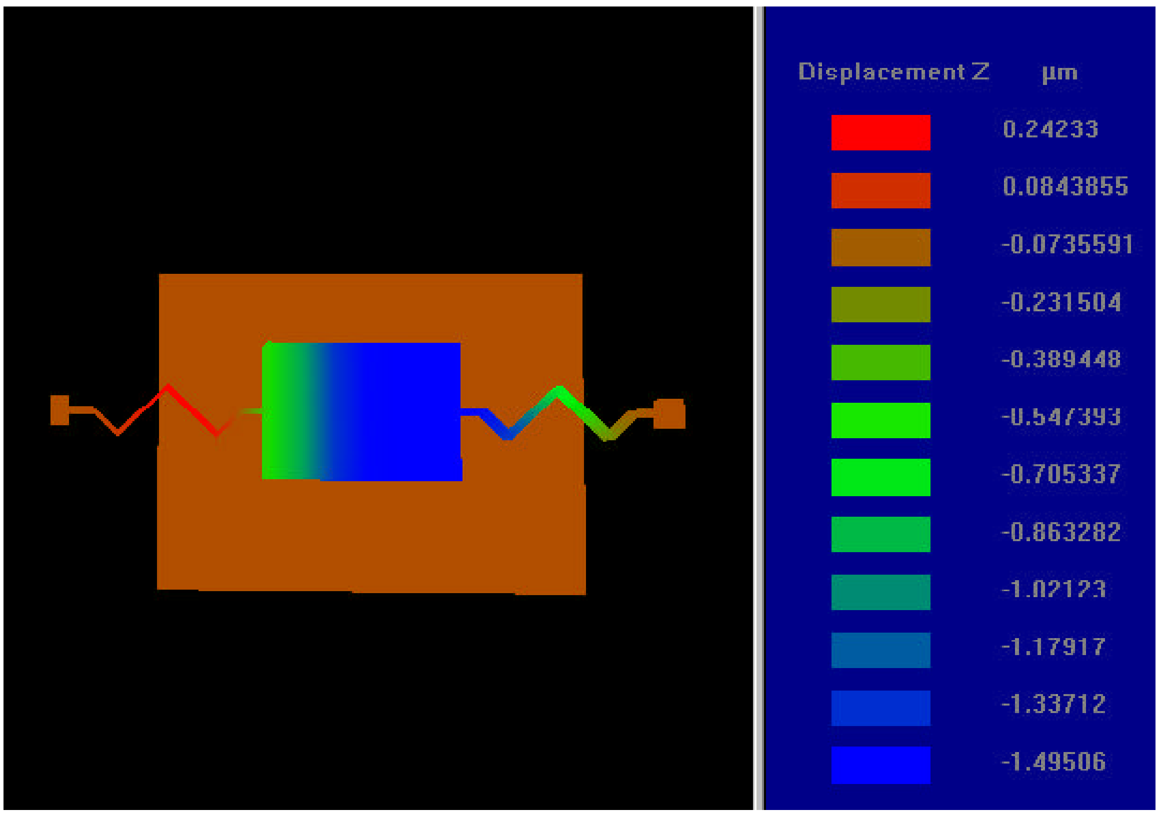

Figure 6 SDA z-displacement under applied voltage load

The step size, indicating average SDA step size, was about 0.1 µm. These results are comparable to those found by Langlet et. al. [1].

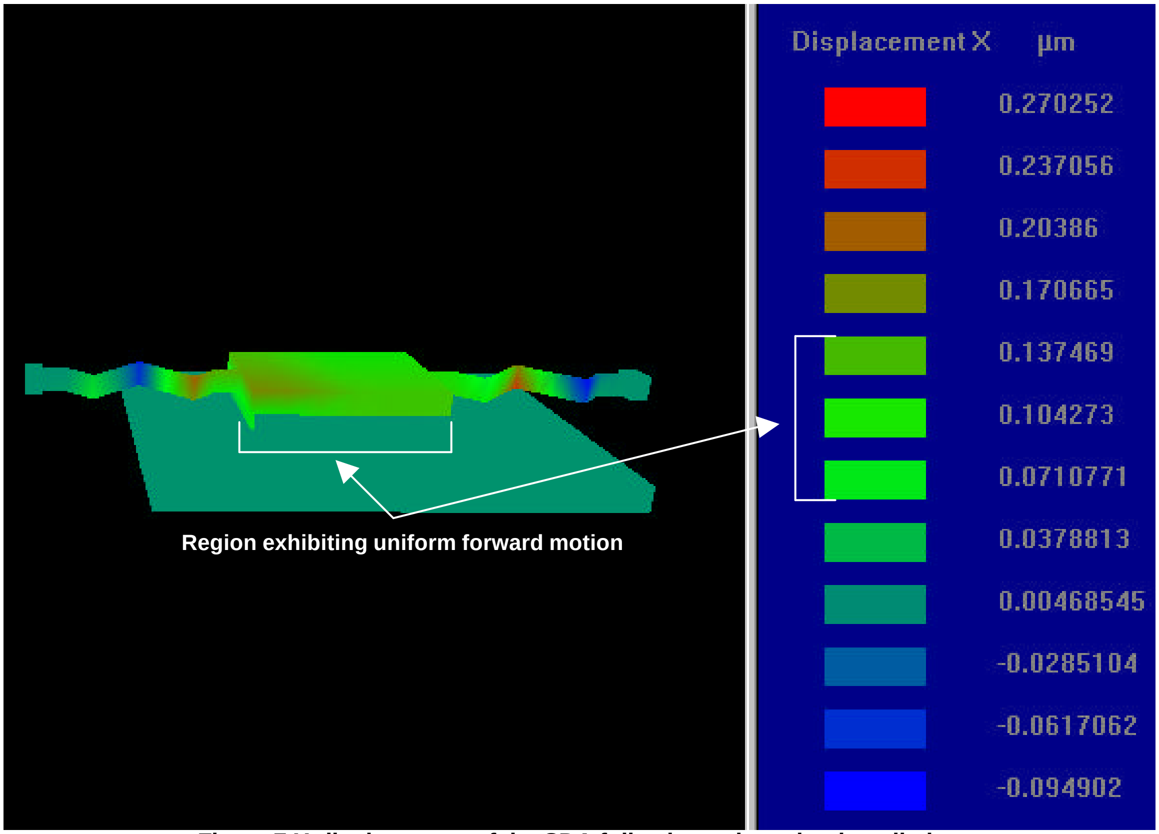

Figure 7 X-displacement of the SDA following voltage load appliation

5 STEP 2: RECOVERY AFTER REMOVAL OF APPLIED VOLTAGE LOAD

After the voltage load is removed, SDAs release from the base but move forward, dragged by the bushing. In simulation, this results in stress release in the plate and bushing and stress buildup in the support beams.

Figures 8 and 9 shown the stresses in the extended beam (7) and compressed beam (8) following one step of motion.

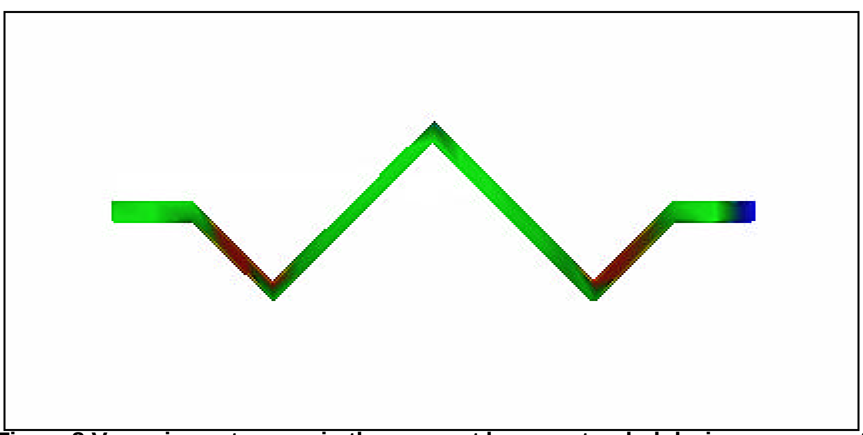

Figure 8 Von mises stresses in the support beam extended during movement

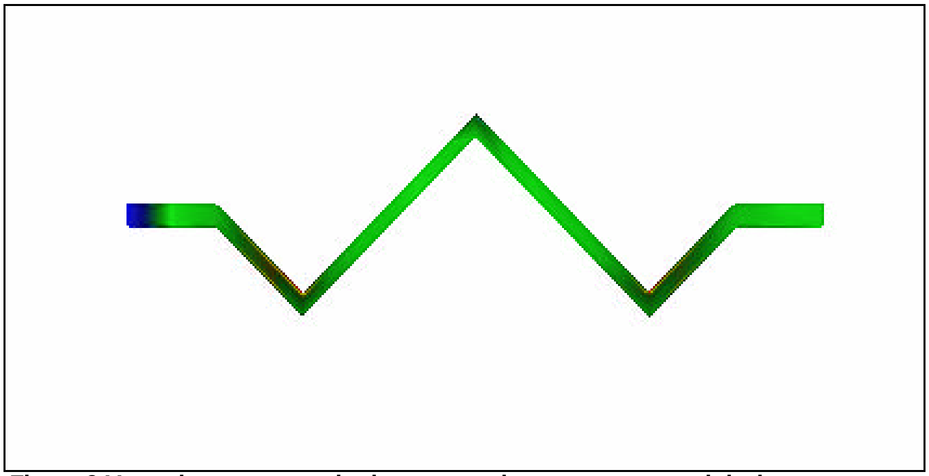

Figure 9 Von mises stresses in the support beam compressed during movement

Note, in true SDA motion, the beams deform plastically. One continuing limitation of CAD for MEMS tools is the exclusive use of elastic deformation. Thus, these beam stresses must be removed prior to further analysis.

6 CONCLUSION

This paper illustrates, through comparisons with experimental results, new capabilities of CAD for MEMS tools. By combining true contact analysis with post-assembly analysis capabilities, IntelliSuite is now able to model full SDA step motion. With the release of the elastic stress buildup in the beams, multiple steps can be simulated.

Further developments are needed to complete the modeling of SDA behavior. Enabling plastic deformation would allow users to apply true pulse loads as a one, rather than three, step process. This would facilitate visualization of true SDA behavior.

By extending recently added functionality of CAD for MEMS tools, we are able to model new types of devices. These features will assist in the development of new devices, particularly those involving self-assembly. Further work can be done to allow for more direct simulation of such behavior, but it is now possible for engineers to accurately model scratch drive behavior.

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