The Beneficial Effects of Thin Film Stress in the Fabrication of a MEMS Device

Justin E. Brown
Microelectronic Engineering
Rochester Institute of Technology
Rochester, NY 14623

Abstract-- Microelectromechanical systems (MEMS) are playing an increasing role in the semiconductor industry today. The modeling and manufacturing of mechanical devices on a microscopic level have made their way from the area of singularly fabricated devices for research into the bulk processing of the commercial market. Many of these commercial devices are of the optical variety. And there has also been successful work done in combining integrated circuits with MEMS. Presented here is a process for the fabrication of an optical device called a microshutter.

The device consists of a moveable electrode constructed of a stack of $SiO_2/Al/SiO_2$. The key to the successful micromachining of this device lays in the stress characteristics of the stacked layer. The physical qualities and methods of obtaining these stresses will also be discussed.

1. INTRODUCTION

A microshutter is a MEMS actuator that is capable of rolling a stacked layer of thin films into itself and unrolling it. This device may be used in regulating the transmission of light waves passing through an underlying substrate. It's practical applications lie in the field of electric display devices. The function of the microshutter will be discussed first, however.

The central aspect of the microshutter is a stacked layer of sputtered thin films. A layer of SiO_2 / Al / SiO_2 is patterned to created a long rectangular "shutter" attached to a contact (image 1: appendix).

This layer will remain curled in on itself during the off state when there's no external voltage applied to the device (image 2: appendix). This is due to the interaction of stresses in the different layers. When a voltage is applied to the device the layer rolls out just like a window shutter unrolls. Through control of the voltage it is possible to determine the rate of the curling and uncurling of the microshutter.

In order to utilize the microshutter in an electrical display there must be arrays of the devices fabricated. These arrays would be assembled on top of a glass substrate. The substrate would pass either white light or ultraviolet light, and an array of shutters would then regulate when this light was allowed to pass. The placement of color filters above certain arrays of microshutters would then allow the microshutters to control what color was viewed [1].

There are many issues involved in producing a successful microshutter. The most crucial is obtaining the correct stress characteristics in the thin film stack. This device utilizes a lower SiO_2 layer with compressive stress and a middle Al layer with tensile stress.

Compressive stress is the application of a force that squeezes a member together. In semiconductor processing this will cause a thin film to buckle and look like a bubble or dome from above [2].

Tensile stress is the application of a force that pulls a member apart. This is normally seen as cracking or lifting in thin films [2].

Both of these stresses are necessary for a functional microshutter. And they must be present in a substantial amount.

Stiction is another important issue that must be considered when making the device. When the microshutter is unrolled it will be making contact with the surface beneath it. The microshutter must not become stuck to the substrate; or else the device will be ruined.

The last problem to be discussed here is the charge transfer between the upper electrode and the lower electrode. When the stacked film that makes up the microshutter is at rest in the off state there is no voltage applied to it and charge transfer is not an issue. However, when a voltage is applied and it unrolls the close proximity to the lower electrode allows for charge to be lost.

This reduces the voltage on the upper electrode, and the electric field is weakened. Consequently the electrode will prematurely drift upward out of its rigid on state.

The fabrication of a microshutter and the crucial steps to combat the previous issues is presented here.

2. PROCEDURE

A. Design

Numerous variations of microshutters were included in the overall design. There were three groups of identical arrays that consisted of eight rows of eight square microshutters (metal: appendix 2). There were also three other groups of differing arrays. One contained rectangular microshutters, and another consisted of couplets of thin rectangular microshutters. The final array was composed of hammerhead shaped microshutters.

There was also a number of individual microshutters that were designed. They were all taken from the molds used for the microshutters in the arrays; there were squares, rectangles, hammerheads, and coupled rectangles.

The layout for the overall design of the microshutter involved six separate masks for four levels (appendix 2). The first level was a layer of silicon oxide that was patterned with the Top Contact Window mask for a contact to the lower electrode. The second level was a layer of aluminum that was patterned with the Contact mask in order to provide protection for the aluminum contact with a coating of photoresist.

The third level was a sacrificial layer that would remain underneath the microshutter. The third layer was defined with both the Active mask and the Dimple mask. The Active mask was used in order to define the size of the sacrificial area, and the Dimple mask was used patterned long thin lines into the sacrificial layer

The fifth mask, Metal, was used to patterned the microshutter onto the stacked film of SiO_2 / Al / SiO_2. And the final mask, Contact Window, was used on the same level in order to provide a contact to the upper electrode.

B. Processing

The problematic issue of charge transfer from the lower electrode to the upper electrode was the simplest to correct. The growth of 1000Å of SiO_2 was used as an insulating layer between the lower electrode, which in this case was the substrate, and the upper electrode, the stacked thin films

Following the oxide growth patterning of a contact to the lower electrode was performed using the Top Contact Window mask on the GCA 6700 g-line stepper. The program used was MEMS1\TRENCH. The contact to the substrate was etched, and the wafer was then sputtered with a layer of aluminum.

This layer was patterned with the Contact mask using the MEMS1\ACTIVE program. The aluminum was etched in order to define a contact, and the exposed photoresist was left on the wafer in order to protect the aluminum contact from damage in later steps.

Spin coating a sacrificial layer of Shipley 812 photoresist was next. This layer was exposed first with the Active mask, using the MEMS1\METAL program. It was then exposed again before development of the first exposure with the Dimple mask, using the MEMS1\ALIGN program.

The patterning of the "dimples" in the sacrificial layer was done in order to combat the issue of stiction with the device. Lines running the length of the patterned sacrificial layer were created in order to reduce the contact that the bottom layer of the stacked thin films would have with the oxide layer. Exaggerated cross-sections of this layer are shown in appendix 1.

The "dimples" also provide the added effect of strengthening the stiffness of the stacked layer. This aids in preventing it from curling perpendicular to the direction that it is intended to roll up in [1].

The sputtering of the stacked film followed the coating of the sacrificial layer. The desired thickness for each level of the stacked layer was 300Å. The SiO_2 / Al / SiO_2 layer was sputtered in a Perkin-Elmer X-Randex Model 2400. Both of the silicon oxide layers were sputtered at 700W for 4 minutes with an argon flow of 30sccm at 10mTorr of pressure. The aluminum was sputtered at 100W for 5 minutes with an argon flow of 60sccm at 5mTorr of pressure. These recipes were run in order to obtain a compressive stress in the silicon oxide layer and a tensile stress in the aluminum layer.

Following the sputter the wafers were patterned with the second mask set using the Metal mask with program MEMS1\TRENCH. This defined the shape of the microshutters. A contact to the upper electrode of the stacked films was then exposed onto the layer before the previous pattern was developed. This was done with the Contact Window mask, using program MEMS1\ACTIVE on the GCA 6700 g-line stepper. The patterns were then developed in the photoresist and the stacked film was etched in phosphoric acid.

As in most MEMS devices the removal of the sacrificial layer is an important step and also the last step performed. The photoresist that still remained on the wafer, following the etching of the stacked layer, was the sacrificial layer beneath the microshutters and the covering of the aluminum contacts to ground.

These patches of photoresist were removed using an O_2 plasma in an asher for ten minutes.

3. RESULTS

The sputtering of the silicon oxide resulted in 800Å for both the top and bottom layers. While there was 300Å of aluminum sputtered. The characteristics of these thin films are shown below:

Material	Average Stress	Maximum Stress	Center Stress
SiO_2	-18 MPa	-115 MPa	-70 MPa
Al	126 MPa	235 MPa	147 MPa

The negative signs are used to denote the compressive stress of the silicon oxide, and the tensile stress is valued as positive.

The wet oxide growth for the insulation layer resulted in 1180Å of SiO_2.

4. DISCUSSION

The increased thickness of the insulating oxide layer was not a serious problem, since the insulating layer is not crucial to the function of the device. However, the increased thickness of the SiO_2 presented a difficulty.

The process used for depositing the silicon oxide did not provide a large compressive stress. Therefore the addition of weak silicon oxide would only help to prevent the microshutter from curling up when the sacrificial layer was released.

Possible modifications could be made to the recipe for the sputtering of the SiO_2 in order to increase its compressive stress. One method would be to bombard the surface of the silicon oxide with ions. The momentum transfer from the ions to the SiO_2 atoms would move them into closer proximity with each other. This would result in a compressed state for the film once the growth was completed. This method is known as "ion peening" [3].

Another method that could be used to create a higher compressive stress would be to add material beneath a deposited layer. Chemical reactions that occur during the deposition process could produce this stress if they were reacting for some time beneath the growth surface of the thin film. When the growth surface rises and the thin film begins to harden the extra material would cause the compressive stress beneath it. This is typically performed in a poor vacuum with oxygen purposefully added as a background gas in order to cause oxidation [3].

Another difficulty in the process besides obtaining the correct film stress was the simple alignment of masking levels. The program recommended for use with the mask set was CMOSMIXA.FAC, however the alignment marks were not located in the same place for this mask as they were for the masks used with the CMOSMIXA.FAC program. The MEMS1 program was able to find the alignment marks though.

Therefore large amounts of time were spent on simply trying to align subsequent levels of the device. Significant X and Y alignment errors were evident on the second level, though the following levels aligned correctly with the second level.

The main result of this was that the contacts to ground were made thinner due to the protective coating of photoresist being offset. There were also a number of sacrificial layers that did not line up correctly with the microshutters patterned in the stacked film that was deposited on top of them.

5. CONCLUSION

The microshutter was unable to be manufactured successfully due to the weak compressive stress of the SiO_2 layer and the increased thickness of this layer. Alignment issues with the GCA 6700 g-line stepper also prevented the successful placement of many devices.

The design and implementation of a process, along with the difficulties found, for this device have left it as a good project for future work. Possible enhancements would be fabricating the device on a glass substrate and adding the color filters as previously discussed.

REFERENCES

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Justin Brown, originally from Cape Cod, Massachusetts, received a B.S. in Microelectronic Engineering from Rochester Institute of Technology in 2000. He attained co-op work experience at Intersil (formerly Harris Semiconductor) in Palm Bay, FL and Motorola in Austin, TX. He is planning on enjoying his summer and then working in the New England area for the fall of 2000.