OPTICAL ATTENUATORS ON A SINGLE CHIP

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ABSTRACT

The use of micromachining has risen in popularity due to an increasing need to reduce the size, cost, and power consumption of electromechanical devices. By using these miniature devices, or MicroElectroMechanical Systems (MEMS) devices, bulky and expensive optical systems that are currently used in many industries can be replaced. This paper presents a novel method of fabricating moving gate optical attenuators on a single chip. Using MEMS technology, remote sensing and satellite-to-satellite communication, with on-board independent optical and signal processing systems, are now possible.

INTRODUCTION

The idea behind micromachining is to provide a method of designing and fabricating miniature structures for space applications. Due to the inaccessibility of aircrafts, spacecrafts, or satellites, it is necessary to develop miniature, light-weight systems that are independent of ground control. An area that has a great potential for this technology is remote sensing. There are an unlimited number of applications, including the Mars Pathfinder, taking air-borne measurements of the ozone layer, volcano emission monitoring, crop analyzing, and urban expansion tracking (Hardin, 1999).

MEMS device fabrication uses the same technology as Integrated Circuit (IC) device fabrication. Therefore, funds do not need to go toward the development of fabrication processes, as the same equipment is used. The dimensions of MEMS devices are on the order of micrometers, which means that several devices can fit on a single die of 1 cm x 1 cm. MEMS devices rival in size with spider mites (Figure 1) and are fabricated one layer at a time two dimensionally. Depending on whether the attenuator gates are positioned together or apart, all, some, or none of the signal passes through the system.

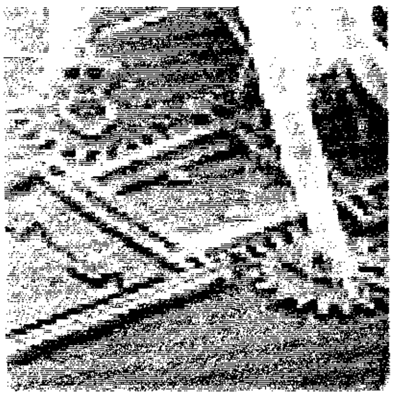


Figure 1
A spider mite overshadows the gears of a MEMS device
http://www.mdl.sandia.gov/micromachine/images.html

METHODS

Computer Simulation & Scale Modeling

In designing MEMS devices, computer simulation software is used in conjunction with physical three-dimensional scale modeling. Since the designs rendered in the software program L-Edit are two-dimensional, there is a need to represent the structure three-dimensionally for analysis. Using L-Edit, it is possible to construct the design of the different components of a MEMS optical attenuator, layer by layer. This project focuses on the design and fabrication of two movable polysilicon gates, which are each held with two supports and three latches and have the capability of rotating on hinges (Figures 2a – 5).

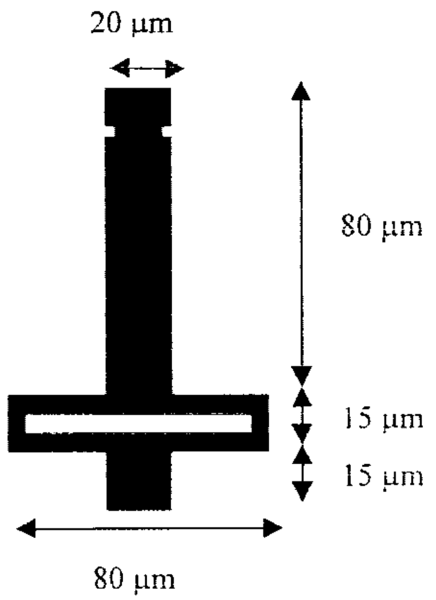


Figure 2a
Latch (top view)

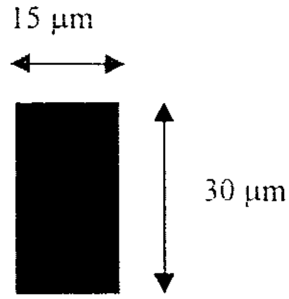


Figure 3a
Hinge (top view)

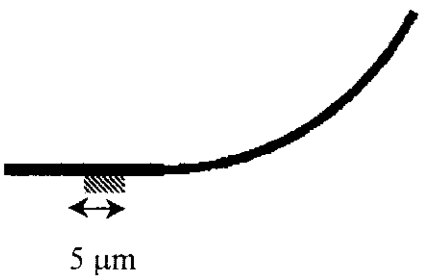


Figure 2b
Latch (side view)

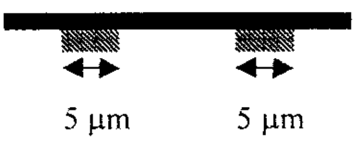


Figure 3b
Hinge (side view)

Figure 4
Support with hinges
(top view)

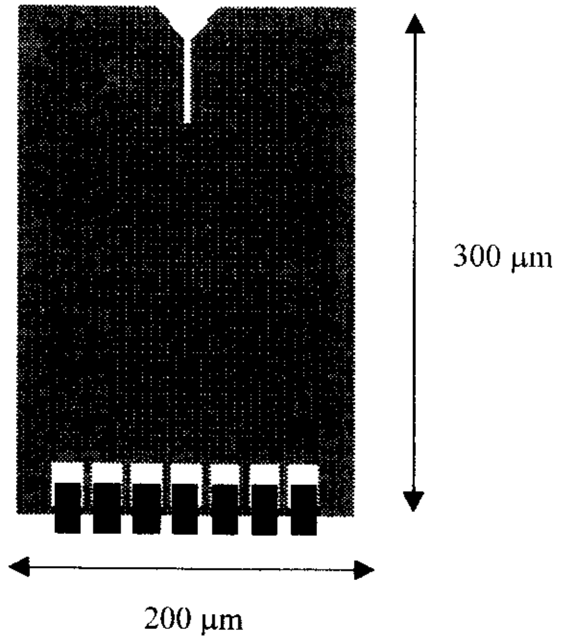
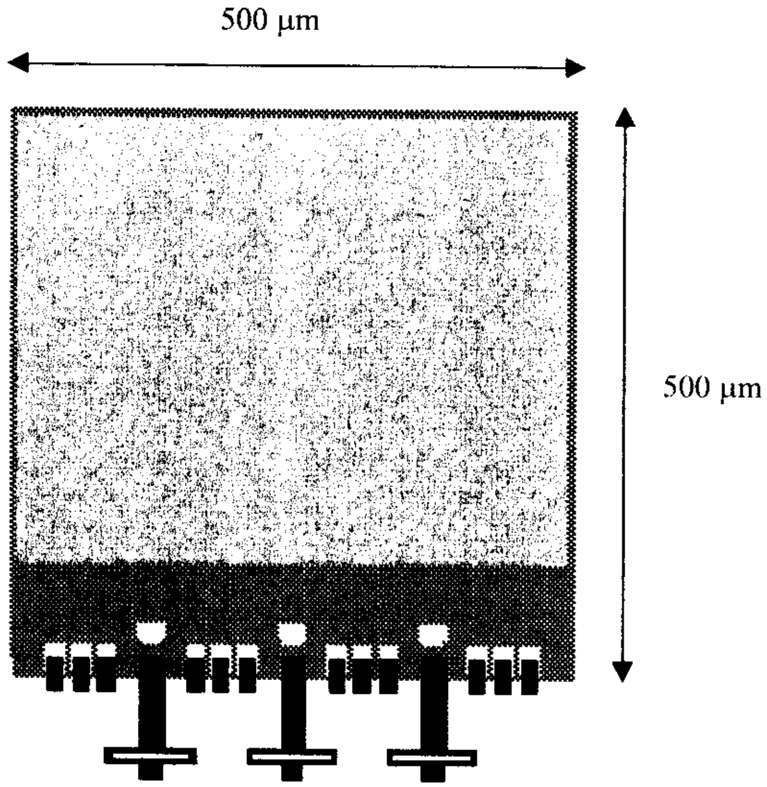


Figure 5
Movable gate with
hinges & latches
(top view)



Gray dots (gate and support) represent the Poly1 layer
Solid black (hinges & latches) represents the Poly2 layer
Solid gray (gate) represents the metal layer

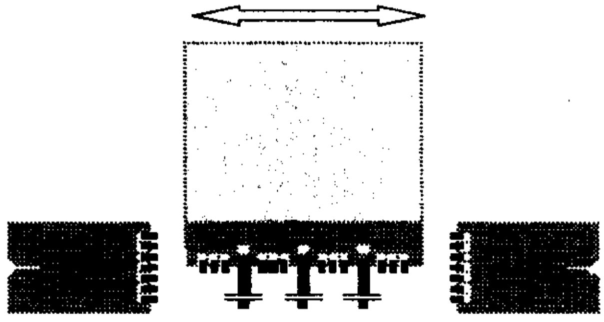
MEMS Fabrication

The three-layer polysilicon fabrication process of MEMS devices are outlined in the MUMPs™ Design Handbook. The Multi-User MEMS Processes, or MUMPs™, is a program that provides micromachining fabrication for industrial, governmental, and educational purposes (Koester et. al, 2000). The features of this process include the use of polysilicon as the structural material, deposited oxide as the sacrificial layer, and silicon nitride to separate the polysilicon and substrate.

The first step of the fabrication process is to dope 100 mm n-type wafers with phosphorous. A 600 nm layer of silicon nitride is deposited, followed by 500 nm of polysilicon. This polysilicon layer is known as Poly0, and serves as the base of the MEMS structure. The wafers are then coated with photoresist and lithographically patterned by exposing the surface to ultraviolet light through the mask (Poly0 layer). Undesired polysilicon is removed through reactive ion etching (RIE), and the photoresist is removed in a chemical solvent bath. A 2.0 μm layer of phosphosilicate glass (PSG), or Oxide1, is deposited by chemical vapor deposition and acts as a sacrificial layer. It is removed at the end of the process to release the first mechanical layer of polysilicon. Next, a 2 μm layer of polysilicon is deposited to form layer Poly1. The wafer is again coated with photoresist, patterned, and etched. Another layer of PSG (0.75 μm) and another polysilicon layer (Poly2) are deposited, patterned, and etched on the wafer. During this process, there are anchors created to connect the top polysilicon layers to the substrate, and holes and dimples to allow for an easier release of the structures when they are ready for use. The final layer is a 0.5 μm layer of gold for electrical conductivity and to provide a highly reflective surface. To release the structure, immerse the chip in a 49% HF bath for 2 minutes. Rinse with DI water and alcohol for several minutes, then bake in an oven at 1100° C for at least 10 minutes.

Operation of the MEMS Optical Attenuator

Once the structure is released, the device is tested on its mechanical abilities and durability. The layout of the gates and supports (top view) is shown in Figure 6. The components are fabricated two dimensionally, but when a small voltage is applied, the structure becomes three-dimensional. Depending on the position of the gates, a certain amount of power is allowed to pass through the gates. Each gate is attached to scratch drive actuators, which are the mechanisms that pull and push the gates. The gates move together to block the signal, and move apart to allow 100% of the power to pass through. Therefore, it is possible for any percentage of the total power to pass through the movable gates. The gates, supports, hinges, and latches are composed of only the Poly1 and Poly2 layers. Anchors attach the Poly1 and Poly2 layers to the Poly0 layer, which composes the base of the structures.



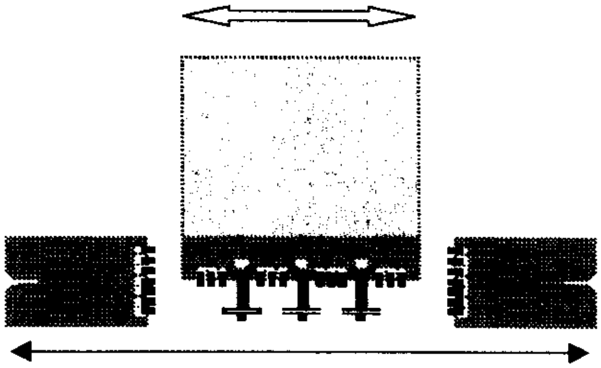


Figure 6
Movable gates with supports
(top view with no applied voltage)

DISCUSSION

In the designing process, problems arise in modeling due to the wide range of dimensions. For the physical model, scaling is sacrificed in some areas to test maneuverability. In addition, the layers are difficult to design according to the fabrication specifications in the MUMPs ™ handbook. The separation distance between anchors and devices need to be greater than 3 μm, which is difficult at times to achieve since the thickness of each layer was less than 2 μm.

The polysilicon layers are extremely thin compared with the dimensions of the gates and supports, yet the structures are remarkably sturdy. However, since the device is on the order of micrometers, there are additional concerns. One example is the presence of water molecules, which leads to the permanent adhesion of different pieces of a MEMS device. This is due to surface tension, van der Waals, and electrostatic attractions (Cohn et. al, 1998).

CONCLUSION

A MEMS optical attenuator design has been developed for space applications. A computer simulation program L-Edit, along with physical modeling, was used for the design. This software made it possible to view the structures two-dimensionally from the top, while modeling gave a three-dimensional perspective. Fabrication is done according to the steps outlined in the MUMPS™ handbook. Finally, the MEMS structure is released in a chemical bath and tested.

A problem that arose was the unexpected duration needed for the design process, more specifically, constructing the device according to fabrication limitations. Also, microscopic forces become problematic and cause adhesion of the different structures.

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REFERENCES

Cohn M., Bohringer K., Noworolski J., Singh A., Keller C., Goldberg K., and Howe R. (1998) Microassembly Technologies for MEMS. *Microelectronics Structures and MEMS for Optical Processing IV.*

Hardin, R. (1999) Remote Sensing Satellite Market Pits Industry Against U.S. Policy. *SPIE OE Reports.*

Koester D., Mahadevan R., Hardy B., and Markus K. (2000) MUMPS™ Design Handbook Revision 5.0. Cronos Integrated Microsystems.