Design and Fabrication of Solenoid-Based Silicon Wafer Gripping Mechanism for Photolithography

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Abstract— Photolithography is a micro-fabrication process widely used for integrated chip manufacturing. This microfabrication technique is also used for the fabrication of microfluidic devices like Lab on Chip (LoC), Organ- on chips etc. As of now, automation has become a standard in almost all manufacturing processes. Automation reduces cost of the product and the human errors that may arise, making it very popular. By developing a table-top photolithography unit, the entire process can be fully automated. This will also eliminate the need of a 'clean-room'. The work shown below aims at designing and fabricating a silicon wafer gripping mechanism for small-scale photolithography unit. The gripper is the most important part of a photolithography unit as it has to handle the brittle silicon wafer safely while picking and placing as well as during the transfer of the wafer from one working station to another. The presented work shows a gripper, operating, in principle, similar to a solenoid. Instead of using vacuum suction or robotic arms to pick and place the silicon wafer, here a simple mechanical device is fabricated to handle the wafer.

Keywords: Photolithography, Automation, Wafer, Gripper

I. Introduction

Semiconductor devices are now being an unavoidable part of this 21st century. The introduction of wide varieties of semiconductor devices made a drastic improvement in all areas of life including electronic appliances, telecommunications, medical science, manufacturing industries, space researches etc. Every such device consists of several electronic components like integrated circuits, diodes, transistors, circuit boards, resistors, capacitors, inductors etc. For the fabrication of integrated circuits as well as micro-fluidic devices, silicon wafer is used as the substrate. The fabrication requires various chemical as well as physical processes. The IC fabrication processes are mainly film deposition, patterning, and semiconductor doping. Out of this, pattern transfer is widely used for both micro-fluidic devices and ICs. Lithography serves as the basics of this pattern transfer. [1] Photolithography transfers patterns using ultraviolet light and is widely accepted as the best method for IC fabrication. The most important factor in photolithography is the requirement of a clean room which is rather expensive to maintain. There can be no dust or other impurities settling on the wafer. The silicon wafer will be coated by a light-sensitive substance known as photo-resist, onto which the patterns are transferred by the UV light. Since the top portion of the wafer is being coated, it has to be gripped from either the sides or the bottom portion. Vacuum chucks use suction to hold the wafer in place.

Hoche, Jens H., et al. (1998) presented a silicon microgripper for photolithography and fast anisotropic silicon etching applications. They developed a microgripper which was driven by a differential-type shape memory alloy (SMA) actuator. SMA was used because they exhibit the best power- to-volume ratio, do not release any particles, and can perform various movements like bending, elongation or twisting.

Engelbrecht, Orest (1989) developed a wafer handling system which automatically removes a randomly oriented wafer from the cassette and characterizes in X, Y, and θ with respect to the spin axis in one spin. It also precisely aligns each wafer for each exposure with least handling.

Kalkowski, G., et. Al. (2001) developed high precision electrostatic chucks for electron/ion-beam applications. The selection of a proper chuck dielectric was crucial and different materials including sapphire, quartz and glass-ceramics were tested for chucking force under vacuum conditions.

Roch, I., et al. (2003) fabricated a shape memory alloy thin film. The SMA was used as the actuation part for a gripper made of SU-8 thick photoresist. Finite element analysis showed that a force of 50mN should be produced by the SMA actuator.

II. Design and Fabrication

The work presented in this paper focuses on designing a simple, cost effective and efficient wafer gripping mechanism. The entire mechanism consists of two major parts:

- Arm
- Gripper module

The general idea of the gripping mechanism can be understood from schematic diagram Fig 1. The arm houses the gripper modules which in turn does the actual gripping. The gripper modules contain the mechanism for gripping and releasing the silicon wafers. Three gripper modules will be arranged in the arm, each contacting the wafer at a single corresponding point.

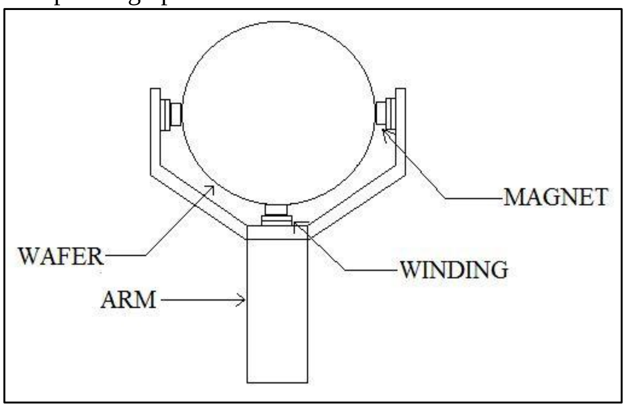

Fig. 1: Schematic diagram of wafer gripping mechanism.

A. The Arm

As mentioned earlier, the arm houses three gripper modules. The arm is designed to grip silicon wafers of 4 in. diameter. The arm surrounds one half of the circle of the wafer as shown in fig. 1. For fabrication of the arm, Polymethyl methacrylate sheets (commonly known as acrylic sheets) of 3mm thickness were used. Acrylic was chosen for this application since UV does very little damage to it over time. Acrylic sheets are also easily available and inexpensive.

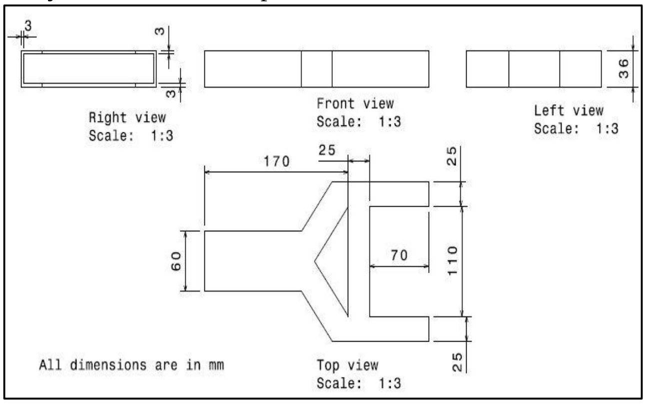

Fig. 2: 2D drawing of the arm showing all views

In Fig 2 the full scale dimensions of the designed arm can be seen. The drawing was drafted in CATIA V5R19 from its corresponding 3D model.

B. Gripper Module

The gripper module is the part of the whole gripping mechanism that is responsible for holding the silicon wafer. Silicon wafers are quite brittle and if gripped tightly, it will break. Also care must be taken to ensure that adequate pressure is applied while gripping the wafer otherwise it will fall off and be damaged. In this design, both these cases have been carefully considered. The basic working principle of the gripper is Faraday's Laws of Electromagnetic Induction. The working will be understood once all the parts of the module have been explained. The different parts of the module are:

- Solenoid coil
- Core for the solenoid
- Body

As mentioned earlier, the wafer is gripped and released by the action of a solenoid. The movement of the solenoid determines whether the module is in contact with the wafer or not.

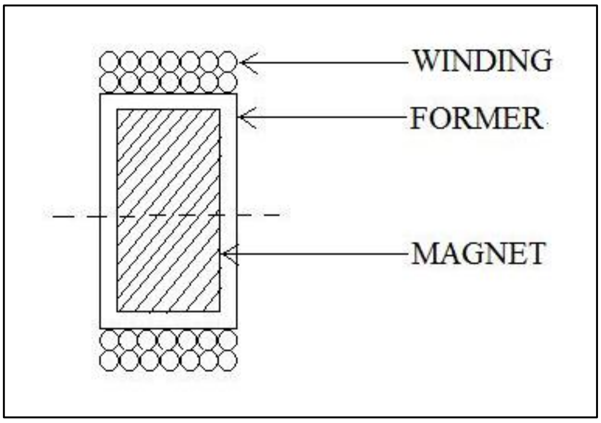

Fig. 3: Schematic diagram of the solenoid

The first step in fabricating the solenoid was to identify a suitable core. The core had to be small owing to space restrictions yet have good magnetic strength. Based on these constraints, Neodymium magnets were selected. The magnets are 10mm in diameter and 3mm thick.

A former was made onto which the coil can be wound. The former had to be made out of a material that was rigid yet flexible enough to be bent and made into a circular form of the required diameter. For this purpose Triacetate and polyester sheets were used which are commonly used for making X-ray films. The former had a diameter of 10.5mm and thickness of 4mm.

The coil was hand-wound using 33 SWG copper winding wire. The small wire gauge was selected so as to accommodate greater number of turns. Because inductance is directly proportional to the number of coil turns, more turns would create more inductance. The wire was wound layer by layer, each layer having 9 turns. This was fixed at 9 turns because the 4mm thick former could not accommodate more than 9 turns per layer. A total of six layers were wound thus making the total number of turns to be 9x6=54.

Fig. 4: Image of the fabricated solenoid coil

The outer diameter of the coil thus came to be 14mm. Each turn of the coil was bonded to the former/lower layer by ethyl 2-cyanoacrylate, commonly known as Super Glue. The coil has a resistance of 1.8Ω. The flow of current through the coil creates a magnetic field which will cause the magnet to attract to it or repel from it.

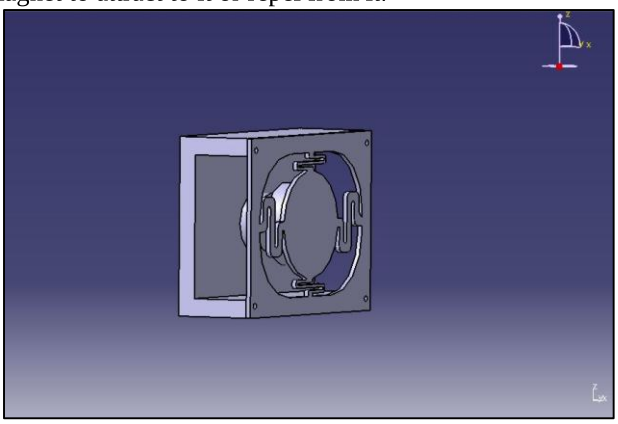

Fig. 5: 3D model of the gripper module

The top, bottom and rear side of the module body was fabricated from 3mm thick polycarbonate sheets. The front facing side of the module was laser cut into a planar spring design. This design allowed the to and fro motion as the solenoid was energized and de-energized. The above said part was fabricated from 0.8mm thick Mica laminate sheet. Mica sheets are thin, has good resilience and rigid, making it an excellent choice for this purpose.

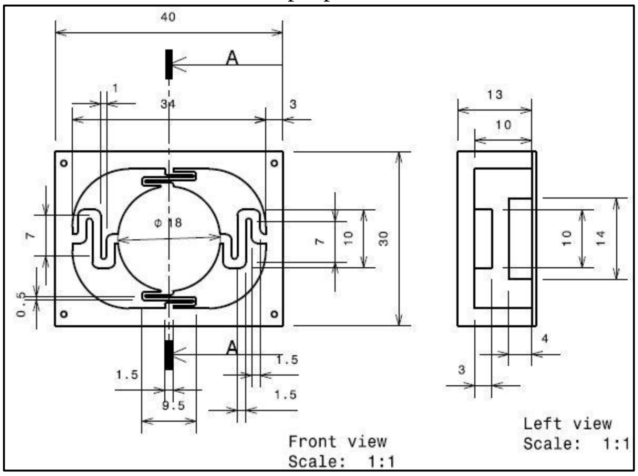

Fig. 6: 2D drawing of gripper module showing front and left side views. All dimensions are in mm.

The 14mm outer diameter solenoid coil was bonded onto the rear side of the Mica sheet using epoxy resin and hardener adhesive. The 10mm diameter neodymium magnet was bonded using the same adhesive onto the polycarbonate sheet as shown in Fig 6. Small circular pieces of the mica sheet laminate will be bonded onto the front side of the module, at the centre, so as to form the contact point. This will be in contact with the silicon wafer.

III. WORKING

When the coil is energised, it will be attracted towards the magnet thereby releasing the wafer. When the coil is de-energised, the mica sheet will spring back to its original position, where it will grip the wafer. The gripping is ensured by the stiffness of the mica sheet. This arrangement will provide a fail-safe mechanism whereby even if the power fails the wafer will still be gripped. Since no other external force is provided, the wafer will not break from undue pressure.

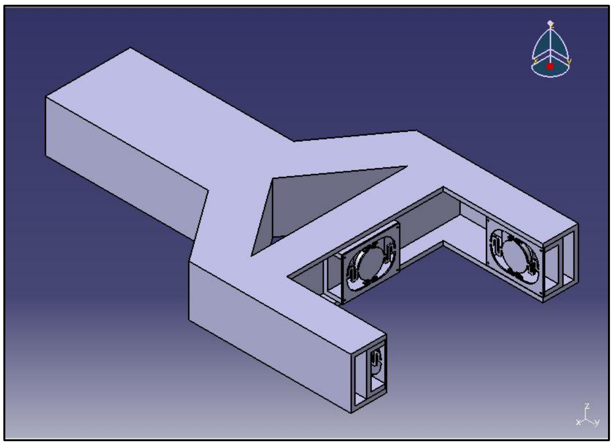

Fig. 7: 3D model of the wafer gripping mechanism

A Switched-mode Power Supply was used for providing the necessary voltage. Generally, SMPS provides 3.3V, 5V and 12V positive voltages. After testing with each output voltage, it was found that the 5V supply provided the necessary current for a satisfactory displacement of the gripper contact point. The gripper will be controlled by an Arduino UNO board which will energise and de-energise according to a programmed sequence. For testing purpose a simple LED blinking code was compiled and the gripper was found to be working satisfactorily. The Arduino cannot be directly used to drive the gripper since the excessive current will damage its circuit. Due to this reason, a 5V relay module which can easily support 10A of current was used to switch the gripper on and off. The digital signal from the Arduino will turn the relay on and off which in turn will switch the gripper, on and off, that is connected to its high voltage side.

IV. RESULTS AND DISCUSSIONS

The wafer gripping mechanism was fabricated and the gripper module was tested to ensure operation. The coil has a resistance of 1.8Ω. By Ohm's law,

$$R = V/I \quad (1.1)$$

Where, V is the supply voltage
I is current and
R is the resistance

From equation 1.1 we can calculate the current that is passing through the coil when a 5V supply is given.

$$I = V/R = 5/1.8 = 2.778A$$

If the supply voltage was 12V the current flowing through the coil would have been 6.667A. It was noticed that when such an amount of current passes through the coil, it heats up almost instantaneously and cause the adhesive binding the coil together to vapourize.

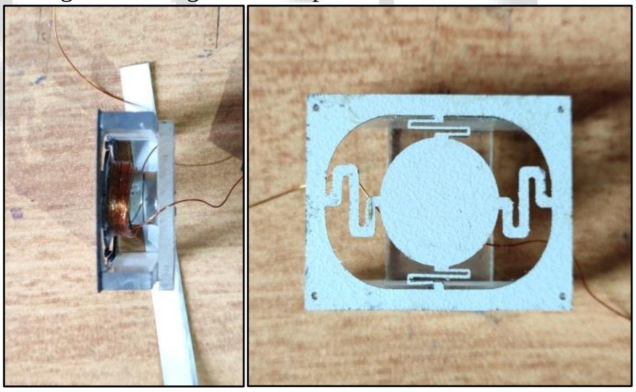

Fig. 8: (left to right) Fig 8: (a) Right side view of the fabricated gripper module.
Fig. 8: (b) Front view of the fabricated gripper module

When 3.3V is supplied a current of 1.83A will flow through the coil but it was found to cause insufficient displacement. Hence the supply voltage was fixed to be 5V. With a supply of 5V the gripper module made a displacement of 0.6mm. But even with the 5V supply the coil does heat up after about 4 sec, vapourising the adhesive bond. Thus we have a time slot of less than 4secs to release the gripped wafer and move the arm away from it.

V. CONCLUSION

The gripping mechanism designed in this work was found to work satisfactorily. The arm can be fixed onto a linear motion guide-way to transport the wafer. Servo motors can be used to give motion to the arm so as to orient the wafer in the direction desired. Since the gripping is entirely dependent on the stiffness of mica sheet and the displacement of the solenoid is below 1mm, very close tolerances were kept. The module had to be placed precisely. As of now the gripper modules were bonded to the arm. Further development can be made by fabricating an arm with movable links so that it can be used for wafers of other dimensions as well. The module can also be made movable for minor corrections by using a screw mechanism. Overall this design provides a simple and safe mechanism to handle silicon wafers.

References

[1] Gary S. May, Costas J. Spanos. "Fundamentals of Semiconductor Manufacturing and Process Control." DOI:10.1002/0471790281, May 2006.
[2] Hoche, Jens H., et al. "Silicon microgripper for microassembly realized by photolithography and fast anisotropic silicon etching." Microrobotics and Micromanipulation. Vol. 3519. International Society for Optics and Photonics, 1998.
[3] Van Doren, Matthew J., et al. "Wafer gripper." U.S. Patent No. 5,700,046. 23 Dec. 1997.
[4] Engelbrecht, Orest. "Wafer handling system." U.S. Patent No. 4,846,626. 11 Jul. 1989.
[5] G.Kalkowski, S.Risse, G.Harnisch, V.Guyenot; "Electrostatic chuck for lithography applications" Microelectronic Engineering Volumes 57–58, September 2001, Pages 219-222
[6] Roch, I., et al. "Fabrication and characterization of an SU-8 gripper actuated by a shape memory alloy thin film." Journal of Micromechanics and Microengineering 13.2 (2003): 330.
[7] Santiago, E., Stephen Roux, and Justin L. Kreuzer. "Wafer handling system for use in lithography patterning." U.S. Patent No. 6,778,258. 17 Aug. 2004.
[8] Daniel J C, Jason T W, Rajan P and Faiz R. "Photolithography with polymethyl methacrylate (PMMA)." Semicond. Sci. Technol. 31 (2016) 025010
[9] Kimberly L. Berkowski et al., 2005 "Introduction to Photolithography: Preparation of Microscale Polymer Silhouettes." Journal of Chemical Education. Vol. 82 No.9.

