DESIGN AND DEVELOPMENT OF A UNIFORM SPRAY COATER FOR SPIN COATING

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Degree of Master of Science

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April 2021

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Thesis/Dissertation submitted in partial fulfillment of the requirements for the degree
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DECLARATION

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The above candidate has carried out research for the Masters thesis under my supervision.

Signature of the supervisor:

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Prof. D. P. Chandima

ACKNOWLEDGEMENT

First, my sincere thanks must go to my advisor, Prof. D.P. Chandima for his continuous advice, guidance, encouragement and patience throughout the course of this work. It has been a privilege to work under his guidance. I am also thankful to the course coordinator, Prof. Buddhika Jayasekara and the staff of the Department of Electrical Engineering, University of Moratuwa for their continuous encouragement.

Further, I am thankful to my mother for believed that I can always do better than I believed in myself. A special thank goes to my wife for encouraged me to reach for a successful end.

W.G.G. Amal
April 2021
University of Moratuwa.

ABSTRACT

Semiconductor coating is a principle technique which is used to fabricate semiconductors. Spin coating is the commonly use technique to coat the semiconductors among the several coating techniques such as spin coating, spray coating, physical vapor deposition (PVD) and chemical vapor deposition (CVD). Spin coating is a process used to deposit uniform thin films to flat substrates by applying a small amount of coating material on the centre of the substrate, which is either spinning at low speed or not spinning at all and the substrate is rotated at high speed in order to spread the coating material by centrifugal force. Although there are few researches done with spin coating technique and its improvements, there are several defects such as limited to flat surfaces, high material wastage and etc. Hence, to overcome from the limitations based on spin coating, this thesis presents designing of a spray coating machine which is better than the existing spin coating technique and to be used in multiple applications.

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LIST OF ABBREVIATIONS

UV	Ultraviolet
CMOS	Complementary Metal-Oxide Semiconductor
PZT	Lead Zirconate Titanate
AC	Analog Current
DC	Digital Current

1. INTRODUCTION

The semiconductor industry is developing rapidly with new technologies. The feature size of the devices is shrinking continuously and the number of devices on an integrated circuit is increasing rapidly. Semiconductor device fabrication is the process that used to produce these integrated circuits which are present in everyday electrical and electronic devices. With the developments of the industry, semiconductor device fabrication processing technology has become more complicated. The fabrication process is a process with multi-steps and it creates the electronic circuits on silicon wafers. The main steps of the semiconductor fabrication process are as follows. [1]

- Photolithography

Pattern of the circuit should transfer to surface of the wafer and this process is call as lithography. In this process, the pattern is transfer to the wafer surface from a photomask. The pattern information is recorded on a photoresist layer and then apply to the top of the wafer. The photoresist is either developed by dry or wet etching. When the photoresist exposed to several forms of light or illumination, its properties can be changed. [1]

- Etching

To create a specific pattern, material should remove and this process is call as etching. Dry etching or wet etching can be used to remove the material. Dry etching is a process which perform the etching by hand while chemical involve in wet etching. To transfer patterns with sub-micron feature size, wet etching is not suited. However, it has a high selectivity and the material is not damaged by it. Alternatively, dry etching is less selective and highly anisotropic but it’s more capable with transferring the small structures. [1]

- Deposition

Deposition is the process to deposit multiple layers of different materials. The two most important deposition methods are chemical vapor deposition and physical vapor deposition. In the physical vapor deposition method, gas ions which are accelerated, sputter particles from a sputter target in a plasma chamber with low-pressure. In chemical vapor deposition method, there is a reaction of a gas mixture on the wafer surface with chemical at high temperatures. [1]

1.1.Photolithography

Photolithography is a method practiced in microfabrication which is used for pattern parts of a thin film or the bulk of a wafer which is also called as a substrate. Photolithography is also called optical lithography or UV lithography. In this process, light is used to transfer a geometric pattern from a photomask which is also called as an optical mask to a photosensitive chemical photoresist on the wafer as shown in Figure 1.1. Then, a series of chemical treatments are used to etches the exposure pattern into the material or deposition is enabled for a new material in the chosen pattern upon the material below the photoresist. Sometimes CMOS wafer will go through the photolithographic cycle as many as 50 times, in complex integrated circuit.

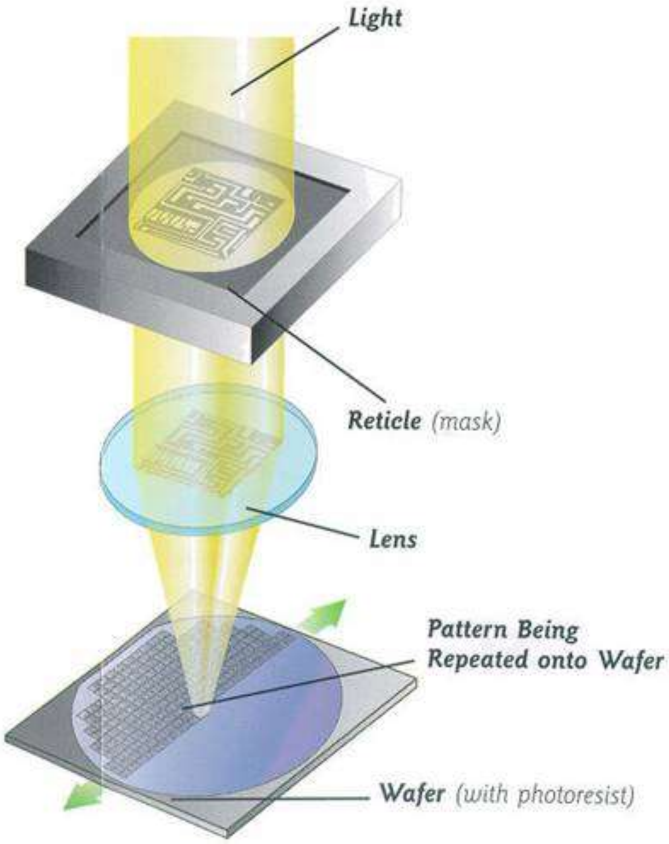

Figure 1.1: Process of photolithography

Photolithography shares some fundamental principles with photography which create the pattern in the photoresist etching with a projected image by using a photomask or by exposing it to light directly without using a mask. This technique is comparable to a high accuracy version of the method which used to develop Printed Circuit Boards (PCB). In the process, subsequent stages have more in common with etching than with lithographic printing. Extremely small patterns, down to a few tens of nanometres in size can be created by using this method. It offers accurate control of the size and shape of the objects it creates and can produce patterns over an entire surface with cost-effectively. Its main disadvantages can be taken as the requirement of flat wafer to start, not very effective at forming shapes that are not flat, and extremely clean operating conditions can be required. The standard method of printed circuit board (PCB) and microprocessor fabrication is Photolithography [2]. Photolithography with positive and negative photoresist is shown in Figure 1.2.

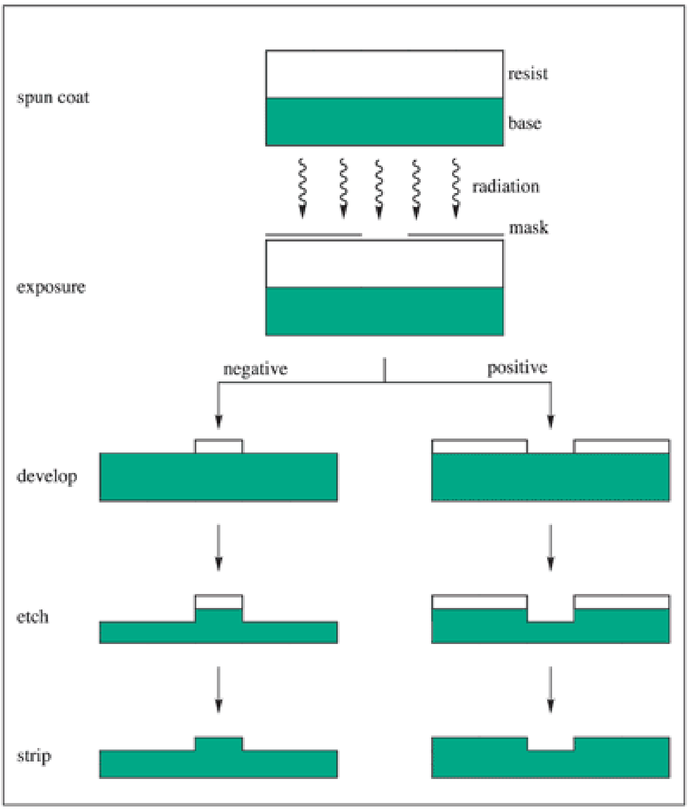

Figure 1.2: Photolithography with positive and negative photoresist

1.1.1. Photoresist

The fundamental materials related with photolithography are called as photoresists. The photoresists materials which are sensitive for light contain with a sensitizer, a polymer and a solvent. Each of these elements contain with a specific function. When the polymer is exposed to radiation, it changes its structure. The purpose of the solvent is to allows the coating photoresist to be spun and form thin layers upon the surface of the wafer. The sensitizer or inhibitor is to control the reaction of the photochemical in the polymer phase.

There are two types of photoresists positive photoresists and negative photoresists. In positive photoresists, the photochemical reaction which happens through the exposure weakens the polymer, tending it more solvable to the designer and hence it achieves the positive patterns. Therefore, a particular copy of the pattern which is to persist on the wafer is contained on the mask, as a template for subsequent processing. When consider the negative photoresist case, the polymerization of the photoresist is caused with the exposure to light. Hence, the negative photoresist remains on the wafer surface where it is exposed and only the unexposed areas are removed by the developer solution. Therefore, the masks used for the negative photoresists comprise the opposite or photographic 'negative' of the pattern which is to be transferred. Both the positive and negative photoresists have disadvantages and advantages. The advantages of positive the photoresists and the negative photoresists are given in Table 1.1.

Table 1.1: Advantages of using positive photoresist and negative photoresist

Advantages of positive photoresists	Advantages of negative photoresists
better resolution	better adhesion to silicon
thermal stability	economical
	less processing time

In order to enhance the bond of the photoresist, a previous training of the wafer is typically carried out. A promoter which gives rise to strong bond of the photoresist to the semiconductor wafer, is applied. This process in semiconductor fabrication is the base for this thesis. To apply the promoter mainly there are two methods as given below.

1. Deposit the promoter by spinning – a process called Spin Coating
2. Deposit the promoter by introducing the wafer to a desiccator with the promoter which can be adhered by evaporation. [3]

1.1.2. Spin Coating

The simplest method for fabricating a film on a wafer is spin coating. An example spin coating is shown in Figure 1.3. With this technique, thin-resist layers are coated for photolithography. The process of spin-coating begins with the weakening of the material to be placed in a solvent.

Subsequently, the solution is distributed on the wafer surface. Then the wafer is rotated from a high speed. The spinning speed, surface tension, and viscosity of the solution are used to determine the thickness of the film.

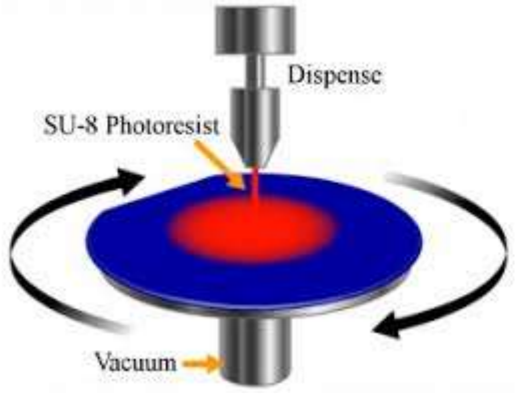

Figure 1.3: Spin coating

During the spinning process, the solvent is removed partially because of the evaporation and partially by subsequent baking at the temperatures which are elevated. The results of spin coating results in a comparatively planar surface. This method is often used for the purposes of planarization. Process of spin coating can be used for the deposition of sol-gels. In this procedure, solid particles of a polymer compound which are dissolved in a solvent are spin-coated on the wafer surface [4]. The procedure creates a gelatinous network on the wafer surface. Subsequent removal of the solvent solidifies the gel, resulting in a solid film. This method can be used for the deposition of several ceramics, such as lead zirconate titanate (PZT). The following process can be used to transfer a resist layer to the wafer surface, besides spin coating. [7]

- dip coating
- dry lamination
- electrodeposition
- spray coating

1.2. Limitations of the existing coating methods

Presently, there are some studies for the coating process of the photoresist for wafer with several methods of coating such as conventional spin coating, extrusion spin coating and conventional spray coating. This section describes about these different methods and the limitations of these methods.

1.2.1. Conventional spin coating

The conventional spin coating method is a coating method which is used to spread a thin coat of the coating photoresist on the wafer surface. As shown in Figure 1.4, in the conventional spin coating method, the coating photoresist is spread over the semiconductor wafer surface by using a centrifugal force and the photoresist is produced as a thin film [2]. This process contains with three stages,

- First dispense the photoresist onto a wafer
- Then spread the photoresist over the semiconductor wafer surface
- At last, the wafer is rotated by giving a high angular speed to reduce the photoresist layer thickness until it reaches the end film thickness and also the uniformity of the coating.

In the initial stage, a slight amount of the photoresist is distributed to the semiconductor wafer surface. Then, in the next stage of the conventional spin coating is spreading the liquid photoresist through the edge of the wafer surface by accelerating the wafer and creating a centrifugal force. In the final stage, spin the wafer continuously with the final angular speed. In this stage, the thickness of the photoresist film is reduced [2]. This photoresist is flowing out from the wafer surface as the concentric waves and reach to its final thickness.

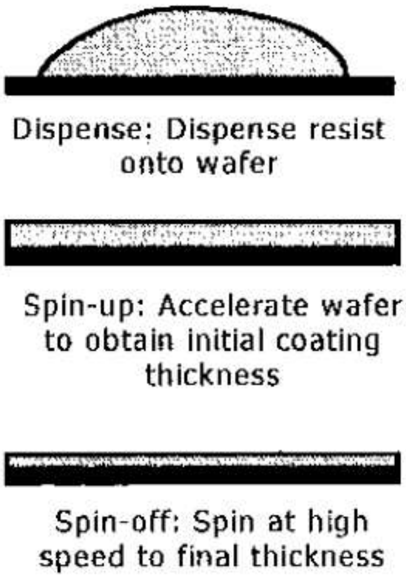

Figure 1.4: Steps of conventional spin coating

Reducing the thickness of the photoresist film is also instigated by solvent evaporation because of the high convection over the surface of the wafer. The viscosity of the photoresist gradually increases, as the solvent fraction in the photoresist decreases. This cause the photoresist outward flow to reduce until it almost finishes. Subsequent reducing the thickness of the photoresist comes mostly from solvent evaporation. Spinning is stopped, usually after about 30 seconds, when the solvent becomes almost evaporate. Then, to evaporate the remaining solvent from the photoresist, soft bake the wafer at a higher temperature.

When consider this conventional spin coating method, less efficiencies of the spreading stages between the dispense and sin-up stages that consumes nearly 60% of the photoresist, is effectively address as a main disadvantage [2]. As an alternative, a model was introduced which was to assume with an primary coating layer of the photoresist which exists on a disk before begin the spinning. Simply thrown off any extra photoresist from the wafer and has no effect on the final thickness of the coating. The conventional spin coating models cannot predict the minimum amount of photoresist needed to coat a wafer, since they don’t model the photoresist spreading from the dispense until an initial layer is established on the disk. Hence, to compensate for the inefficiency created between the dispense and the spin-up stages of conventional spin coating, a new method called extrusion spin coating was developed. To be effective, the extrusion spin coating method must also improve or maintain the coating uniformity, defect level, and coating time of spin coating [2].

1.2.2. Extrusion spin coating

Extrusion spin coaling method was introduced with combinations of the high uniformity capability of spin coating and the high efficiency capability of extrusion-slot coating. To spread a primary photoresist coating layer on a wafer, use the extrusion coating method and then spun the wafer with high speeds to improve the thickness uniformity and to decrease the thickness of the fluid layer [2].

By the extrusion coating process, it’s difficult to coat a flat disk, since the wafer does not contain with a continuous coating width. To resolve this problem, some researches proposed to use a coating die with smal1 extrusion slot which has much smaller coating width than the radius of the disk**.** As shown in Figure 1.5, the extrusion slot is oriented along the diameter of the disk. The disk is spun at fluctuating angular speed, in combination with the relative speed between the wafer and the extrusion head. To apply a uniform thickness layer, this velocity is maintained as a constant throughout each experiment. When the disk is rotated, extrusion head of the coating mechanism is moved along the diameter of the disk

As shown in Figure 1.6, a spiral shaped coating is created with the rotating of the disk at a rate which is proportional to the speed of the extension head. Other than a spiral coating, coating geometries are able to be formed by the help of the rotation rates of other disk and the extrusion head speeds [2]. As in the typical spin coating method, once the complete surface of the disk is coated with liquid, the disk is spun at a high speed to attain the final coating thickness.

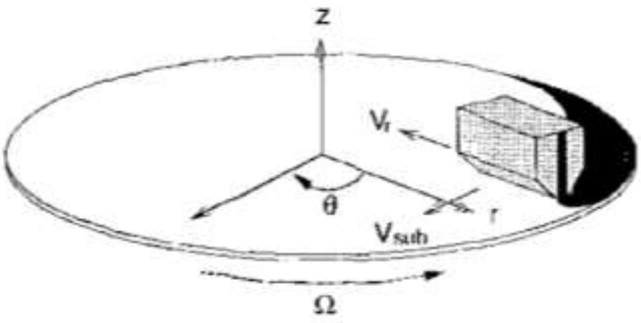

Figure 1.5: Extrusion spin coating

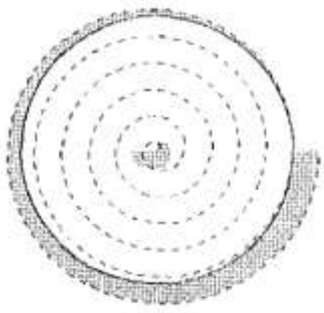

Figure 1.6: Top view of spiral shaped coating

1.2.3. Conventional spray coating

The spray coating technology is not developed as spin coating method. Functions of the spray coating method is on a different principle when compared to spin coating. The spray coating method doesn't suffer from the variations of the photoresist thickness caused by the centrifugal force but it shows the variations in thickness of photoresist due to the photoresist condensation at the spray nozzle. As shown in Figure 1.7, there is a straight spray system which contains an ultrasonic spray nozzle and produces a spreading of droplets in the scale of micrometer. Since, the photoresist droplets are supposed to stay where they are being deposited, the effect of fluid dynamics of the liquid photoresist on the wafer can be reduced. The vital part of the aerosol is advanced to the distribute nozzle which is created to redirect the photoresist spray perpendicular to the wafer surface and to reduce the carrier gas pressure. The wafer is rotated slowly while the swivel arm of the spray coating unit is moved across the wafer, during spray coating. The low spinner speed is maintained to minimize the centrifugal force. Rotating also allows the photoresist to cover all the angle of the cavities.

For coating non-planar surfaces, spray coating presents some advantages when compare with the spin coating method. First, this method uses much less photoresist than spin coating. Spray coating can affect by a less photoresist consumption up to 70% compares to the spin coating process, since the spray process requires no spin off photoresist. Next, the reproducibility of the spray coating is much better than the spin coating. Thickness of the photoresist is repeatable over all cavities with the same size, unrelatedly the cavities of the position on the wafer.

Figure 1.7: Conventional spray coating

Even though the spray coating method shows better results than spinning, fluctuations in the thickness of photoresist can be observed, due to the cavities with a huge difference in size are present on the same wafer and due to the photoresist condensation at the spray nozzle. The thickness of the resist at the base of a slight crack is thicker than the one in a bulky crack. It will lead to a considerable distinction in the thickness of photoresist among the cracks, if there is a huge difference in the dimensions of cracks. Therefore, when applying a similar exposure energy to the wafer, this can disturb the resolution of the patterns which are printed in the photoresist. Hence, if the dimensions of cavities on the same wafer are similar, controlling of the patterning process will be easier. Another issue is the photoresist flowing due to its gravity. As a result, a thicker layer of photoresist at the corner of the base and a thinner layer at the top corner of the same cavity can be observed. This effect of the flow will be a excessive impact for the patterns which run in and across the cracks.

1.3. Objective of the research

Since, the semiconductor industry is moving forward from silicon (Si) to gallium nitride (GaN), industry is no longer limited to flat circular substrates (wafers). Also, the industry is concerning about the material wastage and defects, with the growth of production capacities in nowadays.

Therefore, the main objective of this research is to design a prototype spray coating machine which is better than the conventional spin coaters to be used in multiple applications. The following approaches are proposed in this thesis to achieve the above objective.

- Design a prototype spray chamber with spray head and test the assembly with existing X-Y plotter
- Identify the required process improvements and design a 3D model of concept apparatus based on those improvements
- Implementation of proposed spray coating machine
- Test and troubleshoot the final product

As describe in this chapter, different coating techniques are used for the coating process of the photoresist for wafer. Conventional spin coating, extrusion spin coating and conventional spray coating are the mostly used techniques for this purpose. The spin coating methods are limited to only flat surfaces and not suitable for multiple applications. Therefore, an improvement of spray coating technique is selected as the proposed coating method in this thesis.

1.4. Thesis Outline

The remain of the thesis is ordered as mentioned below.

Chapter 2 presents the methodology proposed for this research. Chapter 3 presents the designing and developing of the spray coating machine. First, it is discussed the limitation identification of the existing spray coating method. Then, the designing of the prototype spray chamber with spray head and improvement identification. Finally, the implementation of the proposed spray coating machine. Chapter 4 presents the testing and troubleshooting of the final product. It is discussed on the spray head testing for uniform particle distribution and the spray head testing for uniform flow. Finally, a test results comparison was done.

2. METHODOLOGY

As discussed in the previous section, the spray coating technology is not developed comprehensively. Hence, a spray coating machine for semiconductor spin coating which is better than the conventional spin and spray coaters and to be used in multiple applications was proposed. Methodology for design and development of this spray coating machine is given in this section.

2.1.Testing of existing spray coating method

Since, the spray coating method is not developed comprehensively, the conventional spray coating method was tested with a spray nozzle. Using this spray nozzle, a semiconductor wafer without cavities was coated to observe the defects. When testing the coated wafer using magnification camera, the main defects of this method were identified. After that, a novel spray chamber and a spray head were designed to full-fill the requirements which were identified from the above test and a prototype spray chamber was developed with the designed spray head.

2.2. Designing the prototype spray chamber with spray head

The conventional spray coating method describe in section 1.2.3. has direct spray system which includes a spray nozzle. After identified the drawbacks of this conventional methods from the test, primarily a spray chamber with a spray head was proposed to eliminate those defects of the conventional spray coating. Then the prototype of proposed spray chamber is designed with a novel spray head and then, this prototype is tested with an X-Y plotter. An example x-y plotter is shown in Figure 2.1.

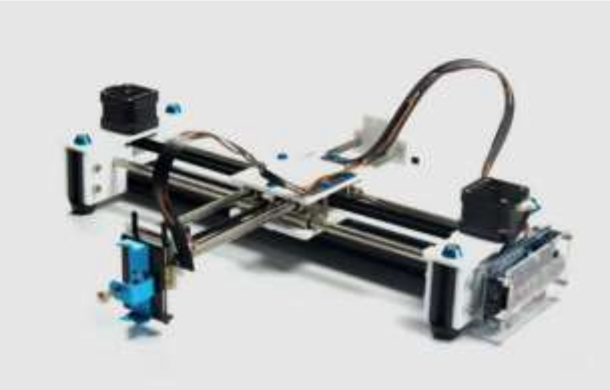

Figure 2.1: XY plotter

2.3. Identify the required improvements

The designed prototype spray chamber and the spray head was tested with the X-Y plotter to identify the required improvements of the prototype design. Therefore, to identify the required improvements first the designed model was implemented on a 3D modelling software. Then, tested with an existing X-Y plotter and relevant improvements were identified. Based on those identified improvements, a 3D model of concept apparatus was designed. The 3D model is modelled by using 3D modelling software and verified the model within the software.

2.4. Implementation of proposed spray coating machine

After designing the 3D model of the concept apparatus of the proposed spray coating machine, it was implemented. According to the finalized design, the required components to develop the proposed spray coating machine were fabricated and purchased. Then, concept apparatus was assembled to develop the complete machine. The developed spray coating machine finally direct to the testing and troubleshooting.

3. DESIGNING AND DEVELOPING OF THE SPRAY COATING MACHINE

3.1. Testing of existing spray coating method

Existing spray coating method or the conventional spray coating method was tested to identify the main drawbacks. Among the several spray coating techniques (such as air spray systems, ultrasonic spray systems, electrostatic spray systems, etc..), the conventional spray coating for semiconductor manufacturing used ultrasonic spray coating method, as described in the section 1.2.3. In the ultrasonic spray systems, there is chip at the end of the nozzle. By ultrasonic waves, it generates the vibration and leads the coating fluid to spread over the chip. Once the coating fluid spread over the chip, ruffling occurs on the surface. After the ultrasonic output overdoes the surface tension, the coating fluid drops from the surface as an acceptable vapor.

To test this conventional spray coating technique, an ultrasonic spray coater with a spray nozzle was used. From this spray coater, a semiconductor wafer was coated to observe its performance. Two main defects were identified from the test and those two are listed below.

- Difficult to control the coating thickness by direct spraying
- Difficult to control the particle size by direct spraying

3.1.1. Importance of coating thickness in thin film deposition

It’s difficult to confirm that the specifications are going to be fully encountered, without achieving a proper thickness distribution. The coating can encounter thickness requirements on several areas of the substrate. However, if it’s not uniformly applied, other areas will be too thick or too thin and may not encounter the performance requirements [8].

Therefore, uniform thickness of the layers in semiconductor fabrication process is very important. After a layer is patterned, if a portion of the layer is thicker than the other portions, it will lead each portion to pattern completion at different times [9]. When some regions are over-etched to achieve etch completion in the other regions, then linewidths in the over-etched regions will be reduced below designed values [9].

3.1.2. Importance of particle size in thin film deposition

The average particle size and the distribution of the width of the particle size on the coating structure is affected for the final product. A variation in the distribution of the width of the particle size effects the micromechanical properties and coating structure as well [10]. The different particle sizes will be caused in different friction and mobility, which is based on the measurements of the response angle, inducing the deposition mechanism at the interface [11]. When the particle size was greater than certain value, the deposition was outstanding mainly for the deformation and cracking during the collision with the wafer.

Therefore, by considering the two main defected that identify by the primary testing a novel spray coating technique is proposed from this thesis. From the above-mentioned test, requirements from the novel (or indirect) spraying technique was exposed. For this indirect spraying technique, the spray chamber and a spray head were designed especially to full filled the requirements which were identified previously.

3.2. Designing the prototype spray chamber with spray head

After identified the required improvements of the existing spray coating method, design and implement the prototype of the proposed coating machine and tested with an existing X-Y plotter. To control the coating thickness and the particle size in suitable way, a spray chamber was designed with a spray head. Instead of direct spraying from the nozzle, the coating liquid is vaporized in the spray chamber first and then discharge the vapor from the spray head uniformly. By vaporized the coating liquid first inside the spray chamber, it leads to give a uniform thickness for the final coating and uniform size of the particles. Therefore, the main improvement done with the proposed method is the spray chamber with the spray head and those two are describe in detail from the following sections.

3.2.1. Prototype spray chamber

To avoid the defect caused by thickness variations of the photoresist droplets due to photoresist condensation, a prototype spray chamber was developed. In this spray chamber, the liquid photoresist is converted to vapor and the vaporized photoresist is conduct to the spray head using a pneumatic tupin. In spray chambers, the liquid is sprayed or dispersed in fine droplets, through a nozzle which is located at the side of the chamber. These droplets are mixed with air within the nozzle and produce a liquid vapor inside the chamber.

The developed spray chamber is shown in Figure 3.1. The spray chamber was developed using nylon material and to vaporized the photoresist inside the chamber, an atomizing pneumatic nozzle is used in the side of the chamber. Atomized photoresist vapor is flown through the vapor out port in the top of the chamber and this happened continuously due to pressure difference created inside the chamber with pneumatic nozzle.

Figure 3.1: Developed spray chamber

3.2.2. Spray head

Because of the two parts of this coating method, spray chamber and spray head, this method can also be identified as a secondary spraying method. After vaporized the photoresist liquid inside the spray chamber, this photoresist vapor is distributed through a spray head. The designed spray head has four input points which are connected to a single point of the spray chamber through a pneumatic tupin to transfer the photoresist vapor from chamber. To spray the photoresist uniformly the spray head consists with multiple output points. Nylon material was used to develop this spray head. The developed spray head is shown in Figure 3.2.

Figure 3.2: Developed spray head

3.2.3. X-Y Plotter

An X–Y plotter is a plotter that operates in two axes of motion ("X" and "Y") in order to draw continuous vector graphics. This plotter provides a plot of the variable with time in the "x" axis and the "y" axis. Two stepper motors which are controlled by an Arduino were used to control the "x" and "y" axis of the x-y plotter. For a better positioning and accuracy, micro stepping of these hybrid stepper motors was used with a basic step angle of 1.8 degree. Two limit switches which are electromechanical devices with an actuator linked to a set of contacts mechanically were used to control the plotter, as safety interlocks. When an object comes into contact with the actuator of these limit switches, the device operates the contacts to make or break an electrical connection.

This x-y plotter was used to observe the output of the existing spraying mechanism with the spray head. To perform a linear spraying from spray head, it is mounted to a X-Y plotter assembly and by programming the movements to the plotter spraying of photoresist is performed on top of the silicon wafer. Figure 3.3 shows the X-Y plotter which was used to move the spray head in horizontal and vertical directions.

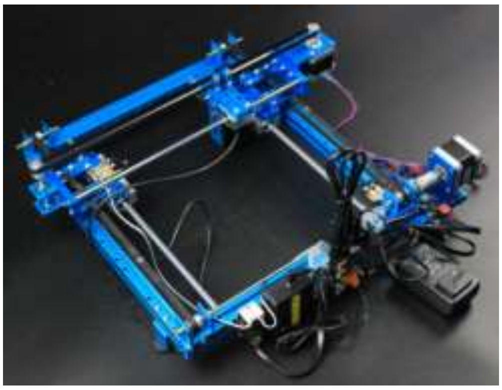

Figure 3.3: X-Y plotter used for testing

3.3. Testing of the spray chamber with X-Y plotter.

The developed spray chamber with the spray head was tested with the X-Y plotter. The 3D drawing which was designed using Autodesk Inventor software with the connections of the spray chamber, spray head and X-Y plotter is shown in Figure 3.4.

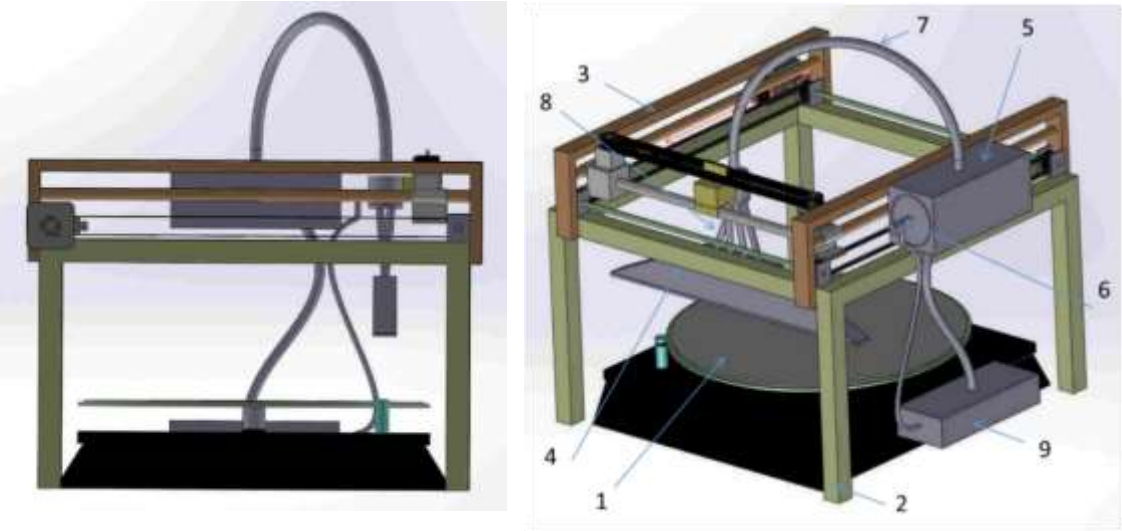

Figure 3.4: Front view and isometric view of test apparatus with X-Y plotter

The parts of the designed model can be described as follows,

1. Silicon wafer
2. Supporting frame
3. Moving arms
4. Spray head
5. Spray chamber
6. Spray nozzle
7. Flexible tube
8. Spray divider
9. Liquid tank with pump

A silicon wafer is a circular shaped thin slice of crystal semiconductor, such as a material made up from silicon crystal. Spray head and the x-y plotter is supported by the supporting frame. Moving arm is provided the capability to move the spray head on this x-y plotter. The spray head described in section 3.2.2. was connected to the spray chamber described in section 3.2.1. to spray the photoresist on the silicon wafer. The spray nozzle was provided the photoresist liquid into the spray chamber and support to convert the liquid to vapor. The photoresist liquid was stored in the liquid tank with the pump. Flexible tube and the spray dividers were used to deliver the vaporized photoresist to the spray head from the spray chamber.

Actual implemented prototype of the coating machine is shown in the Figure 3.5. To test this prototype coating machine, linear motion was added simply to the designed spray head while generating the photoresist vapor inside the spray chamber. Here, an actual silicon wafer is used to test the prototype. From the test some required improvements for the prototype were identified and those improvements are described in the section 3.3.1.

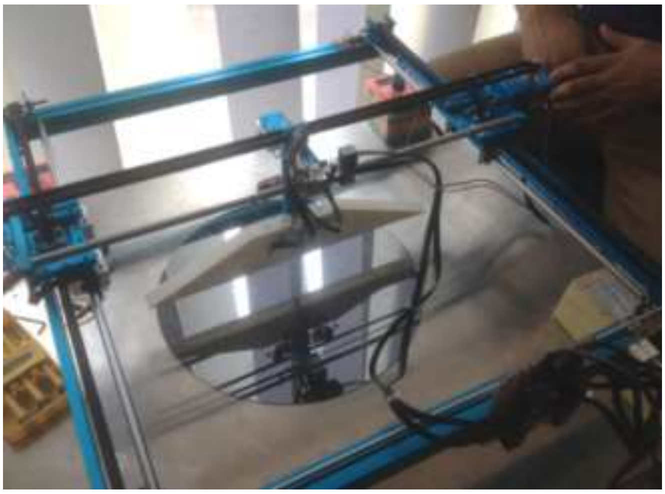

Figure 3.5: Assembling of test apparatus with X-Y plotter

3.3.1. Required process improvements for the prototype spray chamber

After the testing of the assembly with a silicon wafer, two main issues which required changes were identified. The length of the vapor delivering tubes and the linear coating marks on the silicon wafer are the main limitations which were identified from the output of the above test. Due to length of the vapor flowing path from spray chamber to spray head, it is condensed inside the wall of the tupins and result of that condensation, large liquid particles ware flown to spray head. And they were drop on top of the substrate surface and got deformed the coating layer. Substrate having a linear coating marks parallel to the motion of the spray head and due to that overall coating layer having different non uniformed thickness.

Therefore, the following improvements were suggested to control the vapor condensation and to maintain the uniform thickness of the coating layer.

- Vapor should spray against the gravity to obtain uniform fine elements. By spraying against the gravity, it can improve the uniformity of the size of vapor particles and always large particles are avoid to reach to surface due to its weight.
- Should apply an electrostatic force to the vapor to obtain a uniform coating. While spraying vapor against the gravity it is required to apply an electrostatic force to the surface or the substrate to drag uniform size of particles to the surface.
- Spray head should mount on the spray chamber to minimize the vapor condensation. Since vapor got condense inside the walls of the tupins, it is essential to minimize the length of the vapor flowing path. This can be minimized by mounting the spray head top of spray chamber.
- Substrate should rotate to obtain a uniform coating. To overcome the linear coating marks had on top of the coated surface, substrate should rotate during the coating process with a controlled speed.
- Enclosure is required to protect the coating layer from dust particles and it should satisfy the clean room conditions. Since the prototype is required to test semiconductor fabrication method, it is required to meet clean room standards. The prototype is required to have a properly designed enclosure to protect coating surface from dust particles.

3.4. Implementing the proposed spray coating machine

To implement the spray coating machine by introducing the improvements required as described in the section 3.3.1, primarily the spray mechanism should be changed, wafer chuck assembly should be changed and an enclosure should be implemented. The overall design was 3D modelled using Autodesk inventor software and then fabricated by three main systems.

3.4.1. Spray mechanism

Based on the improvements of vaporized photoresist should spray against the gravity and to minimize the vapor condensation in the conducting tubes, spray head is designed to mount top of the spray chamber. This combination of spray chamber and spray head was designed to move horizontally on a linear flatform using linear bearings and assembly is mounted to belt driven stepper motor to perform the spraying. The stepper motor is programmed to rotate using an Arduino MEGA development board and the program is implemented to change the speed of the motor and also the number of cycles of the motor. The combined design is shown in the figure 3.6 and 3.7 with naming all the parts.

The structure frame was designed by mounting two hard plywood plates to two galvanized box bar frames and plywood base plate also mounted to fix development board with motor drivers. Motor bracket was designed to mount stepper motor to the structure frame by using aluminum material. Spray nozzle was purchased and mounted to spray chamber to atomize and create photoresist vapor inside the chamber.

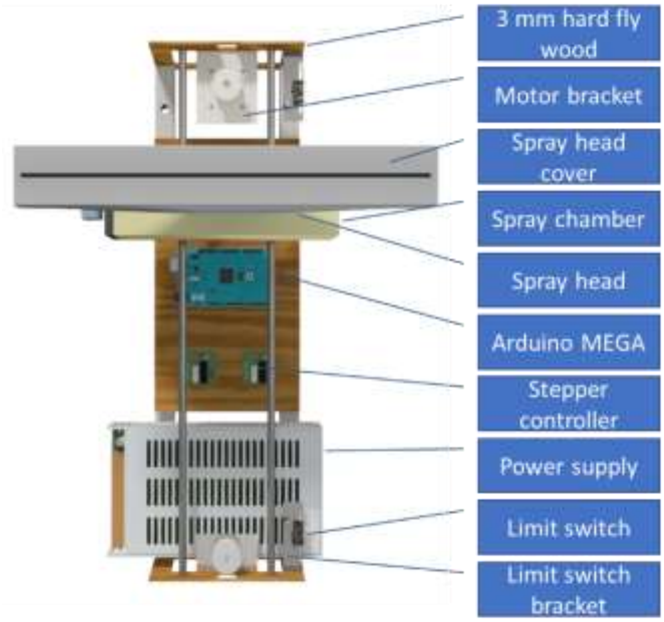

Figure 3.6: Top view of spray mechanism

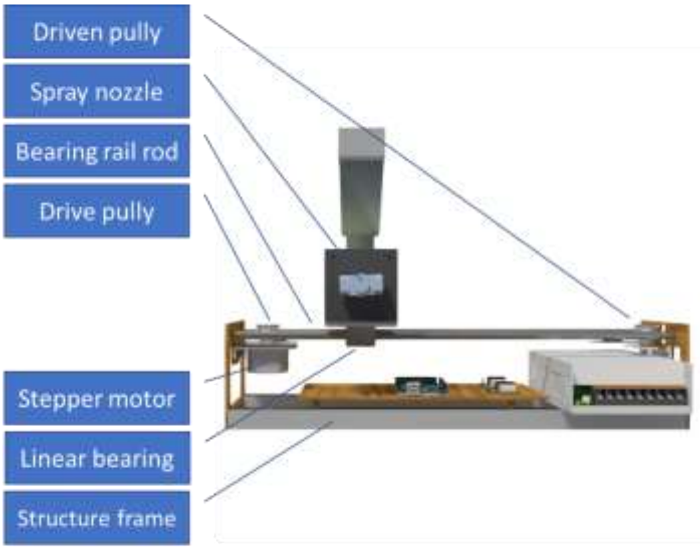

Figure 3.7: Side view of spray mechanism

Spray chamber was fabricated using nylon material and top of the chamber is designed to mount spray head separately and the nozzle is mounted on the side of the chamber. In the bottom there is a drain line connecting port where the condensed photoresist inside the chamber walls is drained back to the liquid storage tank through the drain line. Spray head was 3D printed using plastic material and inside the spray head there is a cavity which is connected inlet port and multiple outlet ports together. By changing the shape of the cavity, several spray heads were designed and tested to obtained a uniform flow.

Arduino MEGA was the development board which is used to control the process of the prototype sprayer. Mainly two inputs and four outputs were connected with this system. Inputs are the signals from limit switches mounted on left and right corner of the structure frame of spray mechanism. Outputs are the rotation speed to the stepper motor controller of the spray mechanism and rotation speed of the stepper motor controller of wafer chuck assembly, the supply to the two DC pumps of liquid circulation system and the supply to the DC pump connected to the wafer chuck assembly.

A 12V 4pole hybrid stepper motor is used to obtain the linear motion of the spray mechanism. The spray chamber is mounted to the belt which is rotate using this stepper motor. A TB6560 stepper driver is used to rotate the stepper motor which gives a micro step resolution up to 1/16. Inputs to this motor controller is given by Arduino MEGA development board. With a maximum current of 3 A continuous, the TB6560 driver can be used to control quite large stepper motors. This chip has several safety functions built-in like over-current, under-voltage shutdown, and overheating protection. However, have to consider about the power supply connection, since the chip does not have reverse-voltage protection. AC to DC 12V power supply is used to supply input voltage to the Arduino MEGA development board, motor controllers and to the DC pneumatic pumps.

Two limit switches are mounted on the left and right corners of the linear flatform to get the position feedback of the spray head to the development board. Two linear bearings and two bearing rail rods are used to create the linear flatform. Where the spray chamber is mounted on top of these two linear bearings and assembly can moved through rail rods smoothly. The overall implemented assembly of the proposed spray mechanism is shown in the Figure 3.8.

Figure 3.8: Implemented assembly of spray mechanism

3.4.2. Wafer chuck assembly

Since the photoresist vapor is spray against the gravity, the silicon wafer should place upon the spray head. Therefore, a wafer chuck was designed to mount to the shutter of the enclosure. Also based on the improvement required that wafer should rotate to obtain a uniform coating layer, the wafer chuck was designed to rotate using a stepper motor.

A 2KV high voltage supply was given to the rotating wafer chuck using a 12V DC high voltage generator and a developed limit switch to obtain the electrostatic force to the vapor particles.

The complete assembly of this wafer chuck was modelled using Inventor software and the model is shown in the Figure 3.9 and 3.10 with naming all the parts. Then the implemented wafer chuck assembly is shown in Figure 3.11.

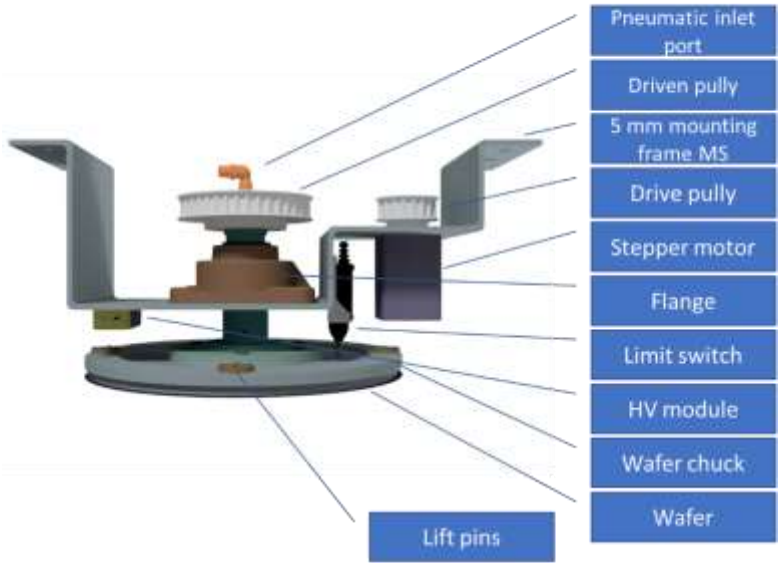

Figure 3.9: Side view of wafer chuck assembly

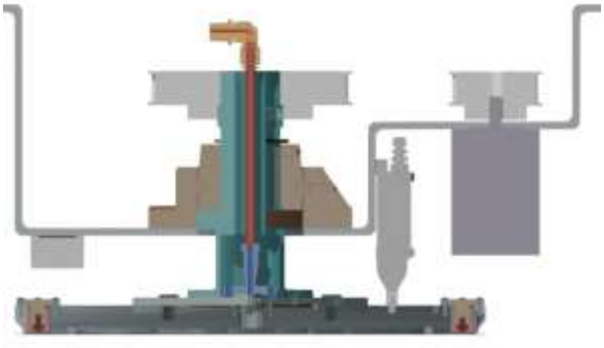

Figure 3.10: Sectional view of wafer chuck assembly

The wafer chuck is designed to hold the silicon wafer by creating a vacuum between the wafer and the chuck. The chuck is machined cut with paths to flow negative pressure to create a vacuum between two surfaces and those paths are connected to the pneumatic inlet port where the vacuum line from the DC pump is connected. 5mm mild steel sheet is used to fabricate the frame of the wafer chuck assembly. Wafer chuck is required to hold and rotate the substrate. To obtain the rotation of the chuck it is connected to a stepper motor. To select the steeper motor, motor torque and the motor power was calculated using the equations 3.1 and 3.2. This is a 12V DC stepper motor which is controlled by TB6560 stepper controller.

A four-bolt pillow block bearing is used as the flange to mount wafer chuck on the frame with rotation freedom. A roller plunger limit switch is used to transmit high voltage from the HV generator to wafer chuck without disturbing the rotational motion. 12V DC high voltage generator is used to transmit high voltage to the wafer chuck to create electrostatic force between the spray head and the silicon wafer. Wafer chuck is designed by CNC machining of aluminium plate to the designed shape with vacuum generating paths.

$$motor\ torque,\ \tau = I\alpha = I\frac{\omega}{t} = I\frac{2\pi N}{60t} \qquad 3.1$$

$$motor\ power,\ P = \tau\omega \qquad 3.2$$

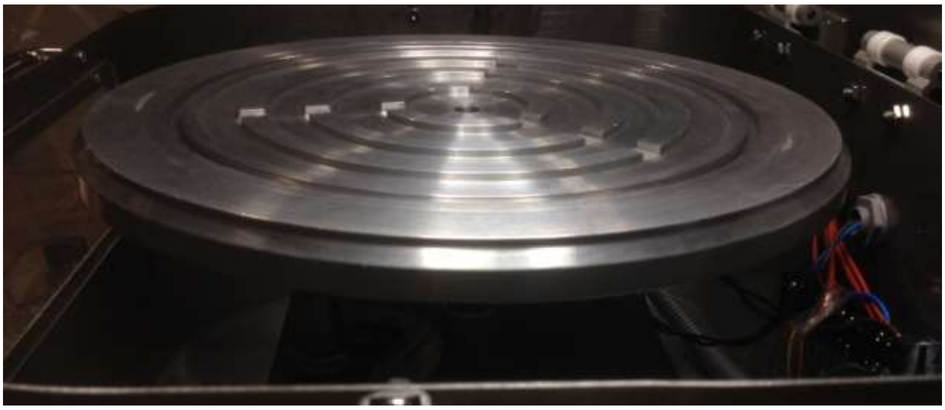

Figure 3.11: Implemented wafer chuck assembly

3.4.3. Enclosure

Enclosure is designed to fulfilled the required protection of the coating layer from dust particles and it is fabricated with stainless steel grade 316 sheet metal to satisfy the clean room conditions. Enclosure is designed with two parts. The lid is mounted to the base of the enclosure using hinges to perform open and close manually. The 3D model of the enclosure is design using the Inventor software and the front view and the isometric view of the enclosure is shown in Figure 3.12 and 3.13 respectively. The enclosure with naming all the parts is shown in the Figure 3.14.

Figure 3.12: Front view of enclosure

Figure 3.13: Isometric view of enclosure

2mm stainless steel grade 316 sheet metal is used to fabricate the lid of the enclosure with designed dimensions. 2mm acrylic sheet is used to fabricate the observation glasses of the enclosure to visually inspect the silicon wafer and the coating surface during the coating process. A U channel rubber seal is used to seal the lid of the enclosure properly. This rubber seal is prevented entering dust particles from outside to the spray coater through the gap between the lid and the base of the enclosure. 3mm stainless steel grade 316 sheet metal is used to fabricate base of the enclosure with designed dimensions.

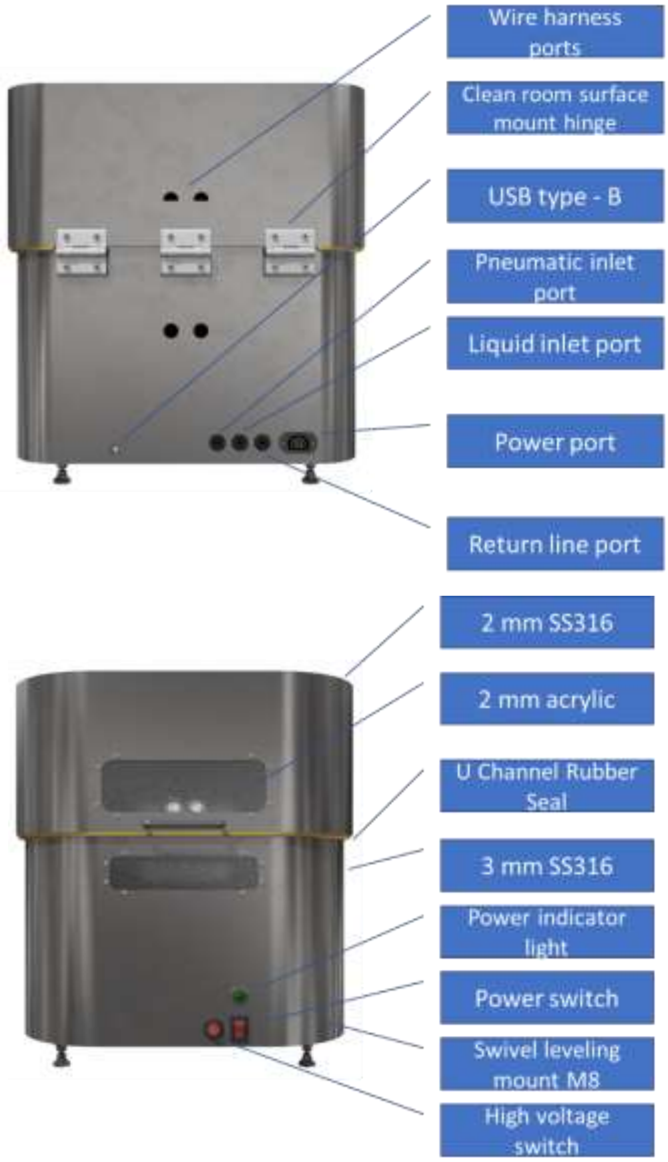

Figure 4.14: Enclosure with naming all the parts

Power indicator light is mounted on front of the enclosure to visually get feedback for switched ON and OFF from the spray coater. A four-pin rocker switch is mounted on the front surface of the enclosure to manually switched ON and OFF the spray coater. 8 mm stainless steel grade 316 swivel levelling mounts were used to level the enclosure. Separate push button is mounted next to the power switch to separately switch ON and OFF the high voltage supply to the wafer chuck. Two holes are cut in the back of the lid and base to connect wire harness from the linear flatform to wafer chuck assembly.

Three clean room standard aluminium surface mount hinges are used to mount lid to the base of the enclosure to perform manual open and close. A USB type – B port is mounted on the back of the enclosure connecting the Arduino MEGA development board from the inside. This allowed to connect PC to the development board from the outside. A hole is designed in bottom back side of the base to lay pneumatic inlet tupin. Pneumatic is supplied from outside separately. Another two holes were designed next to the pneumatic inlet port to connect liquid inlet line from liquid storage tank to coating liquid pump and return liquid line from return liquid pump to storage tank. Female 10A/250V 3PIN C13 Inline Socket Plug Adapter is designed to mount next to the liquid inlet and outlet ports to supply direct power to the spray coater. The adapter is connected to the 12V AC to DC power supply from the inside. After develop the enclosure in Inventor software, the it was implemented and the Figure 3.15 shows the actual images of fabricated enclosure.

Figure 3.45: Implemented enclosure

3.4.4. Liquid circulation system

The liquid circulating system circulate the coating liquid between the liquid storage tank and the spray chamber using two pumps. The coating liquid is sent to the spray nozzle from the liquid tank by supply line pump and the separate pneumatic line is connected to the other side of the spray nozzle. When the both pneumatic and liquid supply to the nozzle is positive, the atomization happened inside the spray chamber. Drained liquid collected inside the spray chamber by condensation during the atomization process is sent back to the liquid storage tank by return line pump. The overall system is shown in the Figure 3.16.

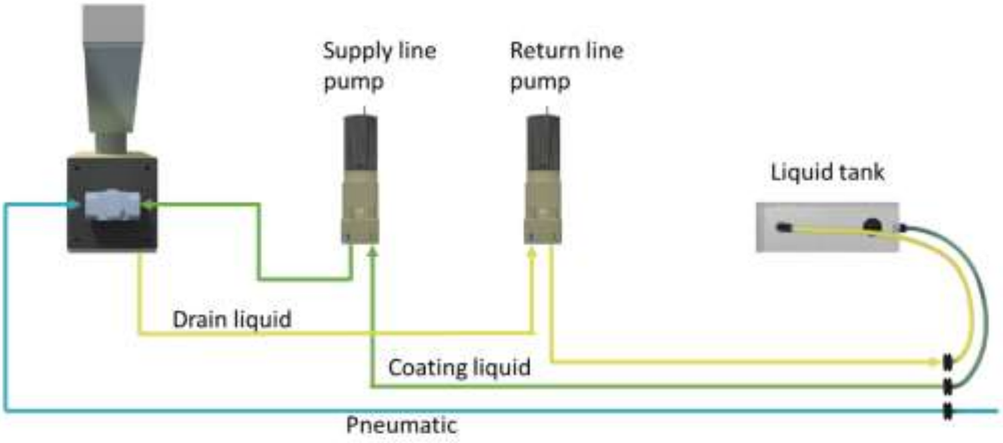

Figure 3.16: Liquid circulation system

3.4.5. Combined design

Using Inventor software, the 3D design of the combined spray coating machine was developed. The completed 3D model of spray coater is shown in Figure 3.17. The spray mechanism including spray head with the spray chamber was placed in the base of the enclosure while the wafer chuck assembly was placed in the lid of the enclosure. The liquid circulation system was placed at the base of the enclosure as shown in the Figure 3.17. From the liquid circulation system, both pumps were mounted inside the base of the enclosure while the storage tank was mounted outside of the base. The liquid tank was placed on the outside of the enclosure base by considering the convenience of refilling the tank with photoresist liquid.

Figure 3.17: Isometric view and top view of combined design

After developed the 3D model of the complete spray coating mechanism, the model was simulated with same software to identify the mechanical issues with the system. From the software simulation, it's identified that the proposed method was satisfied the desired requirements. The prototype of the proposed spray mechanism was implemented according to the 3D model shown in Figure 3.17. The actual implementation of the spray coater is given in Figure 3.18 to 3.20.

Since the semiconductor wafer was placed on the lid of the enclosure and the spray mechanism was placed on the base of the enclosure, the photoresist vapor can spray against the gravity. This will lead for an output with uniform fine elements on the wafer surface and improve the uniformity of the size of the vapor particles because the large particles always avoid to reach the wafer surface due to their weight. Since the spray head was mounted on top of the spray chamber, it leads to minimize the vapor condensation by reducing the length of the vapor flowing path. Since the wafer was allowed to rotate during the photoresist coating process, a uniform coating can be obtained on the wafer surface. Finally, with the enclosure the coating layer is protected from the dust particles and satisfy the clean room conditions.

Figure 3.18: implemented spray mechanism of spray coater machine

Figure 3.19: Implemented wafer chuck assembly of spray coater machine

Figure 3.20: Side view of implemented spray coater machine

3.5. Working procedure

After the prototype spray coater is implemented it is tested for several spray head designs by changing the coating direction, coating speed and the number of cycles need to coat. The working procedure of this developed spray coating machine is described in this section. A complete coating cycle is shown in Figure 3.21.

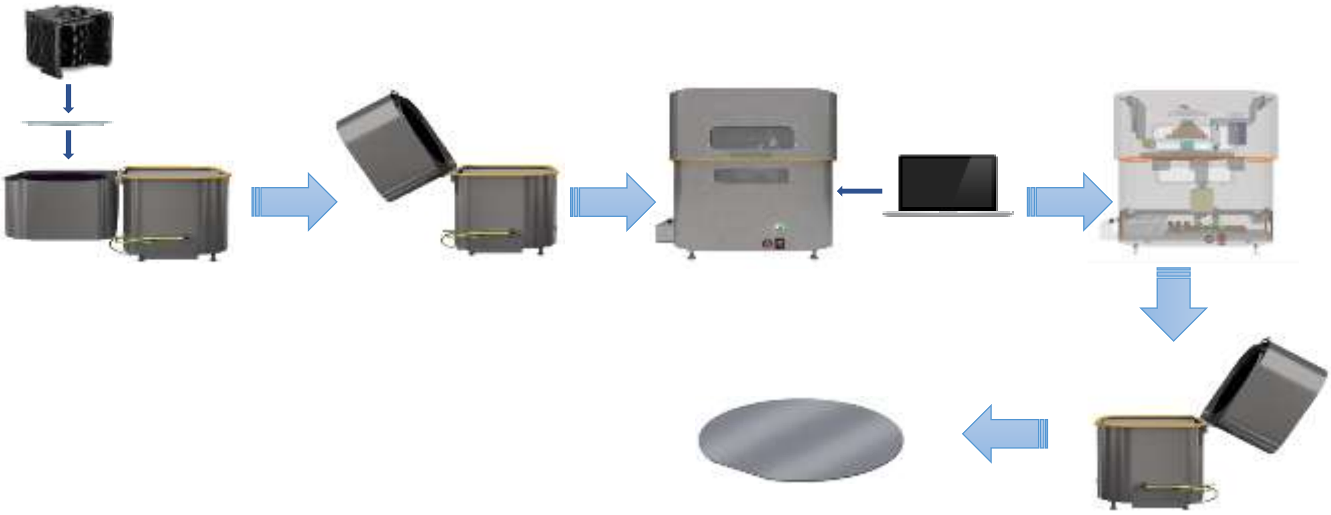

Figure 3.21: A complete coating cycle of spray coater machine

Figure 3.22 shows the step 01 of the coating process. In the initial stage lid is kept open and double checked the supplied power to the spray coater and to the high voltage generator is switched off. The wafer which need to coat, is kept on top of the wafer chuck by aligned with it. Then switched on 12V DC pump next to the wafer chuck assembly connected to the pneumatic inlet port of the wafer chuck by giving signal from the programme to the pump. The wafer is then attached to the wafer chuck by vacuum pressure applying from the pneumatic inlet port in the wafer chuck assembly. With a high vacuum pressure, chuck marks can be applied on the wafer and it can be affected to the quality of the coating layer. Therefore, the vacuum pressure is maintained less than one bar to avoid these chuck marks.

Figure 3.22: Inserting silicon wafer to the spray coater

The wafer should be coated with free of dust particles. Hence, lid of the enclosure should be closed using the safety locks to avoid the entering of dust particles. Step 02 is shown from Figure 3.23. Before closing the lid, the surface of the silicon wafer is checked for dust particles. Then the liquid storage tank is filled with coating liquid manually.

Figure 3.23: Closing of spray coater to initiate coating

Figure 3.24 and 3.25 show the step 03 of the coating process. After the lid is closed properly the spray coater is switched on and checked for the connectivity with external computer. Then the Arduino program is updated with the required parameters and uploaded to the Arduino MEGA development board. When consider the program used for the coating process, there are several functions include with the program. Only the main functions of the program are mentioned in this section and the complete program is not given in this thesis.

First, the rotation speed of the semiconductor wafer should be given to the program. The wafer chuck is started to rotate with that given speed. Then the supply line pump should be started to circulate coating liquid and same time return line pump should also be started to complete the liquid circulation through the spray chamber. The pneumatic solenoid valve is opened and started to supply air to spray nozzle. The atomization is automatically started inside the spray chamber with positive liquid and air pressure. Then the spray mechanism is started to move linearly by rotating the stepper motor with given speed.

Then the supply to the high voltage generator is given by switching on the high voltage switch manually. When the given number of cycles are completed, above mentioned process is stopped by the program. Several parameters which require to maintain during the procedure are listed below.

- High voltage is applied manually and maintained at 2kV
- Rotating speed of the wafer was maintained as 60 rpm
- Time taken to move from left to right of spray mechanism was set to 1s
- Number of teeth at rotating pully of stepper motor was taken as 20
- Number of teeth at belt length was taken as 68
- Number of rotations required for one linear motion was 3.4 rounds
- Required speed to maintain 1s for a motion was 204 rpm
- Spraying air pressure is maintained at 4.5 bar
- Coating liquid flow rate is maintained at 2.8 ml/s
- Number of cycles are maintained at 1000 for each test

The number of rotations required for a one linear motion of the spray head and the speed required to maintain the one second for a motion is calculated according to the equation 3.3 and 3.4 respectively,

$$\begin{aligned}&\text{Number of rotations required for one linear motion}\\&\qquad = \frac{\text{Number of teeth at belt length}}{\text{Number of teeth at rotating pully of stepper motor}} = \frac{68}{20}\\&\qquad = 3.4\ \text{rounds}\end{aligned} \tag{3.3}$$

$$\begin{aligned}&\text{Required rpm to maintain 1s for a motion}\\&\qquad = \text{Number of rotations required for one linear motion } \times 60 = 3.4\ \times 60\\&\qquad = 204\ \text{rpm}\end{aligned} \tag{3.4}$$

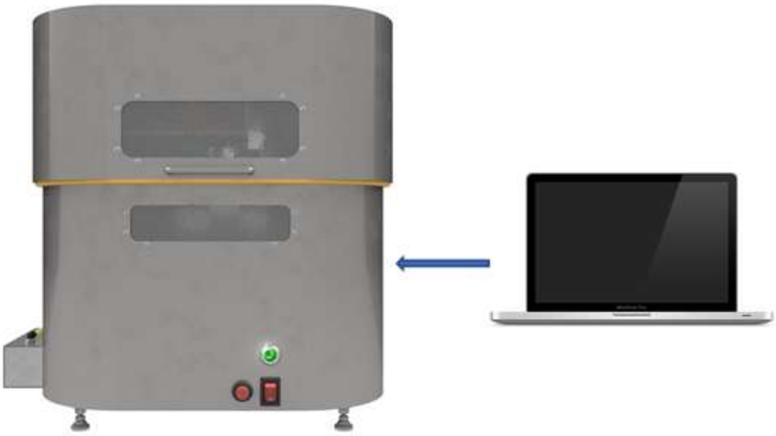

Figure 3.24: Initiation of coating

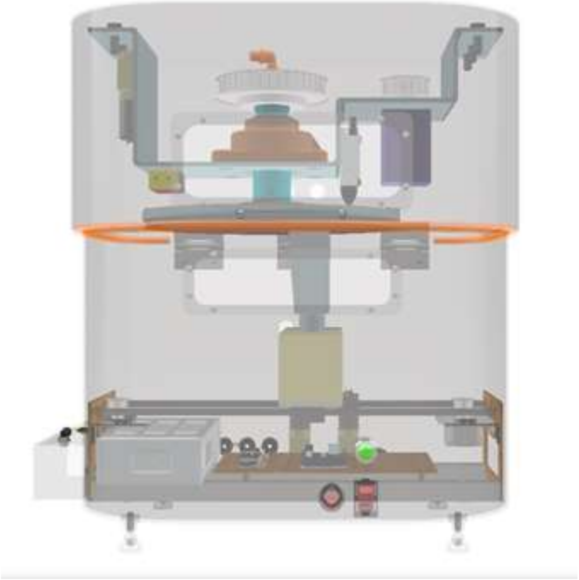

Figure 3.25: Internal view of spray coater while coating

The program was written for 1000 of iterations. Therefore, coating will continuous for 1000 cycles and after 1000 cycles, the program is stopped automatically. Once the program is stopped the high voltage connection have to disconnect by manually. Finally, the lid of the enclosure can be opened carefully and the semiconductor wafer which has been coated from the photoresist can be taken out from chuck. To get out the wafer from the chuck, it required to remove the vacuum pressure since, the wafer was connected to the chuck using vacuum pressure. Final step of the process is shown in the Figure 3.26.

Figure 3.26: Completion of coating

4. TESTING AND TROUBLESHOOTING

After fabrication and assembling of spray coater is completed, the testing and troubleshooting is done to obtain a best quality coating layer. For the testing actual 300mm silicon wafers designed for semiconductor fabrication were used and zinc oxide miscible water is used as the coating liquid. The spray coater is tested for uniform particle distribution on spray head and for uniform flow from spray head.

4.1. Spray head testing for uniform particle distribution

Basically, the spraying can apply in two different ways. Those are spraying done perpendicular to the spray head and spraying done parallel to the spray head. To identify the best method of uniform particle distribution, both methods are tested separately and compared the results.

4.1.1. Spraying done perpendicular to the spray head

When consider the perpendicular spraying, here the spray head is moved perpendicular to the position of spray head and Figure 4.1 shows the movement of the spray mechanism. For this test above mentioned parameters in section 3.5 were maintained from the Arduino program. For the test, 3D printed spray head with four vapor flowing paths were used. The sectional view of this spray head is shown in Figure 4.2.

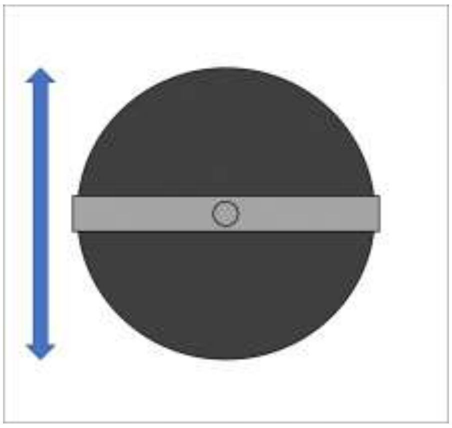

Figure 4.1: Spraying perpendicular to the spray head

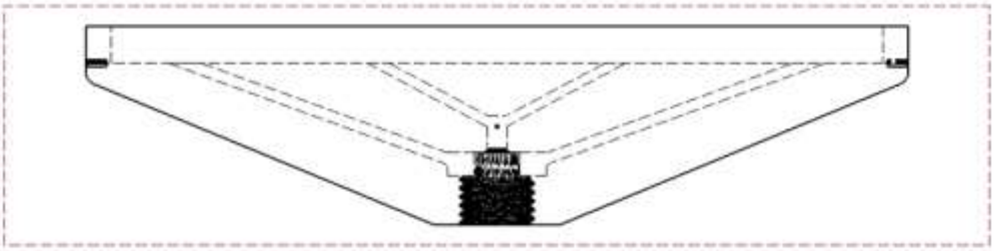

Figure 4.2: Vapor flowing path of 3D printed spray head

After completion of 1000 iterations of the program, the photoresist coating layer of the semiconductor wafer was tested and observe the preciseness of this spraying method as well as the defects. The main positive observation of this spraying method was that the photoresist particles were covered all over the wafer surface. There were two main defects from this perpendicular spraying method also. The photoresist particle distribution on the wafer was non uniform and also the size of the photoresist particles was non uniform. The test results of this perpendicular spraying method after 1000 cycles are shown in Figure 4.3 and 4.4 from the actual images the wafer that used for the test.

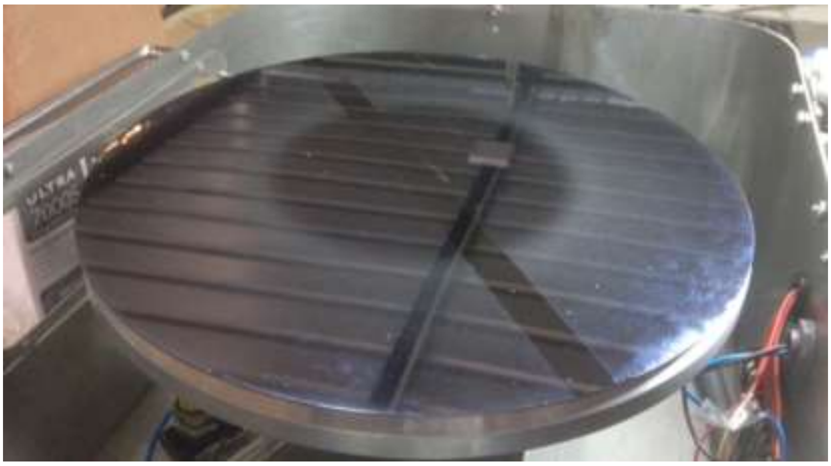

Figure 4.3: Test results after 1000 cycles with perpendicular spraying (1)

Figure 4.4: Test results after 1000 cycles with perpendicular spraying (2)

4.1.2. Spraying done parallel to the spray head

Figure 4.5 shows the movement of the spray mechanism. The spray head is moved parallel to the position of spray head. For this test also, above mentioned parameters were maintained from the program. For this test, spray head fabricated from 3 mm acrylic sheets were used. The actual image of this spray head is shown in Figure 4.6. Before do the fabrication, Ansys simulation were done with the model design for uniform particle distribution and the results of the Ansys simulation is shown in Figure 4.7.

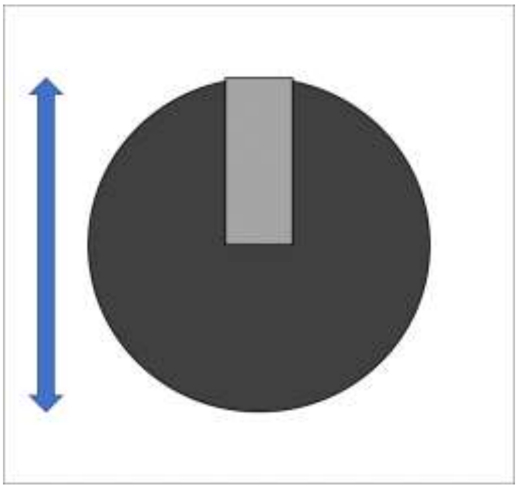

Figure 4.5: Spraying parallel to the spray head

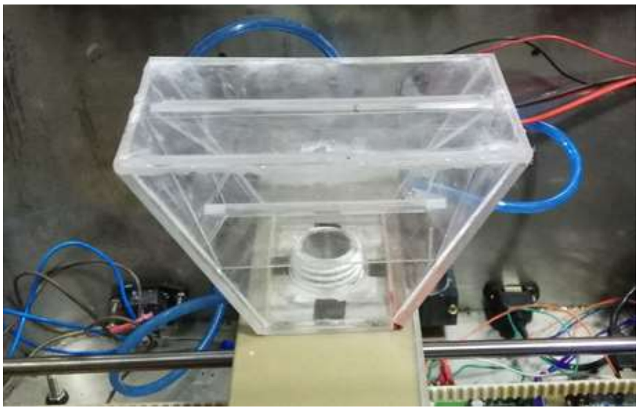

Figure 4.6: Implemented spray head for parallel spraying

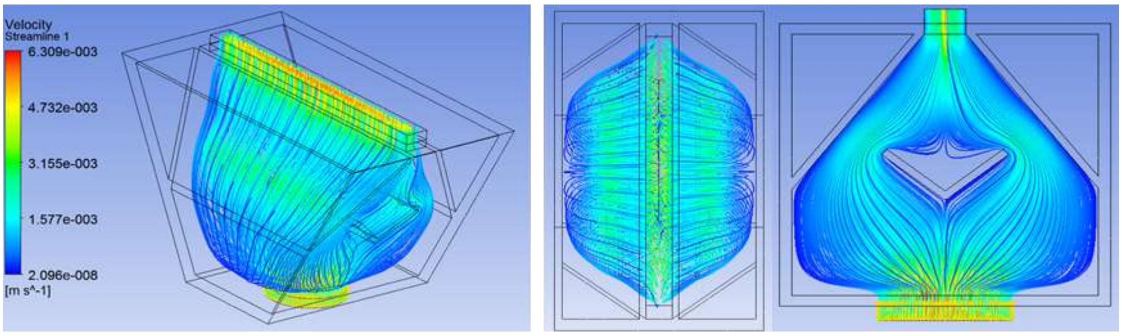

Figure 4.7: Ansys flow simulation results of spray head used for parallel spraying

After completion of 1000 iterations of the program, the photoresist coating layer of the semiconductor wafer was tested and observe the preciseness of this spraying method as well as the defects. The main positive observation of this parallel spraying method was that the size of the photoresist particles that were sprayed on the wafer were uniform. There were two main defects from this parallel spraying method also. The photoresist particle distribution on the wafer was non uniform and the photoresist particles were not covered the edges of the wafer surface. The test results of this parallel spraying method after 1000 cycles are shown in Figure 4.8 and 4.9 from the actual images the wafer that used for the test.

Figure 4.8: Test results after 1000 cycles with parallel spraying (1)

Figure 4.9: Test results after 1000 cycles with parallel spraying (2)

By considering the test results taken from both methods of spraying perpendicular to the spray head and spraying parallel to the spray head, a comparison between two methods was given in Table 4.1. Based on the comparison of both techniques, it’s clear that the particle coverage on the wafer surface was better in perpendicular method than the parallel method. Uniformity of the particle size and the distribution uniformity can be adjusted by changing the spray head model. But the spraying method, perpendicular or parallel is mostly affected for the particle coverage on the wafer surface. Therefore, the perpendicular method was selected from these two methods for further improvement. Since particle uniformity is mainly depends with the shape and the internal structure of spray head, a requirement of developing spray head for uniform flow is observed.

Table 4.1: Results comparison of perpendicular spraying with parallel spraying

Observed points	Spraying perpendicular to the spray head	Spraying parallel to the spray head
Particle distribution	Not good	Not good
Particle coverage	Good	Not good
Uniformity of the particle size	Not good	Good

4.1.3. Spray head testing for uniform flow

Spray head used in the perpendicular spraying method had four vapor flowing paths and the results shown that the centre of the coating layer is had a poor particle distribution than the edge of the coating layer. Based on this result, a spray head with a vapor flowing path in the centre is observed.

4.1.3.1. Spray head model one

Based on the above-mentioned requirement, a spray head with modified vapor flowing paths was designed. The designed 3D model of the spray head was modelled on Inventor software and done the flow simulation using Ansys software. The output results verify that the particle distribution is uniform. Therefor the spray head model was implemented and test with a semiconductor wafer. A sectional view of 3D modelled spray head is shown in Figure 4.10 and the actually fabricated spray head model one is shown in Figure 4.11.

Figure 4.10: Sectional view spray head model one

Figure 5.11: 3D printed spray head model one

Spray head model one is 3D printed by plastic material and it is tested with spray coater by maintaining the above-mentioned parameters. After completion of 1000 iterations of the program, the photoresist coating layer of the semiconductor wafer was tested and observe the preciseness with this spray head model as well as the defects. The main positive observations with this spray head model were that the uniform distribution of the photoresist particles and the particles were covered all over the wafer surface. There was a defect with this spray head mode also. There were some large photoresist particles in the coating layer. The test results with this spray head model after 1000 cycles are shown in Figure 4.12 and 4.13 from the actual images the wafer that used for the test.

Figure 4.12: Test results after 1000 cycles with spray head model one (1)

Figure 4.13: Test results after 1000 cycles with spray head model one (2)

4.1.3.2. Spray head model two

Based on the results taken from the spray head model one, a requirement of flow simulation for 3D modelled spray head designs were observed. Changing the vapor flowing path of the 3D modelled spray heads, they are tested with Ansys software for flow simulations. By implementing vapor flowing paths of spray head following test result were taken with uniform particle flow inside the spray head. Figure 4.14 shows the Ansys flow simulation results of the sectional view of the spray head model two. Based on this accurate test results given by flow simulation, spray head model two is 3D printed using plastic material and it is tested with spray coater by maintaining the above-mentioned parameters. Actual image of 3D printed spray head is shown in Figure 4.15.

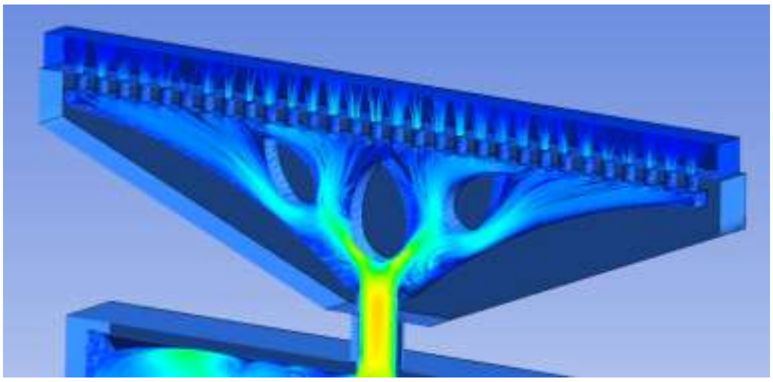

Figure 4.14: Ansys flow simulation result of spray head model two

Figure 4.15: 3D printed spray head model two

After completion of 1000 iterations of the program, the photoresist coating layer of the semiconductor wafer was tested and observe the preciseness with this spray head model as well as the defects. The output results were considered for the main three features, uniform distribution, uniform particle size and covering area as described in the above sections. From the test results it’s verify that all three features were satisfied with this spray head model. That is the photoresist particles were covered all over the wafer surface, photoresist particle distribution was uniform and also the photoresist particle size was uniform. The test results with this spray head model after 1000 cycles are shown in Figure 4.16 to 4.18 from the actual images the wafer that used for the test.

Figure 4.16: Test results after 1000 cycles with spray head model two (1)

Figure 4.17: Test results after 1000 cycles with spray head model two (2)

Figure 4.18: Test results after 1000 cycles with spray head model two (3)

4.1.4. Comparison of test results with two spray head models

Both the results given from spray head model one and model two are compared with magnification camera by magnifying 10:1 scale. Figure 4.19 shows the magnified images silicon wafer coated by spray head model one and Figure 4.20 shows the magnified images of silicon wafer coated by spray head model two. These results clearly show that there is some large size of photoresist particles with the spray head model one. In the results with the spray head model two, it's verified that the particle distribution and the particle size are uniform.

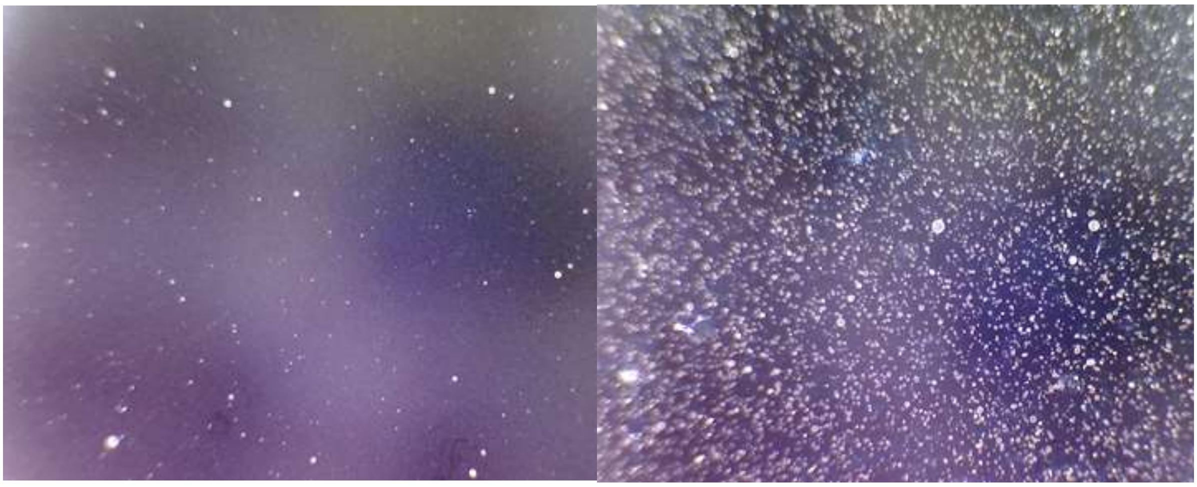

Figure 4.19: View from magnification camera of coating layer with spray head model one

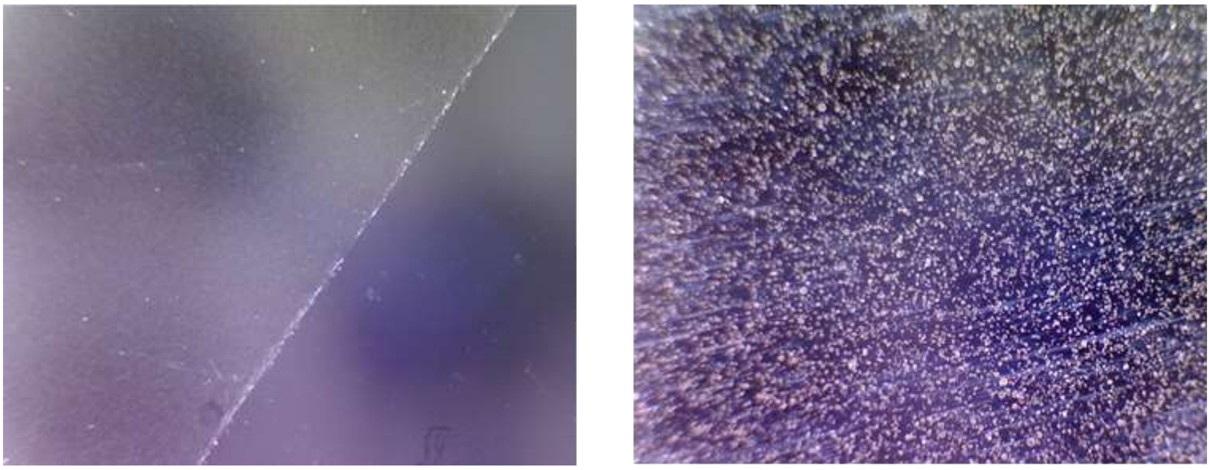

Figure 4.20: View from magnification camera of coating layer with spray head model two

4.1.5. Comparison of test results with spin coated wafer

The results given from spray head model two is compared with a spin coated silicon wafer. magnification camera by magnifying 10:1 scale. Figure 4.21 shows the magnified images of silicon wafer coated by spin coater and Figure 4.22 shows the magnified images silicon wafer coated by spray head model two.

In Figure 4.21 clearly show that the striations over the coating layer of the wafer. This is a common defect can be found in the spin coating. In Figure 4.22 show that by indirect spraying, this kind of common spin coating defects can be eliminated.

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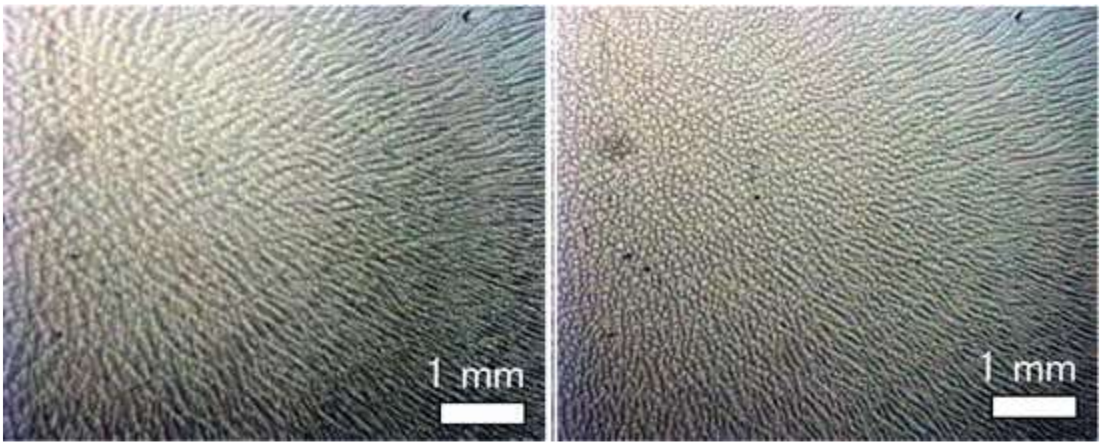

Figure 4.21: magnified images of silicon wafer coated by spin coater

Figure 4. 22: magnified images of silicon wafer coated by spray head model two

In Figure 4.23 show that the common defect called comet in spin coated wafer. Comet usually occurs when relatively large solid particle is impeded the normal flow patterns of the solution on the spinning wafer. In Figure 4.24 show that a wafer is coated with indirect spraying having large solid particle on the coated silicon wafer without damaging the coating layer. Due to the low rotational speed during the indirect spray coating, this kind of defects can be eliminated.

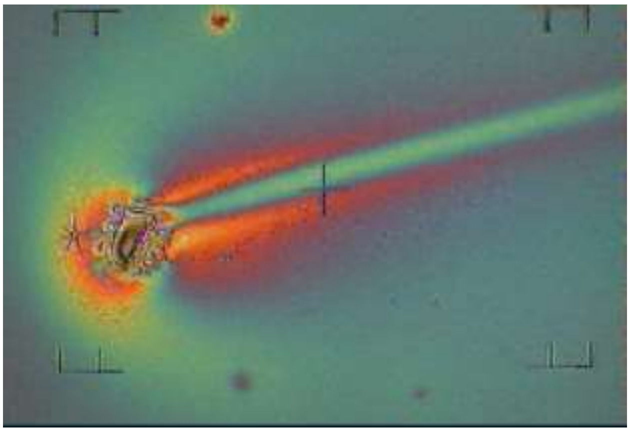

Figure 4. 23: A comet defect happened during spin coating

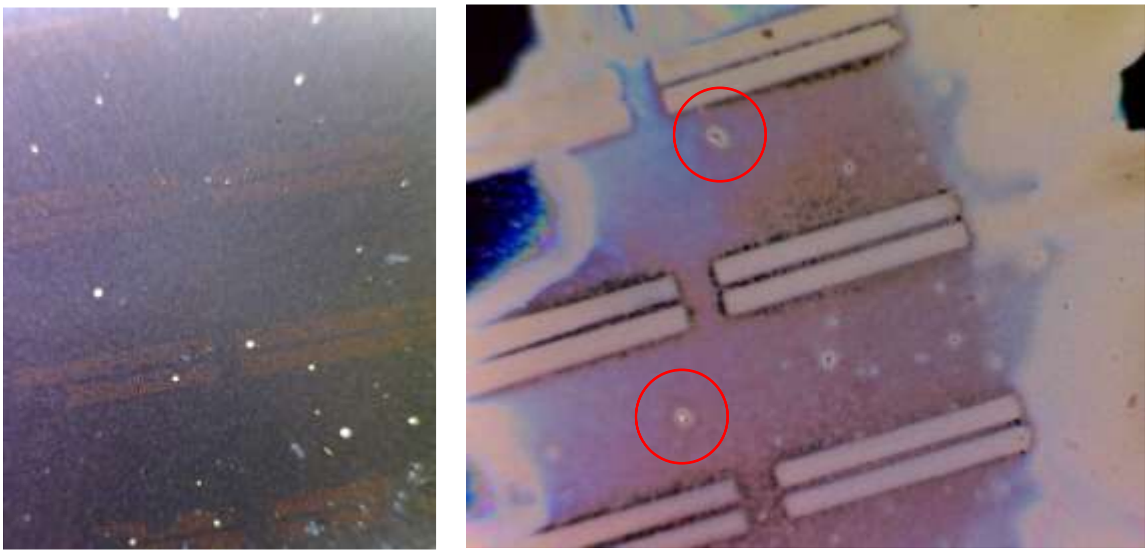

Figure 4.24: Large particles on the indirect spray coated wafer surface

5. CONCLUSION

In semiconductor fabrication process, coating is playing a major role. The spin coating method is the commonly used method for the semiconductor coating and there are several methods with the improvements of this technique. Another way of semiconductor coating is spray coating which is currently used as a conventional method. As discussed in above sections, several defects can be noted with these existing methods. It’s hard to find the facilities and technologies to measure the coating quality of the wafer surface in microscale level. Therefore, the coatings are compared by only using the results obtained by the magnification camera. However, this thesis is proposed a better method with spray coating technique and implement a prototype machine.

The final development can achieve a uniform particle distribution, uniform particle size by spray head model two and a better coating quality and process flexibility by introducing the indirect spraying parallel with overhead spraying. From the results of the final product, acceptable coating quality is achieved by design and implementing the prototype spray coater and proved that the spin coating for photoresist can replaced with the spray coating method. This prototype can implement to industrial scale machine by developing the design parameters furthermore and can introduce real time thickness and spray quality monitoring system.

The developed prototype machine required some implementations as listed follows,

- Wafer chuck should fabricate with less weight for more operation flexibility.
- Better to introduce advanced spray chamber with spray head to reduce the coating time.
- Better to introduce more compact enclosure with semiconductor standards for better handling.
- It is better to introduce curing method also inside the enclosure.
- Should introduce better controller with user friendly user interface with semiconductor standards.

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