MULTIMEDIA UNIVERSITY

FACULTY OF ENGINEERING

ELECTRON BEAM EVAPORATION

EEN3016
PROCESSING AND FABRICATION TECHNOLOGY
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Abstract

This paper contains an assignment on literature review on one of a deposition technology, *Electron Beam Evaporation*. The intention of this study is to understand and be able to acquire the knowledge of the development of fabrication techniques or packaging techniques, to gain knowledge of the operation principles of the fabrication techniques or packaging techniques and to identify the application of the fabrication techniques or packaging techniques of an *e-beam evaporation*. The contain is divided into six parts with the reference from peer-to-peer journal and lab sheets attached at the end of this paper. The contain of this literature review paper is of my own opinion and thoughts with referral of said references.

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1.0 Introduction

Processing and fabrication technology is a study of the build up of a integrated circuits. In any process that takes place, there are steps needed to be followed to complete a quality product. In the context of processing and fabrication technology of a wafer, the procedure can be narrowed down to four main steps; deposition, removal process, patterning and modification of electrical properties. This assignment contains the literature review of the first step of the creation of the wafer which is the deposition techniques.

In term of depositing, there are two ways to do so; by chemical vapor deposition (CVD) or by physical vapor deposition (PVD). The choice of my study is called the 'Electron Beam Evaporation' or also known as 'E-Beam Evaporation'. This type of deposition falls into the cateogry of PVD, physical vapor deposition. PVD is more favorable to be used as compared to its counter part, CVD due to the reason of lower process risk and cheaper in material cost. In any context of engineering process, cost, power and time are the main keys towards the quality of a product.

This literature review paper contains the explanation, development and application of of e-beam deposition.

2.0 Definition

The physical meaning of electron beam evaporation can be understood by its name itself. By direct translation, it means that there will be a process of evaporation of which a change of phase will occur from liquid to vapor and this evaporation activity will be done by the beam of electrons. In other words, the beam of electrons are emitted in a way that it will heat and vaporize the material to be deposited. Once the material changes its state of being a liquid to a vapor, it is able to condense itself on the wafer (substrate).

3.0 Apparatus and Variables

Figure 1 : Electron Beam Evaporator

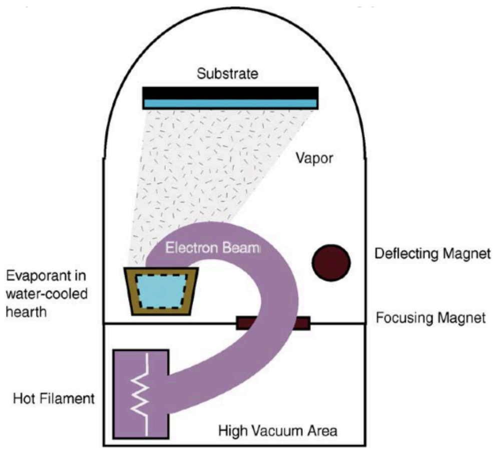

Figure 2 : Apparatus and Variables Setup

3.1 Working Principle

Figure 2 shows the apparatus and variable setup of an electron beam evaporator (Figure 1). The material that is to be deposited is the evaporation in water-cooled hearth meanwhile the wafer, the material that is to be coated is shown as the substrate. The electron beam is produced by a hot filament which is represented by the symbol of resistor. The process of the evaporation is taken place in a high vacuum area to allow molecules to move freely in the chamber and hence condense on all surfaces including the substrate, and this follows the basic principle of evaporation.

The working principle is simple. I divide it to three stages. The first stage is a heating process of the hot filament. The hot filament will produce a beam of electrons that is excited due to heating. This process can be done by applying *thermionic emission*. *Thermionic emission* is a procedure of discharging of electrons from a heated material, in this case, the hot filament. To make the electrons to be able to be excited, the hot filament needs to supply enough energy for the electrons to overcome the attractive force that holds them together. Once the electrons are excited and released, the electrons can move about randomly.

The second stage is the heating of the material that is to be deposited. The material that is to be deposited is shown in Figure 2 as evaporant in water-cooled hearth. The source of the heating process is actually the beam of electrons that is produced from stage one. Now, coming from stage one, since the electrons are required to be used as the source of boiling of the material of stage two, the beam of electrons must have a certain path in order to be fully used effectively. Excited electrons are able to move randomly in the high vacuum area without any force of attraction to it. Hence, to make it to move only towards the material to be evaporated, magnets need to be used. In this case, two magnets are required. The first magnet, a focusing magnet is used to attract the electrons towards it right after the electrons are excited. Then, in order to deflect the route of the beam of electrons towards the material to be evaporated, a deflecting magnet will be used. After the whole process of attracting and deflecting of magnets, now the path towards the material is set and the material can be heated. The material will be heated up to a boiling point, of which governed by the principle of evaporation; once the boiling point is reached, the molecules in the liquid (material evaporant) will collide and transfer energy to each other and thus the liquid would turn into vapor. Therefore, the material evaporant is now be able to move freely in the high vacuum area.

Once the material evaporant is able to move, then it could move towards the substrate and attach on it, which is the last stage, stage three. As shown in Figure 2, the vapor is now able to move towards the wafer, and thus the material evaporant which is now in form of vapor can be condensed on all the surface of the wafer (substrate).

In short, electron beam evaporation is a process of evaporation of material that is to be used to deposit itself on the wafer (substrate) by using beam of electrons to evaporate (heat) it. The electrons themselves are created through a heating process coming from a hot filament.

3.2 Effect Of Temperature On E-Beam Evaporation

As known from *3.1 Working Principle,* wafer (substrate) will be able to be condensed once the material evaporant is heated by electron beam that is coming from the hot filament. Now, a question that is vital in the productivity of *e-beam evaporation*; Does the temperature of the hot filament plays an important role in the process of *e-beam evaporation*?

From the discussion on *3.1 Working Principle* paragraph three, when the electrons are excited, they are able move freely. In this process of moving, the electrons dissipate their kinetic energy in the material evaporant. This kinetic energy then will fuel the process of evaporation and thus creating vapor that will condense on the wafer (substrate). There is a certain amount of speed that needs to be reached for the operation of evaporation to occur successfully. To reach the adequate speed, the temperature of the electron beam needs to be adjusted to reach the temperature that will give the desired speed of evaporation that will create a sufficient vapour tension. As known, the source of the temperature of the electron beam is actually sourced from the hot filament.

So, eventhough the hot filament is just a small part of the whole apparatus and variable setup, it plays the major role in the productivity of the *e-beam evaporation.*

3.3 Type Of Material Used As An Evaporant

Most of the time, the material used as the evaporant in water-cooled hearth is copper. Copper is an excellent material to be used is because it becomes stronger as the temperature decline. It also could hold resistance up to 20kohm. Other reasons to the excellency are; good corrosion resistance, attractive colour, excellent workability and good mechanical properties (best electrical and thermal conductivity). Still, the e-beam evaporation process is able to evaporate any type of materials.

3.4 Type Of Material Used As Hot Filament

The best material to be used as the hot filament is a tungsten. Tungsten is well known for its high melting point. It is good to have a high melting point as it is the major element in the heating of electron beams. When the tungsten has a high melting point, thus it could be used for higher temperature purposes. In other words, the tungsten is good to be used in the e-beam evaporation because it can be used to heat higher and sufficient electron beams energy and thus be able to create a sufficient speed in the evaporation process.

4.0 Effect Of Electron Radiation Generated During E-Beam Evaporation on a Photoresis Liftoff Process

In a research work done by *Kezia Cheng, Minh Le, Donald Mitchell and Larry Hanes,* it is found that there are some resist residual found in the source/drain electrodes' root. These residues are only found at the root and not in any part of the field. The residual is a result of cross linked resist, of which an event of the resist will not dissolve completely in the wet strip process in N-methyl phyrolidane (NMP). N-methyl phyrolidane (NMP) is a process to dissolve the photoresist and liftoff the unwanted materials and thus creating a complete electrical circuit. But with the problem occuring, there may be problems that will arise later in application of the electrical circuit coming from the existing cross link.

A study shows that energetic electron radiation that is cross linking during e-beam evaporation process and impurities in the material vaporant influence the residue problem. Figure 3 shows the resist residue in the source/drain electrodes.

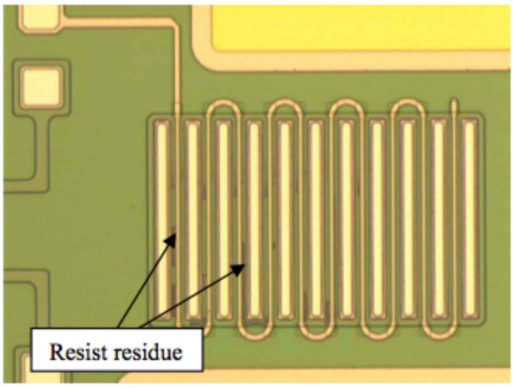

Figure 3: Resist Residue in S/D Electrodes

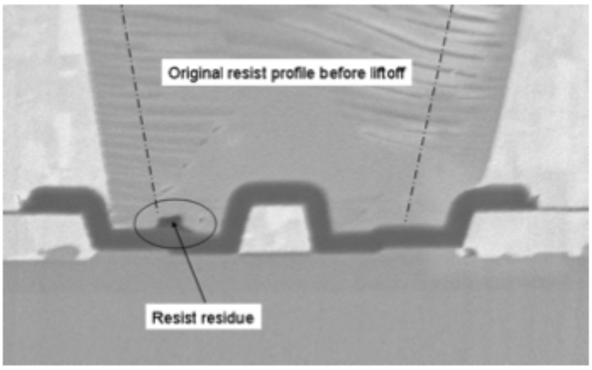

Figure 4: FIB SEM (scanning) shows the resist residue

As seen in the figure above, it is shown that the resist residue remains at the root of the metallized area and none in any other place in the field as said earlier on. In order to produce a high quality of electric circuit, this resist residue problem must be solved. To do so, investigation and experimentation must be done to find the source to the problem and thus creating a solution for it.

4.1 Experimentation Towards The Problem

There are early investigations done to resolve this problem and they are to lower the deposition rates, varying ramp and thermal soak and also by using different evaporators. It seems that these investigations meet to failure ends. The initial theory, thermal cross linking theory was considered in the beginning of the investigation. What is found is that the temperature of the wafer (substrate) must not exceed 80°C. This temperature is lower than the glass transition temperature of 160°C that is set by the photoresist manufacturer. But, there is a contradiction in said theory because if temperature does creates the problem of resist residue, the resist under the metal is expected to be heavily cross linked because of latent heat but instead bear in mind that the resist residue problem only occur on the root of the field. Hence, this leaves us with the other problem that is left; the electron beam radiation during the evaporation.

4.2 Experimental Setup Of Electron Beam Radiation Problem

This experiment is conducted to compare the amount of energetic free electrons during the evaporation process. As mentioned in *3.1 Working Principle,* the electrons are used to evaporate the material in the water cooled hearth. Since electrons are highly unpredictable, it is suspected that there may be stray electrons in the vacuum area and thus radiates during evaporation and form the residual in the resist.

To precisely measure electron charge, a Faraday cup is used as shown in Figure 5. But there is a limitation to the usage of this apparatus as it is only limited to a small area of measurement. The setup is such that an electrode will be fabricated to fit inside the chamber of the electron beam evaporator. The comparison of the energy of the electrons can be done when these electrons are generated from the beam and hit different materials. Since this setup is not done by using any certified standard, the measured energy cannot be used as the actual amount of energy, charge or current.

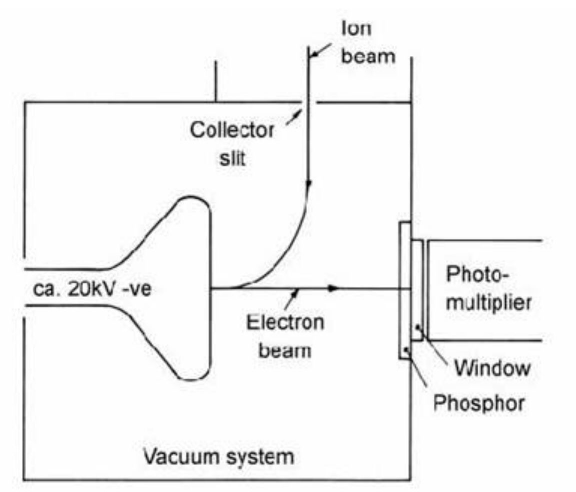

Figure 5 : Faraday's Cup

4.3 Experimental Result Of Electron Beam Radiation Problem

There may be two causes to this problem; the primary electron coming from the emission of beam of electron and also the secondary electron coming from other radiations. It is found that the secondary electron does not affect the resist cross linking since they do not hold a lot of energy. So, that narrows down the problem to only the primary electrons sourcing from the hot filament. In the experiment, it is shown that the electron radiation is at its peak when it hits a a cold, solid metal material. During the change of state of the material from melt to molten state, the electron emission drops and stays constant regardless of the electron power. From the experimental result itself, it is believed that the primary electrons are elastic and thus creating back scattered electrons that retain as much as 10kV acceleration potential cause the problem of resist cross link. In other words, the problem of resist residue that actually arised from the problem of cross linkage of the radiation of a beam of electrons is actually coming from the primary electron that comes from the hot filament that is believed to be elastic and able to create back scattered electrons that could hold an acceleration energy of 10kV.

4.4 Experimental Conclusion Of Electron Beam Radiation Problem

During the process of emission of electrons, the electrons are expected to hit the material provided. In the case of solid or metal material, the electron beam generates a lot of energetic electrons. During the process of electron heating the material provided, the material will start to change its state from melt to molten, the emission level of the electron drops. This phenomenon can be theorize such that when the material has change its state to molten, the electrons do not have any solid surface to hit thus reducing the kinetic energy that is produced. This kinetic energy will then changed to thermal energy that will actually heat the material to evaporate. So that means as the material starts to become more to a liquid, there will be less heat supplied by the emission of the electrons due to less thermal energy created by kinetic energy. This kinetic energy produces back scattered electrons that can be treated as an elastic collision electrons after it collide with the soid metal. The back scattered and secondary electrons generated cause the photoresist to cross link during deposition. During the deposition process, the sidewall of the photoresist are exposed most of the time. Thus, this allows it to be cross linked the most.

This problem can be eliminated by carefully handling the material used and make sure that the contaminants are removed from the source.

5.0 Application

The usual applications of the electron beam evaporation is to be used in an electron beam evaporator. This evaporator can be used in the production of film growth for surface science, doping, metallization, atomic layer deposition, optical films and oxide films.

In the study of this assignment, the main usage of the discussion of the e-beam evaporator is to be used as an atomic layer depositer.

6.0 Advantages And Disadvantages

The advantages and disadvantages here are discussed as to compare the e-beam evaporation and its counter process, sputtering process.

The advantage is that it has high film deposition rate, it creates less surface damage from the impringing atom as the film is being formed, the film created has high purity form (due to the high vacuum area) and has less chance for the wafer (substrate) to be heated unintentationally.

As for the disadvantage, it is more difficult to be controlled incapable of doing surface cleaning, harder to improve the step coverage and could cause x-ray damages by the electron beam evaporation.

7.0 Conclusion

Electron beam evaporation is one of the physical vapor deposition that can be found in the fabrication and processing technology. It has its own unique way of depositing material on the wafer and thus having its own advantage and disadvantage in its application. It is mostly used for creating metallized wafer. In the context of this assignment, I have fully understand the process of deposition and its significant in the whole process of a making a single wafer. Other than that, I have also understand the significant of electron beam evaporation as compared to the other technology of depositions.

8.0 References

1. Figure 1 : Electron Beam Evaporator ; Pg. 4
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