CHARACTERIZATION OF Ti/TiN/AlCu FILM STACK PREPARED BY PHYSICAL VAPOR DEPOSITION

by

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LIST OF SYMBOLS

ΔB	Delta Center Bow
E_A	Activation Energy
J	Current Density
k	Boltzmann’s Constant
t	Acoustic Transit Time
t_f	Substrate Thickness
t_s	Film Thickness
T	Ambient Temperature
Ts	Substrate Temperature
Tm	Melting Temperature
v	Sound Velocity
σ_f	Film Stress
θ	Incident/Diffraction Angle
λ	Wavelength

LIST OF MAJOR ABBREVIATIONS

a.u.	Arbitrary Unit
AHF	Advanced Hi Fill®
AlCu	Al-0.5%Cu
DC	Direct Current
EM	Electromigration
HF	Hi Fill®
I-PVD	Ionized Physical Vapour Deposition
PVD	Physical Vapour Deposition
rf	Radio Frequency
SEM	Scanning Electron Microscope
TEM	Transmission Electron Microscope
Ti	Titanium
TiN	Titanium Nitride
XRD	X-Ray Diffraction

PENCIRIAN TINDAN FILEM Ti/TiN/AlCu YANG DISEDIAKAN DENGAN PEMENDAPAN WAP FIZIKAL (PVD)

ABSTRAK

Kaedah pemendapan wap fizikal (PVD) banyak digunakan dalam industri semikonduktor dalam proses pemendapan filem logam. Didapati bahawa sifat lapisan logam dipengaruhi oleh perubahan parameter dalam mesin percikan PVD. Pemendapan ion wap fizikal (I-PVD) muncul ketika peranti elektronik menyusut dalam saiz yang meningkatkan kepadatan bungkusan peranti. Hal ini menyebabkan nisbah aspek yang lebih tinggi bagi saiz "via" dan garis saling hubung litar bersepadu. Kaedah I-PVD berjaya melegakan isu liputan langkah bagi peparit dan "via" dengan nisbah aspek yang tinggi. Dalam industri semikonduktor, kebolehharapan muncul sebagai musuh utama.

Dalam kajian ini, pemendapan filem logam oleh sistem percikan arus terus (DC) dikaji dan dicirikan. Terdapat dua jenis sistem percikan magnetron ruang kamar panjang yang digunakan, iaitu sistem yang lazim (*Hi Fill*®) dan lanjutan (*Advanced Hi Fill*®). Untuk sistem percikan magnetron DC yang lazim, hanya pincangan substrat diubahkan sedangkan untuk teknik lanjutan, parameter pincangan substrat dan arus gegelung magnet diubahkan untuk pemendapan filem logam. Tindan filem AlCu / TiN / Ti dimendapkan untuk diselidiki pengaruh Ti bawah terhadap filem-filem yang berikutnya. Parameter yang berpotensi untuk pemendapan I-PVD dilaksanakan dalam proses wafer berpola untuk logam lapisan satu dan hasilnya menunjukkan kejayaan peningkatan ketahanan electromigrasi (EM) ketika wafer diuji untuk ujian EM pada tahap wafer.

Sifat-sifat struktur, morfologi permukaan dan fizikal filem-filem tersebut diselidiki dengan menggunakan belauan sinar-X (XRD), mikroskop daya atom (AFM), mikroskop imbasan elektron (SEM), mikroskop penghantaran elektron (TEM), kajisukat tegasan Eichhorn & Hausmann, mesin pengukuran akustik dan probe empat titik.

Dalam penyelidikan ini, proses parameter yang digunakan dalam pencirian percikan filem Ti dengan menggunakan sistem *Advanced Hi Fill®* berserta dengan pincangan substrat dapat membuktikan bahawa ia dapat meningkatkan jangka hayat EM dalam semikonduktor industri.

CHARACTERIZATION OF Ti/TiN/AlCu FILM STACK PREPARED BY PHYSICAL VAPOR DEPOSITION

ABSTRACT

Physical vapor deposition (PVD) method is widely used in semiconductor industry in metallic film deposition process. It has been found that the metallic film properties are influenced by the parameter change in the PVD sputtering machine. Ionized physical vapor deposition (I-PVD) came about when electronic devices shrink in sizes which increase the packing density of the device. This lead to higher aspect ratio of the via size and smaller interconnect lines of the integrated circuit. I-PVD sputtering method had successfully relieved the step coverage issues for high aspect ratio trenches and vias. In semiconductor industries, reliability surfaced as the major enemy.

In this study, metallic film sputtered by direct current (DC) magnetron sputtering system is studied and characterized. Two types of long throw DC magnetron sputtering system were used, which are the conventional (Hi Fill®) and advanced (Advanced Hi Fill®) system. For conventional DC magnetron sputtering, only the substrate biasing is varied while for the advanced technique, the parameter of substrate biasing and magnetic coil current is varied for deposition of Ti metallic film. Film stack of AlCu/TiN/Ti are deposited to investigate the influence of bottom Ti towards the subsequent films. The potential parameter for I-PVD were implemented in patterned wafer process for metal 1 and the result showed a successful increase in resistance of electromigration (EM) when wafers were tested for wafer-level EM test.

The structural, surface morphological and physical properties of the films were investigated using X-ray diffraction (XRD), atomic force microscope (AFM), scanning electron microscope (SEM), transmission electron microscope (TEM), Eichhorn &

Haussmann film stress metrology tool, acoustic measurement machine and four-point probe.

In this research, the implementation of the process parameter used in characterizing the sputtering of Ti film by using Advanced Hi Fill® system together with substrate biasing has proven its ability to increase of EM lifetime in semiconductor industry.

CHAPTER 1
INTRODUCTION

1.1 Introduction

In semiconductor devices, metal interconnection is one of the important areas of study due to the rapid miniaturization of the electrical components. As an example, we can now perform functions previously capable only on a large computer in a small mobile phone. Technology is evolving and there is a necessity for continuation of scaling of the very large scale integrated (VLSI) technology. This integrated circuit technology build from the multilayer of thin films structured from the lithographic patterning in the plane of the films. Small form factor enlarged the issues related to the integrated circuits, where reliability is an issue when the design of the metal interconnects structure is smaller.

This thesis involved the characterization of deposited metallic layers for metal interconnection where physical vapor deposition (PVD) sputtering is applied. The motivation of this research is to explore the Ti thin film properties in terms of physical and structural characterization by altering the parameters of sputtering machine. The PVD sputtering machine is provided by Infineon Technologies (Kulim) Sdn. Bhd. The hardware characteristics of the machine would be further elaborated in chapter three.

In chapter one, basic and fundamental knowledge of PVD sputtering process involved and growth of polycrystalline thin film properties would be introduced. This parameter used would be implemented in BiCMOS device and tested for Electromigration (EM). As mentioned, multilayer of thin films is the basic construction of the metal interconnection of device.

1.2 Physical Vapor Deposition (PVD)

Polycrystalline thin film is deposited by using physical vapor deposition (PVD) sputtering process where the process took place in ultra-high vacuum condition. Physical vapor deposition (PVD) process is defined as a mechanism where high collisions of particle energy hits on the surface of target material and atoms are dislodged from the target material. Argon gas is commonly used as the inert gas in order to create plasma. Four basic steps are involved in the PVD process. Firstly, atomic gas is ionized and directed to the target. The supply of direct current to the target material as referred to Fig. 1.1 enable the positive charged ions to be bombarded onto the target surface. Secondly, sputtering of atoms after the high bombardment of atomic gas onto the surface of target material. The high elastic collision leads to the bond breaking of bonded atoms of the target material. Thirdly, metal atoms are being transported from the target material to the substrate surface through plasma region, in between target material and substrate. Finally, metal atoms would eventually condense on the substrate forming thin film material (SiliconFarEast- http://www.siliconfareast.com/sputtering.htm).

The details on the growth of thin film would be discussed further in this chapter. Direct current (DC) magnetron sputtering is commonly used in PVD process. It is a condition wherein the sputtering process is carried out with the magnet attached to the target material with supply of direct current. A direct current is connected to the target while a permanent magnet is fixed above the target. The rotation of the magnet creates an electromagnetic field near the target surface which attracts the gas atoms. The electrons are trapped in the pathway of electromagnetic field and move in gyro motions thus colliding with argon atoms.

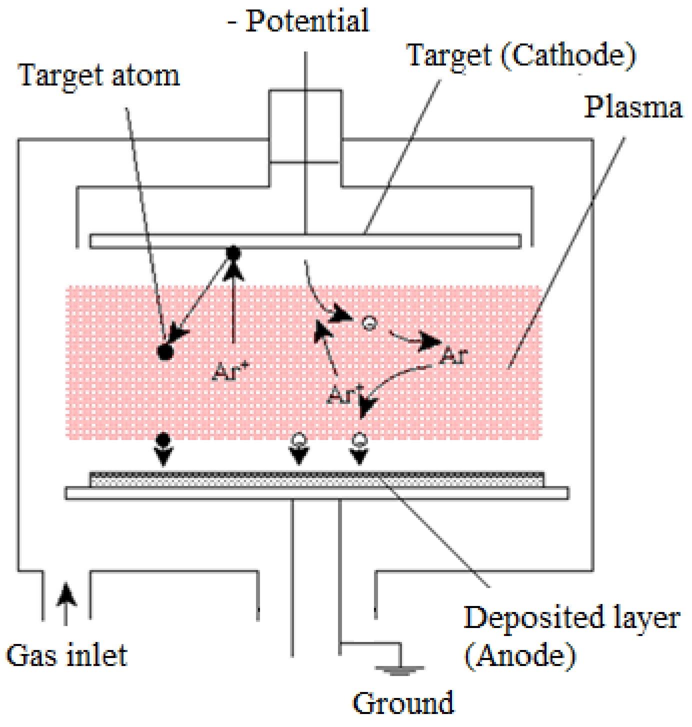


Fig. 1.1 Illustration of sputtering chamber

Under such circumstances, the argon atoms are ionized producing more free electrons after the collisions. With the application of direct current to the target that causing the target to have a negative potential where the positively charged argon ions are attracted to bombard on the target surface to knock out the metal atoms. As this proceeds further, the target surface would become eroded.

1.3 Thin Film Growth

The metallic atoms are deposited on the substrate by sputtering process as mentioned earlier. Metallic thin film is categorized as polycrystalline thin film. The growth of thin film begins from nucleation. Nucleation is defined as the phenomenon where adatoms condense and became adsorb on the substrate surface forming islands. This phenomenon proceeds to the coalescing of the clusters of nuclei and forming the individual grains. These grains would come together building the structure of film which would be explained in grain growth section (Thompson 2007).

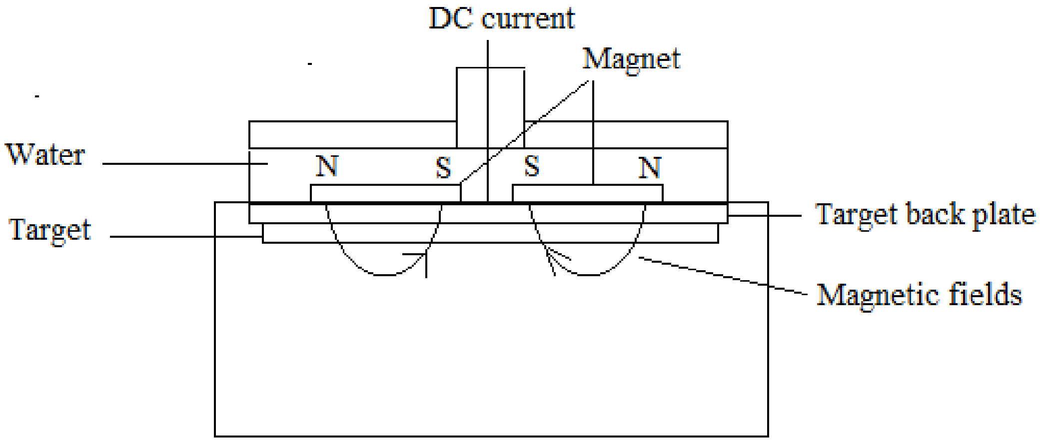


Fig. 1.2 Schematic diagram of DC magnetron sputtering chamber

1.3.1 Nucleation

Polycrystalline film starts with nucleation where the adatoms are adsorbed on the substrate with certain amount of flux. Flux is defined as the number of atoms arriving on the surface area per unit time. Nuclei will grow into clusters and consequently would define the crystallographic orientation which would be influenced by the surface and interface energy. The lowest energy contributes to higher nucleation rate. Thus, this would determine the film orientation.

1.3.2 Coalescence

Fig. 1.3 shows (a) cross sectional and (b) top view of the growth of thin film where nuclei would grow into islands which coarsen and increase in size (Thomson 2007). Finally, the islands would be connected to each other forming grain boundaries. Free surface energies of the islands were eliminated in exchange to newly formed grain boundary energy. Strain energy became significant when the growth of islands were undisturbed by sliding defect. Migration of grain boundaries occurred causing the shrinkage and the diffusion of the smaller grains into the larger ones which in turn increases the average size of the remaining grains.

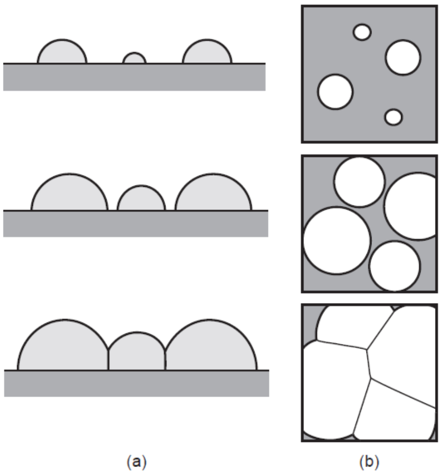


Fig. 1.3 Schematic diagram of the growth of grains from (a) cross sectional view and (b) top view of the growth of thin film from nucleation, coalescence and finally the grain growth (Adapted from Thompson 2007)

1.3.3 Grain growth

According to Barna, the growth stages are only valid when the diffusion of bulk is effective and the substrate temperature adheres to the equation 1.1 where *Ts* represent substrate temperature and *Tm* is the melting temperature of the element (Barna et al.)

$$Ts \geq 0.3Tm \tag{1.1}$$

Barna proposed a basic structure zone model which defines the grain structure into zone I, zone T, zone II and zone III in Fig. 1.4. Zone I belongs to the grain structure with low substrate temperature. It consists of fibre texture and usually proceeds from substrate to film surface. In zone T, competitive growth of different oriented crystals happened in the temperature range of 0.1 Tm to 0.3 Tm as shown in Fig. 1.4. One of the reasons for the successive orientation crystal growth was due to the surface energy which drives the adatoms between each crystal. Cone-like grains were observed in zone T due to higher growth rates of the preferred orientation. As substrate temperature increased, larger grains developed and crystals grow permanently from substrate during film deposition in zones II and III.

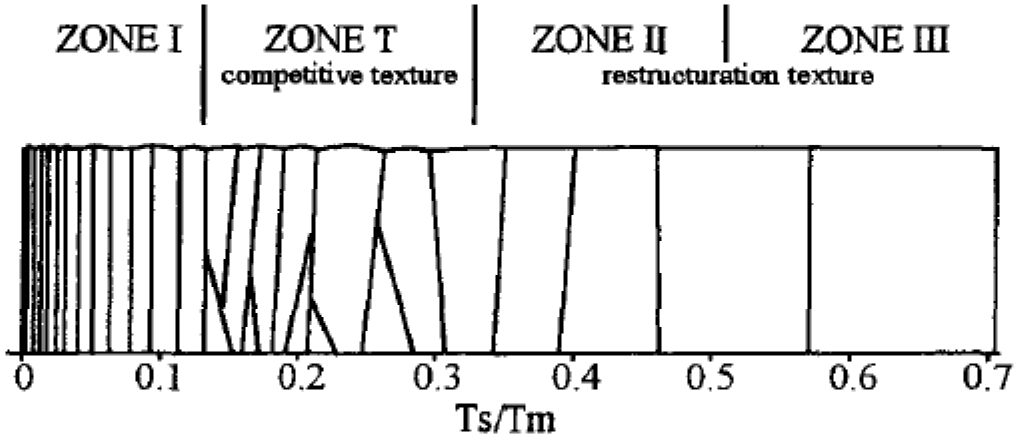


Fig 1.4: Basic structure zone model (Adapted from Barna et al.)

The grain structures of polycrystalline films have a wide variety of applications in electronic devices in which their grain structures would affect their performance and reliability, especially in metallization process. The growth of metallic thin films by sputtering deposition process was initiated with grain nucleation, growth, coarsening, coalescence and finally thickening of thin film. Hence, growth techniques and growth conditions of metal thin film would affect the shapes of the grains, the average grain size and the crystallographic structures and orientation of grains. Structural trends in polycrystalline films would evolve as a function of processing conditions in terms of kinetic processes.

Metallization process is a process wherein a metal layer would be deposited onto the wafer substrate to provide the electrical pathway for the interconnectivity of the device. Physical vapor deposition (PVD) sputtering method is used in this practice. Wafer is placed on the substrate holder in ultra high vacuum (UHV) chamber while a high purity target material is positioned at the top of the chamber with permanent magnet attached. Target material would be bombarded with Ar, an inert gas, to sputter the material off from the target which would condense on the wafer surface as a metal layer. Hence, direct-current (DC) is supplied to the target area to provide sufficient energy for the bombardment to unlock the surface binding energy of the atoms of target material for sputtering to occur. Plasma would be created where it acts a medium for the transfer of metal atoms from the target to the substrate.

1.4 Thin Film Properties

A deposited film is classified as a ‘thin film’ if it is less than one micrometer thick. The properties of a thin film would be different from the bulk material. The physical and microstructural properties of metal films are very much influenced by process parameter, such as, substrate power, target power, temperature and pressure. It is necessary to consider the effect of substrate bias on plasma characteristics in analyzing the characteristics of deposited films in connection with the plasma when the substrate bias is applied for directionality of deposited atoms and the improvement of film quality (Seo et al., 2004).

Apart from that, the texture of underlying metal film in a film stack would directly influence the microstructure of the subsequent metallic film. Much effort has been done to improve the texture of Al (111) in order to obtain a better resistance towards electromigration. Hence Tracy had done numerous deposition conditions and splits to identify the influence of underlayer metal towards the subsequent metal layers. The author also mentioned that, TiN metal layer would degrade the EM lifetime as it would weaken the microstructure of subsequent AlCu metal layer. However, with highly oriented underlayer, stronger texture will be developed for the following metal layer and vice versa (Tracy et al., 1994).

1.5 Application

Al has been used as the major interconnect conductor in microelectronic industry for the past 40 years (Tu 2003). With the advancement of very-large-scale-integration (VLSI) fabrication, electromigration (EM) has become the most serious reliability problem in interconnect metallization. EM was found to be reduced when a small amount of copper (Cu) was introduced to Al to improve the resistance to EM. Al-0.5%Cu was the main interconnect material used for interconnection in this research. In the 1960s, it was discovered that EM, originating from grain boundary diffusion, caused damage in Al lines. This EM was greatly influenced by the Al microstructure.

1.6 Research Objectives

One of the objectives of this project is to study and characterize the underlying Ti film of film stack for an interconnection metal, which was deposited via long throw magnetron sputtering chamber employing two different methods. The first is, conventional sputtering via direct current (DC) magnetron and the other is by ionized physical vapor deposition (I-PVD) magnetron sputtering with the presence of magnetic coil. These two sputtering methods are then studied with different deposition process and magnetic coil current parameters. Bottom Ti in the film stack of Ti/TiN/AlCu is crucial in affecting the microstructure of AlCu (Tracy et al., 1994). This film stack structure of Ti/TiN/AlCu is commonly used in various manufacturing process and reliability studies (Koller et al., 2002) and the same apply to this research. Consequently, the microstructure of AlCu is also studied in project.

In addition to the characterization of film properties, film stack with bottom Ti deposition by using ionized metal plasma methodology would be further tested for wafer-level EM test in a patterned device of BiCMOS to observe the benefit of ionized metal plasma in resistance of EM.

1.7 Research Originality

This research was done in order to perform the capability of the new sputtering machine where it is not being characterized and researched for the thin film metal properties with different sputtering methods and parameters variations in Infineon Technologies Kulim. The machine being used is for high aspect ratio metallization and not on metal line. With an advanced technology machines, this project was carried out to determine the quality of the sputtered metal film. In integrated circuit fabrication, reliability test will be the tested for the overall changes that did on the process flow.

1.8 Organization of Thesis

This thesis consists of six chapters. Chapter 1 introduces the general background of this study. Chapter 2 presents a literature review of the current knowledge and hypothesis of the related study. Chapter 3 includes the details of equipments used and the characterization machines. Methods and split runs on the experiments used to deposit the metal films are explained in details in Chapter 4. Chapter 5 would focus on the discussions of the results, characterization of the deposited films and the result of wafer-level EM test. Chapter 6 concludes the thesis.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

In this chapter, studies and analysis of the ionization that took place in I-PVD sputtering method by few authors are presented. The applications of this method are further explained in this chapter. Majority of the application of I-PVD is for the enhancement of “vias” and trenches with high aspect ratio. The study of the application of I-PVD in metal line in the improvement of EM lifetime is still in progress. W. Zhang proposed that EM lifetime could be improved by I-PVD sputtering method (Zhang et al., 2006). Hence, a brief background and the efforts contributed by some authors on the EM improvement are further described in this chapter. This might be due to the improved crystallographic structure of the deposited metal which would be explained in section below.

2.2 Ionized Physical Vapor Deposition (I-PVD) Processing

I-PVD is a sputtering method wherein the number of ions generated is higher than the number of atoms produced. It is an advanced sputtering technology used to achieve improved step coverage in the fabrication of high aspect ratio lithography patterns in integrated circuits (Rossnagel et al., 1993, U. Helmersson et al., 2006). Unbalanced magnetron sputtering is also known as an I-PVD method due to the unequilibrium of the magnetic field in the chamber compared to the conventional magnetic sputtering chamber (Yang et al., 2009). This is because the additional magnetic coil is situated at the side of the chamber below the target area while another magnetic field is coming from the target material area where a permanent magnet is placed on top of the target material. There are several methods to produce metal ionization plasma, which were i) electron cyclotron resonance plasma, ii) inductively coupled plasma and finally iii) the DC magnetic coil.

Nakamura analyzed the density of Ti ions via inductively coupled plasma (ICP) enhanced DC magnetron sputtering. ICP is the coil positioned in between target and substrate with a supply of r.f power. With the increase of the r.f coil power, electron density in plasma would increase as well until the latter reaches a saturation point. As shown by Nakamura, the electron density almost saturates at an r.f coil power of 240 Watts regardless of the amount of target voltage applied (Nakamura et al., 2004). Hopwood suggested that the mechanism behind the generation of highly ionized, directional metal flux would be, first, high target to wafer distance with low pressure. Second, the sputtered metal would be thermalized by the inert gas as the ionization energy of inert gas, Ar (15.7 eV) is much higher than that of the metal, Al (6.0 eV) (Hopwood 1993). According to Nakamura, density of electrons in the chamber do enhance the ionization of Ti (Nakamura et al., 2004).

Plasma cooling effect was detected with an increase of ionization rate in plasma. Plasma consists of a quasineutral of ions and electrons. Maxwell Boltzmann distribution was used to define the electron distribution in plasma and electron temperature was the temperature of the distribution. A rise in temperature was expected in the chamber due to radiation emission which was the source of the coloration of plasma. A decrease in electron temperature would lead to the plasma cooling effect due to an increase in magnetron sputtering which provides an increase of metal atoms in the plasma. Yang et al. compared the electron temperature during sputtering of Cu using I-PVD with conventional magnetron sputtering. The same target-to-wafer distance was employed in both cases. The electron temperature in I-

PVD was found to be lower than the conventional magnetron sputtering. The reason behind this was that in I-PVD, the plasma was confined by the magnetic field and thus led to more inelastic collisions between the ions and electrons. This shortened the mean free path of the electrons which in turn would cause higher energy loss resulting in a lowered electron temperature. (Yang et al., 2009)

Despite of the decrease of electron temperature with an increase in ionization rate in plasma, there is no correlation done to correlate with plasma density and thin film properties. However, I-PVD method is applied and the metal film properties are studied. In 1999, Hopwood proceeded further in the application of I-PVD on Ti sputtering in enhancing the step coverage of vias and trenches with Zhong after the analysis of ionization via I-PVD together with Rossnagel. Rosnagel and Hopwood analysed on Al ionization by using magnetron sputtering with rf inductively coupled plasma way back in 1993.

Application of I-PVD results in a successive step coverage in “via” liners and trenches. Urbansky et al. stated that I-PVD is a promising method to be applied for contact liner with high aspect ratio (Urbansky et al., 2002). Sputtering of I-PVD in contact liner of Ti/TiN with aspect ratio of 4:1 does promise a decrease in contact resistance. Apart from that, the crystal orientation for Ti shows strong peak of (200) (Yoo et al., 1998).

Besides that, I-PVD is applied for the bottom Ti in Ti/TiN/AlCu metal stack deposition. Zhang *et al* studied the influence of bottom Ti sputtered by using I-PVD method enhanced by substrate bias power. Their findings are somehow contradicted with the results in this studies which would be further explained in chapter 5 (Zhang et al., 2006).

2.3 Electromigration Fundamental

An integrated circuit consists of a combination of electrical components such as transistors, resistors, capacitors and diodes. Thus, it is important that all connections are intact in a circuit. Electrical devices are getting smaller and smaller in size. Hence, the size of the circuit must shrink too, thus increasing the complexity of the circuitry. Therefore, fabricating an integrated circuit, for example, electronic chips, is a very complex process. As complexity of the IC increases, reliability of the chip to perform became more important. Electromigration (EM) is a major concern in reliability where the chip might fail earlier than its expected operational lifetime.

2.3.1 Physics of Electromigration

Electromigration is a major concern for reliability of microelectronic devices. EM is is a phenomenon where transfer of momentum occurs between the metal atoms and the conducting electrons when a current flows through a device. This can lead to a depletion leading to void formation and accumulation (hillock growth) of material in the interconnect lines of circuits when a mass transfer of metal atoms occurred. Eventually, the circuit would fail when the part of the metal line is consumed by voids. However, an EM failure would take years for the device to fail upon electromigration phenomenon.

$$\mathrm{F}_{\mathrm{total}} = \mathrm{F}_{\mathrm{wind}} + \mathrm{F}_{\mathrm{direct}} \tag{2.1}$$

Wind force, F_{wind}, is termed as the force that that is applied on atom at the void surface, in the direction of the electron flow. Direct force, F_{direct}, is the force that is acting onto the metal atoms.

2.3.2 Black's Law

Black's Law is given by the equation as below (De Orio *et al* 2010):

$$\mathrm{MTF} \propto J^{-2} \exp\left(\mathrm{E_A} / k\mathrm{T} \right) \tag{2.2}$$

where, mean time to failure (MTF) is inversely proportional to the square of current density, J^2. An increase of the current density applied will cause a drastic shortened of the mean time to failure of the circuit. T is the ambient temperature, k, the Boltzmann constant and E_A is the activation energy. MTF is defined as the time taken for the material to fail under a constant current density in ambient temperature. EM is influenced by the activation energy of the material. According to Ohring (1998), the activation energy is independent on the diffusion mechanism. This factor is directly contributed by the grain size where the mass transport of material would occur along the grain boundaries.

Although larger grain sizes would lengthen the time for EM to happen, the crystallographic structure of the material also influences EM. For example, AlCu (111) has a "bamboo-structure" arrangement of the grains and thus, eliminate the triple point in grain boundaries. The triple point is where a larger mass divergence occurs due to the wind force. This elimination of the triple point from the grain boundaries could help improve the lifetime of the AlCu (111) structure before EM occurs.

2.3.3 Studies of Electromigration

Scientists and researchers introduced copper (Cu) material to substitute the usage of Al in metal interconnects in order to improve the lifetime of EM. This is because Cu is a better electrical conductor and a low *k* material. However, Al is being used as interconnect material in semiconductor industry until now. This is because Al facilitates the lithographic processing and Cu does poison Si if it were directly deposited on Si devices. Hence, in order to maintain the Al usage and also improve the lifetime of EM, scientists and researchers includes a small amount of Cu into Al material. Al-0.5wt%Cu is widely used in Al interconnect devices. However, more efforts are done to further improve on the EM lifetime (Tu 2003).

Microstructure of Al (111) with bamboo-type structure is most preferable in Al interconnect in order to improve on the EM lifetime. As the sizes of devices shrink, the design of the metal line width shrinks too. By default, the microstructure of Al naturally becomes bamboo like structure. This prevents the formation of triple point boundaries at the grains which encourage the atomic flux divergence that would lead to void and hillock formation (Tu 2003).

Whereas there are a few studies being done in order to improve the microstructure of Al (111). Park and Lee (2001) found that, underlayer of Ti by using DC magnetron sputtering do influence the Al (111) texture compare to underlayer of TiN. In their studies, Al alloy stack with Ti (Ti/AlCu) has stronger peak of Al (111). However, TiN/AlCu has four times better EM lifetime compared to Ti/AlCu. Hariu et al. (1989) had done the similar analysis on Ti/AlCu by using DC magnetron sputtering during deposition of bottom Ti. They found that EM improved by three times when AlCu was deposited at higher temperature of 500ºC with substrate bias of -600V compared to 200ºC. Atomic of inert gas during sputtering, Ar, will be trapped in the growing film where it will retard the growth of atomic grain size. High temperature applied was to desorb Ar atoms. However, crystallographic structure of Ti and AlCu was not emphasized in their paper (Hariu et al., 1989). The effect of the underlayer microstructure was further proved by Tracy et al. where they found that the highly oriented texture of metal film develops from the strong texture of underlayer metal film. In one of their observations, AlCu texture was weakened by an increase in random fraction when AlCu was deposited directly on weak texture of TiN. However, there was no information on how they obtain the random fraction (Tracy et al., 1998). Besides DC magnetron sputtering, Zhang et al proposed a usage of I-PVD for the deposition of bottom Ti in film stack of Ti/TiN/AlCu.

In semiconductor electronic industry, EM reliability is crucial. The increasing failure rate is believed to be due to the potentially shorter time to failure of an interconnection with narrower line width and the increasing sensitivity of the circuits to interconnect line resistances as the circuits are operating at higher frequencies. Underlayer of Ti did improve EM reliability of Al stack film as stated by Park et al (2001).

2.4 Preferred Orientation

Since microstructure of Al (111) and the texture of underlayer or bottom Ti plays major role in reliability issue, the orientation of Ti is studied. The polycrystalline thin film is oriented according to the growth condition of the film. In the I-PVD process, the arrival of metal atoms and ions are normal to the substrate due to the bias applied on the substrate. Furthermore, sputtering process parameters are important in determining the film growth in terms of the microstructure of the film. The main metallic film used in this research were titanium (Ti), titanium nitride

(TiN) and aluminium-0.5% copper (AlCu). Metal liner in Al interconnection consists of Ti/TiN/AlCu/Ti/TiN which is a common metal film stack structure used in integrated circuits. The application of substrate bias was expected to have atomic peening effect. Strong Ti (002) textures are usually reported for deposition at temperature less than 573K. (Tracy et al., 1994)

Besides, Yoo and co-workers characterized I-PVD-deposited for Ti/TiN contact liners and found that Ti and TiN had different orientations when rf substrate power was applied. Superior bottom coverage of Ti film is essential to decrease the contact resistance at small contact.

Preferred orientation depends on the contribution of surface and strain energy. It is therefore determined by the lowest overall free energy resulting from the competition between the surface energy and strain energy on difference lattice planes. According to Pelleg et al., strain energy increases with the increase in film thickness while the surface energy is independent of film thickness. Pelleg and collegues found that a TiB_2 film with orientation of (0001) possessed the minimum surface energy whereas strain energy was dominant at an orientation of (1011) (Pelleg et al., 2005). This was further studied by Greene et al. The authors studied on preferred orientation of TiN grown by using reactive magnetron sputtering, TiN (002) orientation was found to have the lowest surface energy. In the paper, the authors explained that a large strain is expected to play a role in affecting the eventual preferred orientation of the TiN film (Greene et al., 1995).

Besides the above mentioned factors, the preferred orientation could be determined from the underlying texture as studied by Knorr and co-workers. The texture of reactively sputtered TiN depends on underlayer Ti layer, while the preferred orientation of underlayer Ti itself depended on the annealing temperature.

A transition from Ti (0002) to Ti (1011) developed as the substrate temperature increased. The authors concluded that the use of an underlayer Ti (0002) resulted in a TiN (111) structure while an underlayer Ti (1011) produced TiN (311). Stack layer of Ti (0002) / TiN (111) would obtain Al (111) texture when Al was deposited as the subsequent layer. At the same time, Al (311) was observed from Al with bottom TiN (311). The reason behind this was that atomic bonding across the underlayer or overlayer interface would influence the differences in underlayer texture. Covalently bonded substrate material will influence the texture of subsequent metallic film where this explained the Al texture would follow the texture developed by underlayer TiN (Knorr et al., 1998)

CHAPTER 3
EXPERIMENTAL EQUIPMENT

3.1 Introduction

This chapter will discuss the experimental equipments and characterization tools used in this study. A brief introduction on the hardware systems and the methodology that are used in this research would be further elaborated. It consists of direct current (DC) magnetron sputtering and RF self bias platen would be explained before proceed further to the differences of the sputtering chambers, standard chamber and long throw chambers, and chronology of the deposition of Ti/TiN/AlCu in the sputtering chamber. Characterization tools which are used for film properties analysis would be introduced.

3.2 Direct Current (DC) Magnetron sputtering

The DC magnetron sputtering process is illustrated in Fig. 1.2. The sputtering tool consists of a rotating magnet and DC supply attached to the target material. The rotation of the magnet creates an electromagnetic field near the target surface which attracts the gas atoms. The electrons move in gyro motions in the pathway of electromagnetic field thus colliding with argon atoms. Under such circumstances, the argon atoms are ionized producing more free electrons after the collisions. The direct current attracts argon ions to the target which bombard on the target surface to displace and remove metal atoms. As this proceeds further, the target surface would be eroded.

3.3 RF Platen Self Bias

The platen is a stage which holds the wafer positioned in place during sputtering. RF power, alternating current (AC) is supplied to the platen where self-bias is created on the substrate. Generally, the frequency used in industry is 13.56 MHz. The mechanism behind the self-bias is as follow: Electricity flows in constant direction and alternating current (AC) flows in reversing positive and negative with time. As illustrated in Fig. 3.1(a), positively charged metal atoms and inert gas would be attracted onto the wafer substrate when negative potential was applied to the substrate. On the other hand, when the current is alternated, the electrons in the plasma would be attracted to the wafer substrate instead as illustrated in Fig. 3.1(b).

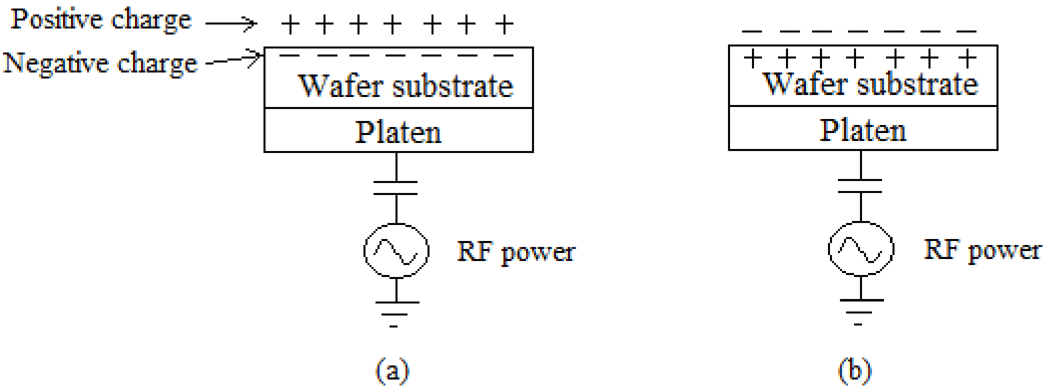


Fig. 3.1 Condition of the wafer substrate with RF bias substrate

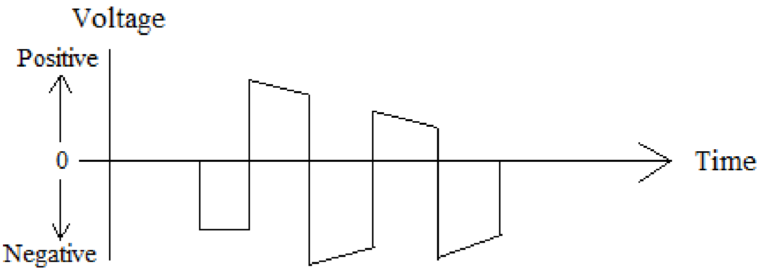


Fig. 3.2 Potential charges accumulated with respect to time

Fig. 3.2 shows the charges accumulated on the substrate surface with time. As the time taken increases, the substrate surface builds up a negative potential. This is because when sputtering takes place on the wafer, the argon ions would bombard on the substrate surface. When a positive voltage is applied, electrons from the plasma would be attracted towards the substrate whereas when a negative voltage is applied, argon ions would be attracted towards the substrate. The argon ions have higher atomic sizes compared to electrons which in turn require a longer time to diffuse back into plasma region when the alternating current is applied. Hence, as shown in Fig. 3.2, the voltage dropped as time increased and this is the phenomenon of self-biasing.

3.4 Sputtering Chamber

A unit of sputtering system consists of AlCu standard chamber, Ti and TiN long throw chamber, Argon pre-cleaning and degassing chambers and a cooling station. All chambers are interconnected and maintained in ultra-high vacuum conditions. The AlCu, Ti and TiN chambers were well equipped with magnet fixed on the target as illustrated in Fig. 1.2. During the transfer of wafer from one chamber to another by using robot arms through an opening slit valves at the chamber wall, all the steps taken were controlled by a recipe which is input into the chamber’s electronic system.

3.4.1 Standard Conventional Chamber

AlCu was deposited in standard conventional chamber. The distance between the target and substrate is 45mm. Fig. 3.4 shows the diagram of the standard sputtering chamber for AlCu where metal target was attached to the top of the chamber with a permanent magnet above. When direct current is supplied to the target material, together with the spinning of the magnet, electromagnetic waves are produced creating a region with high density plasma.

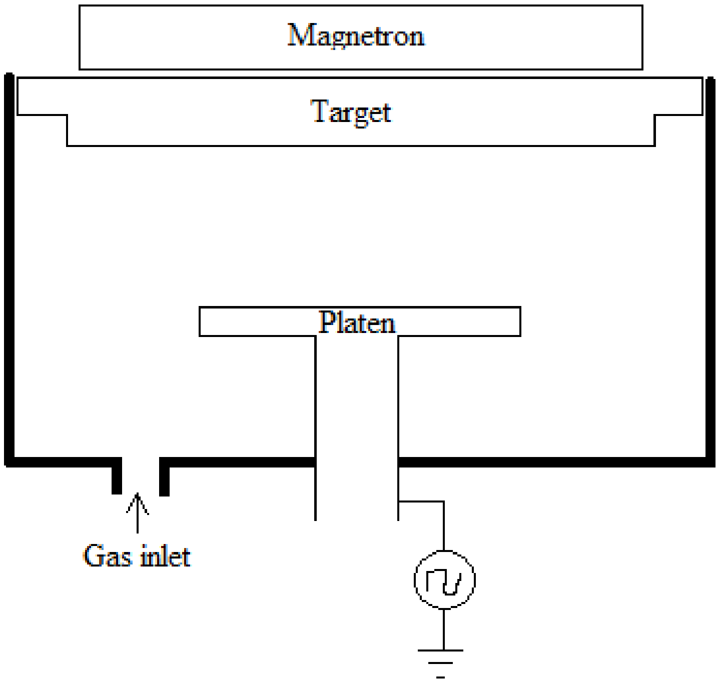
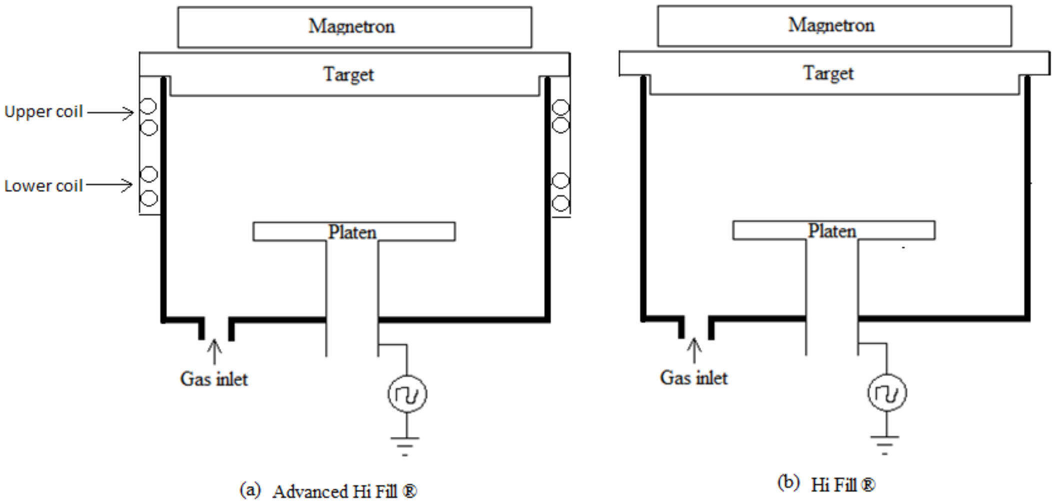


Fig. 3.3 Schematic diagram of standard chamber for AlCu

3.4.2 Long Throw Chamber

The objective of Ti and TiN sputtering in the long throw chamber is to have a good step coverage due to high aspect ratio of the via liner. In the long throw chamber, the height of the chamber is higher than a standard chamber by 200mm and thus provides a longer mean free path and better sputter angle compared to the latter. Besides, there are additional functional hardware embedded in the chamber wall, i.e. the upper and lower coils.

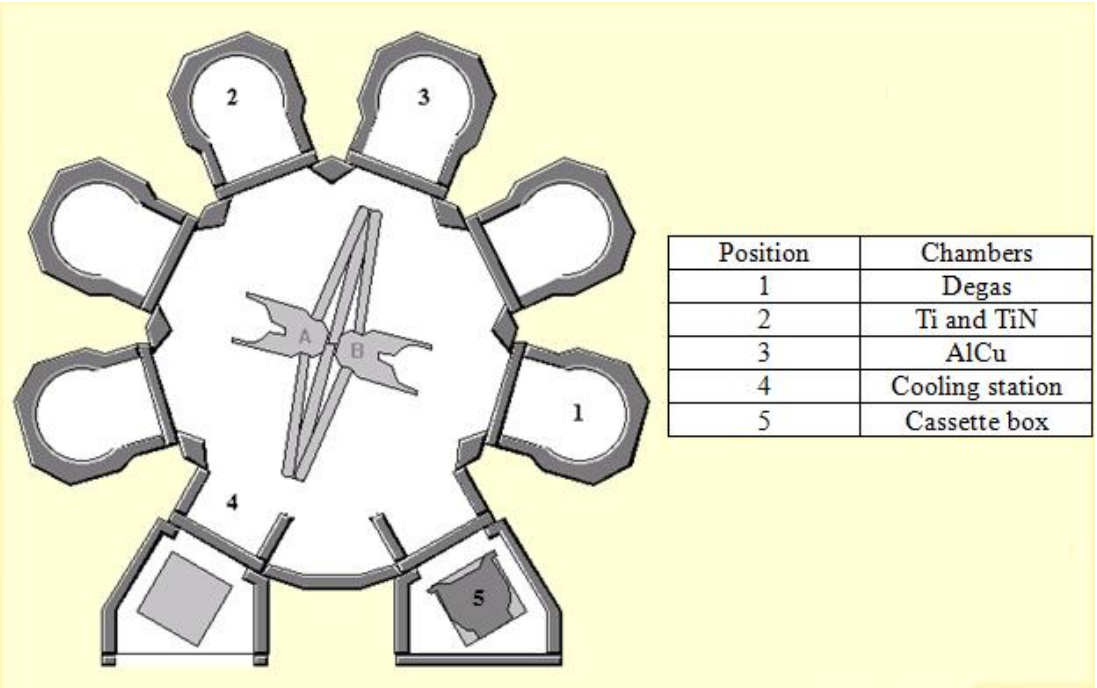
Fig. 3.4 shows schematic diagram of (a) Advanced Hi Fill® and (b) Hi Fill®. There was a slight different in hardware where Advanced Hi Fill® has extra magnetic coils surrounding the chamber. These magnetic coils are divided into upper coil and lower coil where only upper coil parameter is varied in this experiment. It allows the effect of ionized metal plasma condition which, the metal atoms were further ionized by the magnetic field produced by the magnetic coil.



(a) Advanced Hi Fill ®

(b) Hi Fill ®

Fig. 3.4 Schematic diagram of (a) Advanced Hi Fill® and (b) Hi Fill® chambers used for Ti sputtering.



Position	Chambers
1	Degas
2	Ti and TiN
3	AlCu
4	Cooling station
5	Cassette box

Fig. 3.5 The schematic diagram of the chambers. Each chamber is entered by the wafer in the indicated sequence. (Courtesy of Infineon Technologies)

Fig. 3.5 shows the schematic diagram of the chronology of the wafers during the deposition process. The sputtering unit consists of multi chambers include sputtering chambers, degas chamber, cooling station and loadlock chamber for the coated wafers to be placed back to cassette box. Si wafer was used as the substrate for metal deposition. In degas chamber, wafer is heated by using lamps embedded in the platen shows in the schematic diagram in Fig. 3.6. The heated platen can vaporized the water vapor on the wafer surface.

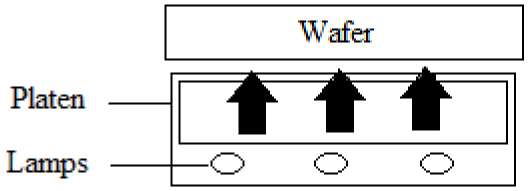


Fig 3.6 Schematic diagram of platen in degas chamber

3.5 Characterization Tools

This research involved seven types of characterization tools. Different process parameters used would influence the thicknesses of the thin films produced. These were measured using an acoustic metrology tool. Different sputtering energies could form different types of intrinsic film stress, i.e. tensile or compressive stress. The intrinsic film stress is measured by the Eichhorn & Hausmann metrology tool. The electrical property of the thin film was measured by a four-point probe. An atomic force microscope (AFM) is used to obtain the root mean square (RMS) quantitative value of the surface roughness. The preferred orientations and grain size of Ti, TiN and AlCu were characterized using X-ray diffraction (XRD). A qualitative analysis was performed by analyzing the surface morphology of the thin films under a