Chapter I

Introduction

1.1 Background

1.1.1 Cu Dual Damascene Process and Cu-CMP

In semiconductor manufacturing, we always directed toward adding device speed and circuit function. Traditionally, we focused on decreasing feature size to reach this goal, and it really worked. However, in deep sub-micrometer region, the impact of interconnect delay has been beyond intrinsic gate delay (Figure.1-1) [5]. It was obvious that interconnect RC delay would limit the overall chip performance as the technology node below 1μm. This was due to the resistance of metal lines increased with increasing length and decreasing width. In addition, the parasitic capacitance of metal lines increased with increasing length and decreasing spacing. The interconnect RC delay was given by

$$RC = \rho\varepsilon\frac{l^2}{td} \qquad \text{(Eq.1-1)}$$

where ρ was the resistivity of the metal, ε was the permittivity of the insulator, l and d were length and thickness of the metal line, respectively, and t was the thickness of the insulator [6]. There were three ways to reduce the RC delay. First, introducing multilevel interconnect structure to reduce l and interconnect complexity. Second, introducing low-dielectric constant materials as insulators to reduce. Third,

introducing low resistivity metals as interconnect materials [5].

Cu as interconnect material could be understood form the view point of material properties. Table.1-1 gave the comparison of properties of several possible interconnect metals [7]. Among these metals, Cu with two primary characteristics of low resistivity (1.7μΩ.cm) and high melting point(1085℃) could exhibit good electromigration resistance and reliability. Therefore, Cu was the most promising candidate for the advanced interconnect metallization. However, owing to lack of Cu compounds with high vapor pressure at low temperature, reactive ion etching (RIE) was not practical method to pattern Cu metal lines [8]. Several different methods for fabrication of multilevel Cu interconnect has been reported [9] [10]. The most promising method was known as dual damascene process with chemical mechanical polishing (CMP) shown in Figure.1-2. Several advantages of dual damascene process using CMP were described below. First, such approach did not need to develop the difficult RIE of copper. Second, the global planarity of surface was achieved by CMP, which means allowing for multilayer stacking of Cu metallization without surface topography buildup[11]. Third, dual damascene process reduced manufacturing process steps and CMP widened the process window [12]. Fourth, Cu CMP was a room-temperature process and this process could reduce the thermal budget. Finally, it was relatively easy to obtain a clean Cu interface after CMP process comparing to

metal RIE, which would significantly reduce contact resistance.

1.1.2 W-plug process and W-CMP

Tungsten-filled vias contacts had several advantages over aluminum-filled vias. Because CVD tungsten deposits a conformal coating, the via is completely filled without the formation of keyholes or gaps. In contrast, physical vapor deposition of aluminum films are nonconformal with regions of thin metal at the bottom of the contact/via. The ratio of the thinnest point in the aluminum film to the thickest point is refered to as the step coverage. Electromigration failured commonly occur at these thin points in the aluminum-filled contact/via [6]. In addition, tungsten metal showed significantly better electromigration properties than aluminum by virtue of its refractory properties [13]. The combination of better step coverage and better inherent electromigration properties make tungsten filling of contacts and vias attractive. The tungsten-filled contact/via is substantially more planar than the aluminum-filled contact/via.

There were several advantages to using CMP to remove the metal overburden, First, metal CMP yields a high degree of local planarity. Unlike the RIE process, the CMP process was self-arresting, Removal of metal was dramatically reduced once the overburden was removed. For tungsten stud formation, several workers had demonstrated almost ideal coplanar surfaces [14]. The high degree of planarity allows

vias to be stacked directly on top of each other. Stacked vias result in considerable reduction in circuit area over staggered vias. However, for the formation of wider structures such as interconnections, dishing effects reduced the local planarity. Tungsten CMP was most widely used for the formation of studs in contacts and vias. There were some reports of tungsten CMP utilized for the formation of interconnections [15]; however, the relatively high resistivity of tungsten(5.65uΩ.cm) compared to aluminum(2.66uΩ.cm) or copper (1.67uΩ.cm), limited the use of tungsten as an interconnect metal.

In Kaffman's model, the mechanism of metal CMP had been significantly defined. At the beginning of polishing process, metal was oxidized as native metal oxide in aqueous solutions. In situ, the protruded metal oxide was electively abraded by the abrasives leading to effective corrosion of underlying metal. By the way, the selective metal removal rates between protruded and recess areas could be obtained. Based on the metal CMP mechanism of Kaffman's model, metal removal rate depends on many factors, such like abrasives, oxidizers, and pH value. In the concern of abrasives in metal CMP~How many factors of 2nd abrasive size in the slurry? (Ex. electric double layer) Furthermore, please identify the characteristics of factors.

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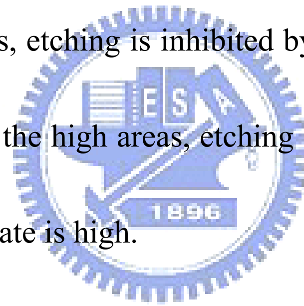
A tungsten CMP slurry may include an etchant and a passivating agent to realize the difference in etch rates between the high features and the low features. The passivating agent forms a surface film on the tungsten to protect the tungsten in the low areas from etching. Mechanical abrasion removes the surface film in the high areas, allowing the etchant to etch the tungsten. In the low areas, the surface film is not abraded because the polishing pad is rigid and does not contact the low areas. Consequently, in the low areas, etching is inhibited by the surface by the surface film and removal is slow, while in the high areas, etching occurs due to the absence of the surface film and the removal rate is high.



For tungsten CMP, the formation of the WO3 surface film has added advantages besides limiting the etch rate in the low regions. WO3 is softer than tungsten and abrades more readily. Thus, the formation of WO3 assists in planarization by allowing higher removal rates in the high region via abrasion, as well as suppressing chemical etching of the low regions. In addition, WO3 is an excellent passivating film against post-polish corrosion. The dense, nonporous nature of WO3 prevents diffusion of corrosive elements to the underlying tungsten, thereby inhibiting corrosion.

1.1.3 The Role of the Electrostatic Forces (Electrochemical double layer)

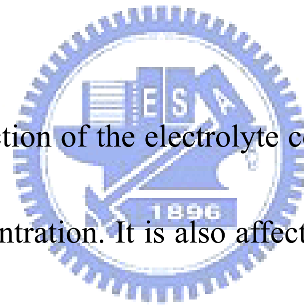
The particles suspended and surfaces immersed in a liquid were usually charged by the adsorption of the ions from solution. The charge on the surface of the particle or any other surface immersed in liquid was balanced by an equal but oppositely charged layer in the adjacent liquid, resulting in a so-called electric double layer shown in figure 1-3. In a liquid with ions and molecules under constant thermal motion, one expects a diffused zone of charges in the solution and a compacted layer on the solid surface. Total charge density in the two zones must be equal and opposite in sign. When the liquid or the particles was in motion the compacted layer on the solid particle surface moves with the particle, whereas the diffused zone of charges in liquid moved with the liquid. The boundary between the two regions of charges was shown as a shear plane in figure 1-1[21]. The liquid velocity v was related to the electrostatic potential Φ, developed surrounding the particle and electric field strength χ, as given by [22]

$$\nu(x) = \frac{\varepsilon X}{\eta}(\phi(\kappa) - \xi)$$

Where ε and η were the permittivity and the viscosity of liquid, respectively, and ξ was the potential at the shear plane and was called the electrokinetic potential of the zeta potential. Note that both ν and Φ were a function of χ, the distance measured

from the surface of the particle. Φ decreased very rapidly as one moved away from the surface of the particle, being zero in the liquid bulk where the velocity was maximum.

During CMP, the slurry flows between the solid wafer surface being polished and the pad. The concept of zeta potential applies for these surfaces as well. Both the wafer and pad surface were charged by attracting ions in the liquid and thus create the double layer. It was also noted that metallic surfaces might behave differently. The concept of zeta potential should be carefully considered when discussing the CMP of metallic surfaces.


ESA 1896

Zeta potential was a function of the electrolyte concentration and pH, decreasing with increasing pH and concentration. It is also affected by an addition of the surface modifiers such as surfactants. Thus by varying concentration of pH, or by an addition of a surfactant to slurry one can manipulate the zeta potential at solid surfaces.

1.1.4 Abrasion Modes

The slurry changed with chemical composition or chemical concentration that would affect the abrasive size. The different abrasive sizes could lead to two different abrasion modes, grinding and polishing. Grinding normally employs abrasives on the order of 1-100 um in diameter, whereas polishing normally employs abrasive on the order of 10-300nm in diameter [23]. In addition, grinding may be broken down into

two categories, brittle grinding and ductile grinding Ductile grinding , alternatively termed microgrinding, occurs with abrasive sizes on the lower end of the range, 0.75-3.0 um in diameter [23], whereas brittle grinding occurs with larger abrasives. Note that transition between abrasion modes depends not only on abrasive size, but also slurry chemistry and the mechanical properties of the film.

1.2 Motivation

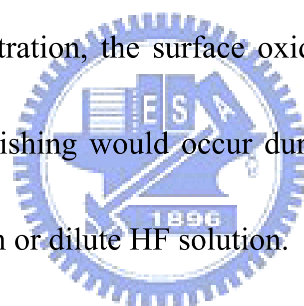
1.2.1 Part of Copper

In order to investigate the additive in the slurry, we would like to add the organic acid in the slurry. It would be change the chemical composition of the slurry. The zeta potential is a function of the electrolyte concentration and pH, decreasing with increasing pH and concentration, so the zeta potential would be changed. If the zeta potential fell between the ± 30mv, the abrasive would be aggregated. Therefore, the size of abrasives on the order of 10-300 nm or 1-100um in diameter would be grinding or polishing, respectively. The consequence of changing the abrasion mode was to change the scale at which material was removed from the surface. Because material was removed in larger chunks with grinding , higher removal rates were achieved. However, grinding produces subsurface damage which was undesirable in electronic applications.

1896

1.2.2 Part of tungsten

In order to reduce COO of CMP, we would like to dilute CABOT W2000 (acidic SiO2 suspension, pH=2-3) slurry with 1 to 6 parts of DI water without degradation of polishing performance, removal rate and non-uniformity. Both slurry pH and solid content would be changed during dilution, which dramatically change the abrasive suspension and mechanical abrasion during polishing. Varying hydrogen peroxide concentration of slurry would lead to complicated surface oxidation on W surface, both thermodynamically and kinetically. Not only removal rate would be changed with various oxidizer concentration, the surface oxide passivation also be changed. Dishing of W plugs after polishing would occur during oxide buffing or post CMP cleaning with alkaline solution or dilute HF solution.



In this study, both dilution of CABOT W2000 slurry and various hydrogen peroxide concentration of slurry formulation would be explored for optimized polishing performance, removal rates, non-uniformity and dishing effect. Finally, we would like to make the Kelvin structure to measurement the contact resistance how to change.

Mechanical abrasion would be reduced as dilute ratio increase owing to solid content drop, so as to removal rate would be reduced. PSC suggest the removal rates would not significantly changed as dilute ratio up to 6. It might be the surface oxide passivation should be varied as dilution. As shown in Pourbaix shown in figure 3-1,

tungsten oxide would be more corroded in alkaline solution. The pH of W2000 slurry without dilution would be 2-3, but may be changed to 4-6 as dilution. The surface passivation could be evaluated by electrochemical measurement (Tafel & impedance). The other factor may be taken into account was abrasive suspension; aggregation of abrasive might occur during dilution, it might lead to enhance removal rates.

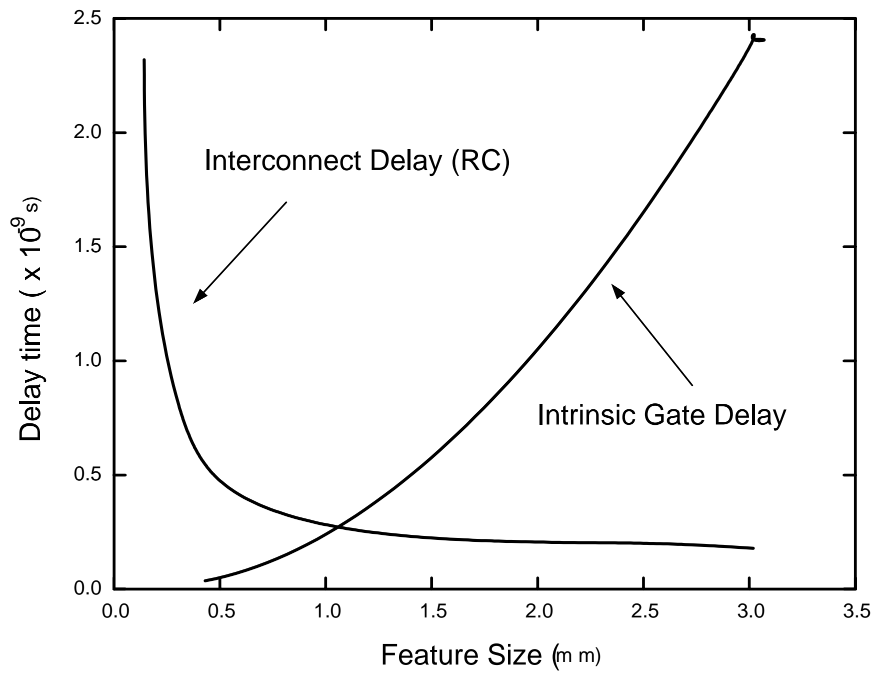


Figure.1-1 Comparison of intrinsic gate delay and interconnect delay (RC) as a function of feature size.

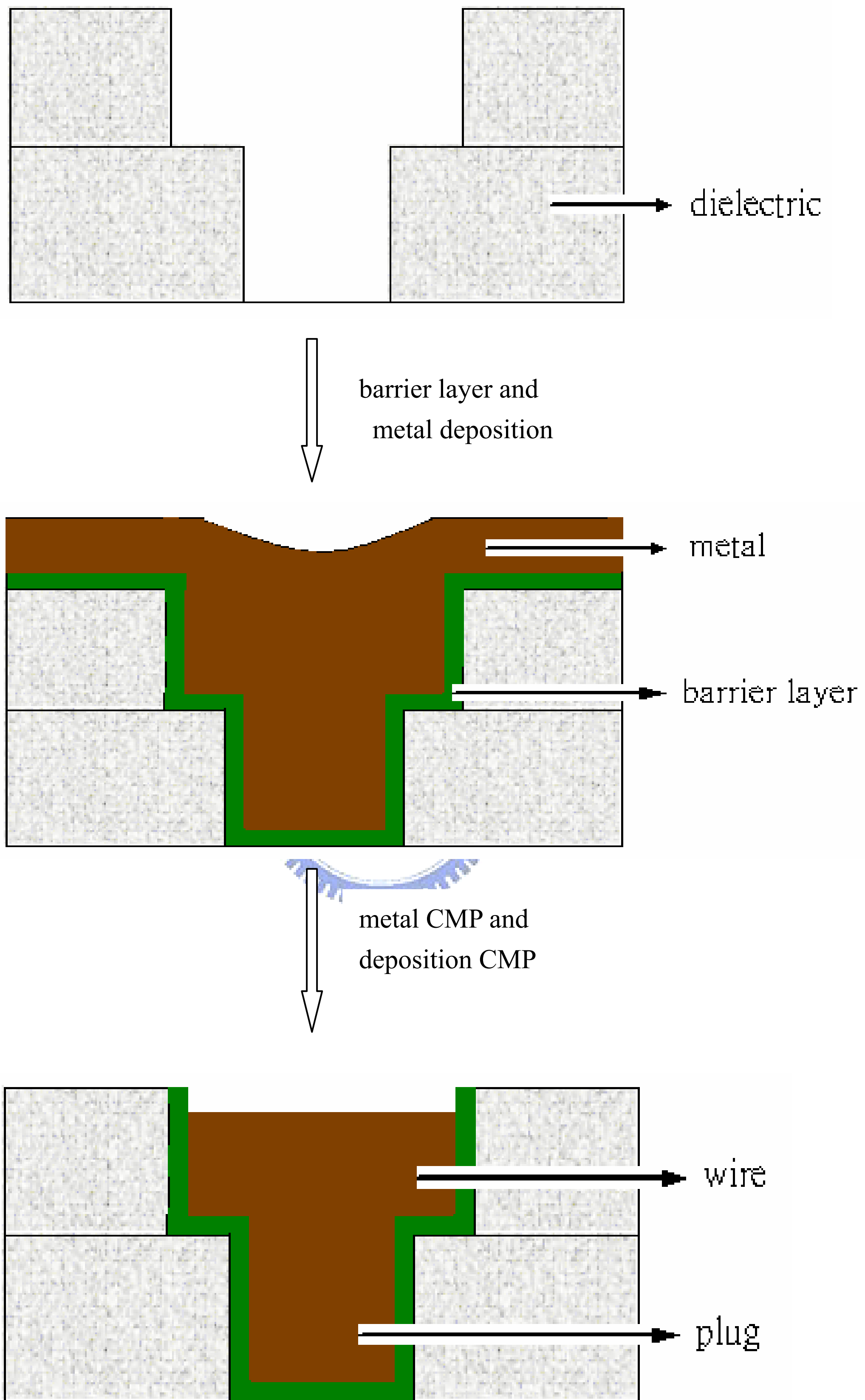


Figure.1-2 Dual damascene process.

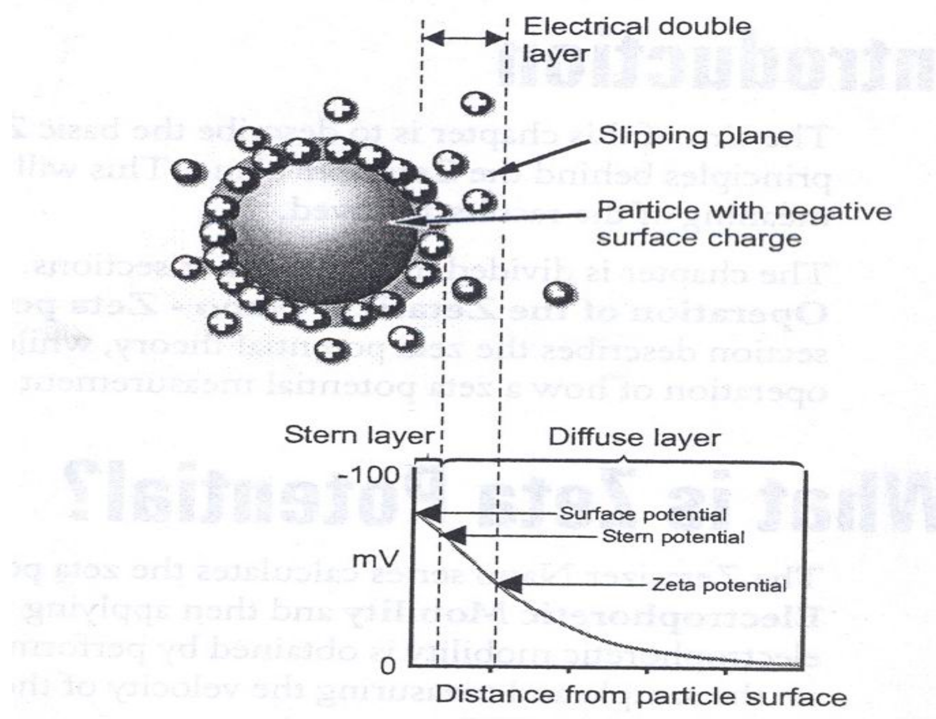


Figure 1-3. Electrochemical double layer

	Ag	Al	Al Alloy	Au	Cu	W
Resistivity(μΩ-cm)	1.59	2.66	~3.5	2.35	1.67	5.65
Electromigration Resistance (at 0.5μm)	Poor	Poor	Fair-Poor	Very Good	Good	Very Good
Corrosion Resistance	Poor	Good	Good	Excel	Poor	Good
Adhesion to SiO_2	Poor	Good	Good	Poor	Poor	Poor
Si Deep Levels	Yes	NO	NO	YES	YES	NO
CVD Processing	None	?	None	None	Avail	Avail
RIE Etch	None	Avail	Avail	None	?	Avail

Table.1-1 Properties of low resistivity metals