Study on chemical mechanical ultra precision process technology of Aluminum Interconnected Line for ULSI

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Abstract. The chemical mechanical polishing ultra precision process technology mechanism of Aluminum Interconnected Line for ULSI was analyzed according the physical and chemical properties of Aluminum. In order to meet the request of environmental protection and reducing ion staining, the alkaline slurry was adopted. The selection reason of pH value regulator and surfactant was discussed, and their actions during polishing were analyzed. According to the experimental results and optimal technological parameters, the higher removal rate and lower surface roughness were gotten, which were 390nm/min and 0.47nm respectively.

Introduction

Aluminum was used as the important metal interconnection material from the first generation integrated circuit(IC) to ULSI manufacturing for its excellent properties, such as low resistivity, low melting point, good adhesive quality, and so on. Above 0.18μm technology node for silicon process manufacture, Aluminum and Aluminum alloy are still the key interconnection material[1].

For the traditional manufacture process, the method of removal metal Aluminum was reactive ion etching(RIE) method. But for lower than 0.25μm technology node device, RIE was not the profit planarization method, for it could’t removal the layer material completely which led to short circuit and lower wafer inner uniformity[2]. For the high precision request, the ultra precision process method of chemical mechanical polishing was adopted by semiconductor industries, which not only provided a promising method to achieve global planarization but also generated new possibilities for the development of innovative semiconductor manufacturing processes. According to the recent research report, lower than 45nm technology node for CMOS process, HKMG technique becomes the main stream, and Aluminum is used as gate electrode material for replace metal gate(RMG). The size of Aluminum line will be thinner and thinner, so how to control the removal rate and surface roughness becomes the research emphases of RMG Al-CMP[3-4].

The low hardness and complicated electrochemical behavior of Aluminum would require a more sophisticated control over the mechanical parameters and slurry chemistries in its CMP process[5]. In this study, in order to achieve good planarity and low surface roughness, the alkaline medium, organic base as pH regulator and FA/O surfactant were selected.

Analysis of Aluminum interconnection line CMP mechanism

Physical and chemical properties of Aluminum. Aluminum is an amphoteric metal, and it is easy to be oxidized in the air to form surface passivation film. Fig1 shows the E-pH diagram of Aluminum in aqueous solution.

From this diagram it can be seen that at the different electric potential and pH regions the different reaction products were formed. There are three pH regions that produce three distinct

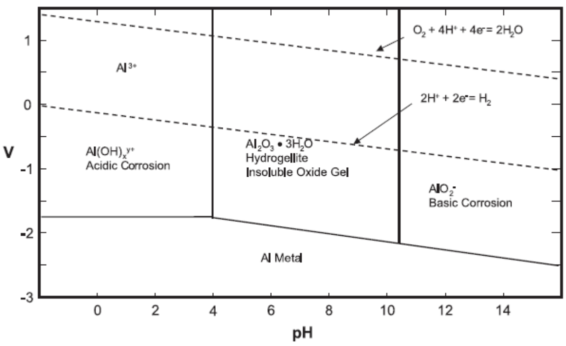


Fig. 1. Pourbaix diagram of Al.

Fig.1 E－pH pourbaix diagram of Al[6]

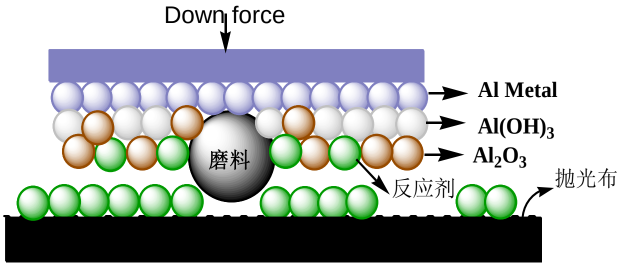


Fig.2 The mechanism model for Al CMP

species.The low(<4) and high pH(>8.3) regions attack Al metal, producing soluble Al ionic species, Al3+ and AlO2-, respectively. When operating CMP within these pH regions, the slurry must leave the metal surface quick enough to avoid formation of pinholes, corrosion, pitting or any other surface imperfections that would lead to higher surface roughness. Conversely, Al under neutral pH chemistries forms a protective oxide($Al_2O_3 \cdot 3H_2O$) that is several times harder than the metal itself and difficult to be removed. So the impossible pH regions for Al-CMP should be lower than 4 and higher than 8.3.

Polishing mechanism of Al interconnection line. According to the Al characters, for Al-CMP the slurry can be acidity, and the Al metal can be translated into Al ion to be removed. Also the slurry can be alkalis, then the Al metal can be translated into AlO2- to be removed. But for acid medium, the formed alum ion causes ionic secondary pollution and it takes more difficult for cleaning. So the alkali medium is selected for alkali has passivating action and it can avoid etching equipment, also alkali medium takes important action for abrasive stability and will not cause ionic secondary pollution.

The mechanism model for Al-CMP is shown as Fig2.

Under alkali condition, the chemical reactions as follows:

$$4Al + 3H_2O_2 \rightarrow 2Al_2O_3 \quad (1)$$

$$Al_2O_3 + H_2O \Leftrightarrow 2AlO(OH) \quad (2)$$

$$Al_2O_3 + 3H_2O \Leftrightarrow 2Al(OH)_3 \quad (3)$$

$$Al_2O_3 + 2OH^- \Leftrightarrow 2AlO_2^- + H_2O \quad (4)$$

$$Al(OH)_3 + OH^- \Leftrightarrow AlO_2^- + 2H_2O \quad (5)$$

First Al metal is oxidized by oxidizer to Al_2O_3 , then Al_2O_3 ,reacts with H_2O and forms the hydrates of α-alumina, and the hardness of such hydrates is lower than Al_2O_3. At the same time, a part of substrate material and hydrates react with alkali, and form water soluble AlO_2^-. $Al(OH)_3$ is a sort of white gelatinous precipitate, so the reactions must meet the dynamic balance and the reaction products must be remove away quickly, or which can influence the surface quality seriously.

Experimental procedure

In this study, the polishing equipment is France Alpsitec E460. After polishing and cleaning, the samples surface roughness were measured on Agilent 5600LS. The abrasive size was measured by Mastersizer 3000HS particle size analyzer.

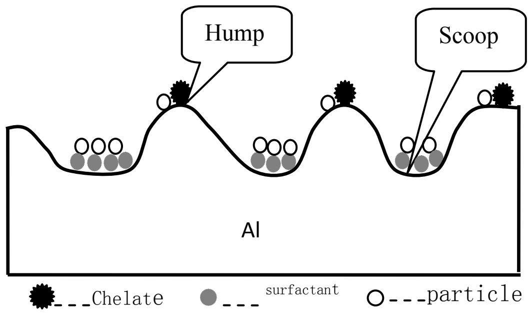
Results and discussion

pH regulator. In order to avoid metal ion introduction, macro molecule hydroxylamine is selected as pH regulator, abbreviated as R $(NH_2)_4$. So the macro molecule and soluble products can be removed away easily from the sample surface, the reaction for mula as follows:

$$Al_2O_3 + NH_2RNH_2 + H_2O \Rightarrow (NH_3RNH_3)(AlO_2)_2 \quad (6)$$

$$2AlO(OH) + NH_2RNH_2 \Rightarrow (NH_3RNH_3)(AlO_2)_2 \quad (7)$$

The action mechanism is shown as Fig3.During the CMP process, there has higher kinetic energy on the hump, so regulator can react with reactant quickly. But at the scoop, the react rate is slower for the low kinetic energy. Such good concavo convex selectivity can achieve higher planar effect.



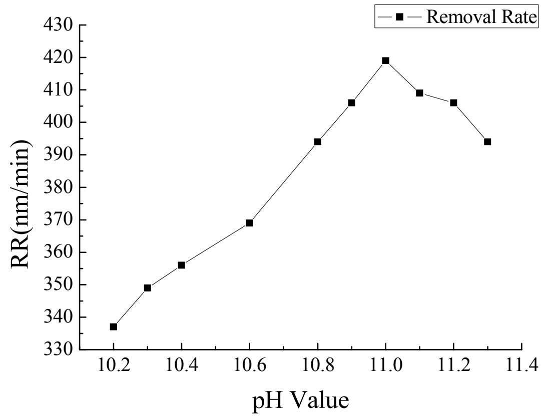


Fig.3 The effect of regent during CMP process   Fig 4 Aluminum RR under different pH value

Fig4 shows the Al removal rate changes with different pH. It can be seen that with pH value rising, the removal rate increase. When the pH value reaches 11.0, the removal rate reaches 419nm/min and begins decreasing. With the pH value increasing, the concentration of OH- ion also increases, and more soluble meta aluminic acid amine is formed, which can lead to higher removal rate. But when the AlO_2^- concentration reaches a certain value, the reaction for mula will be backward, and forms a certain quantity Al()H)$_3$ gelatinous precipitate, which slows down the forming of meta aluminic acid amine and reaction products breaking away from Al surface will be under speed. So the removal rate decreases with pH value increasing. Otherwise when the concentration is higher, the oxidizer H_2O_2 will be decomposed easily and the oxidation properties will be lower. So the pH value was selected 11.0.

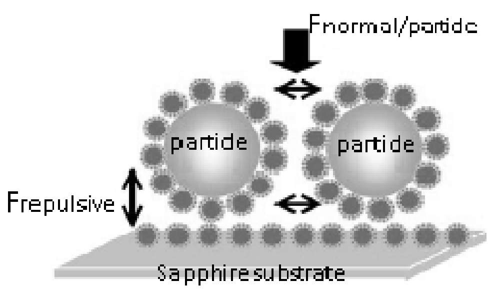


Fig.5 Effect of surfactant on particle-particle and particle-substrate

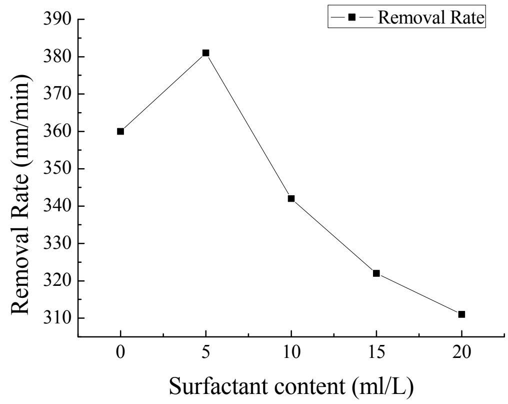


Fig.6 Effect of the surfactant on the removal rate

Surfactant. In this study, FA/O nonionic surfactant is selected, which can ensure slurry stability, enlarge the repulsive force between abrasive particles(Fig5). So the abrasive particles disperse equably and the slurry can keep stable long time. Also it can decrease surface tension and has strong osmosis(Fig3). The removal particles can keep physical adsorption and be taken away from the surface easily.

Fig6 shows the relation of removal rate and surfactant concentration. It can be seen when surfactant concentration is 5ml/L, the removal rate reaches 386nm/min, and with the concentration increasing the removal rate decreases. For more surfactant will weaken the abrasive mechanical action, which leads to the lower removal rate.

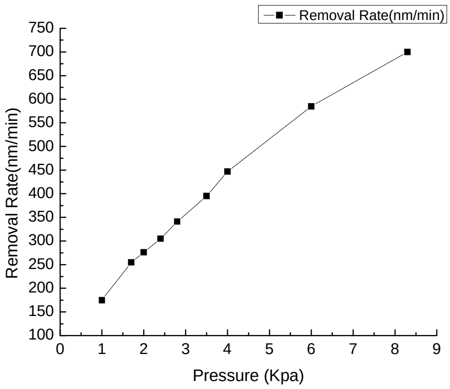


Fig.7 Aluminum RR under different pressure

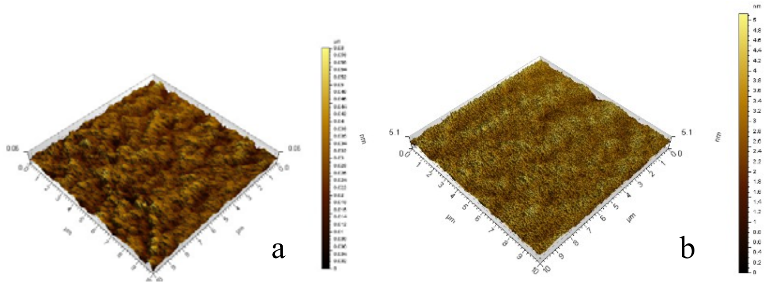


Fig.8AFM images of aluminum surface(a. before CMP,b. after CMP)

Optimal results. Through optimizing the mechanical parameters and slurry chemistries, the removal rate can reach more than 400nm/min, and the surface roughness can reach 0.47nm with the scope 10μm×10μm(Fig8).

Conclusion

Under the foundation of analyzing Al physical chemical properties, the alkali medium was selected for Al interconnection line CMP and macro molecule hydroxylamine was selected as pH regulator, which avoided the ion second pollution and can reach the aim of energy conservation and environmental protection. Through optimizing the mechanical parameters and slurry chemistries, the high removal rate and low surface roughness were achieved, and they were higher than 400nm/min and 0.47nm respectively.

Acknowledgements

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