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Full Length Article

Studying of physical characteristics and optimizing of gap filling for tungsten

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ABSTRACT

The effect of process parameters on the physical properties of tungsten (W) thin film and the preferable condition for W-plug gap filling were investigated. Uniformity (U%) of resistance was found to improve with pressure. This can be explained by reactant gas flow change during the process due to the pressure altered, which further affects the behavior of film deposition. In addition, lower temperature and slower WF6 flow rate lead to better thickness U%, which is ascribed to a slower film growth rate. As to tensile stress, it decreased with the process temperature. It is presumable that there is less impurity in the film and less dislocation with higher temperature deposition. On the other hand, there was lower resistivity with higher temperatures because of larger grain size growth. Using the Taguchi method, pressure of 80 Torr, temperature of 370 °C, and WF6 flow rate of 150 sccm demonstrated the optimized condition to achieve the minimum seam size (6 and 10 nm in the top-view and cross-section, respectively) on the aspect ratio (A/R) 16 of the contact loop. Furthermore, the exposed seam ratio was also found to be the smallest.

1. Introduction

Due to the request of packing density, which increases for proceeding generations of integrated circuits, multilevel metallization and contact fill processes have become important in the structure design and fabrication. When examining the reliability of contact via filling, selective tungsten (W) plug processing has been widely used because of its simple application [1–5]. W-plug resistance (Rc) is critical to maintain the circuit's performance and reliability. Higher resistance may cause several issues, such as the voltage drop and capacitance increase, and further bring about longer signal propagation delay. Furthermore, the control of the thin film's mechanical stress is another noticeable issue. Such stress often determines the limitations of film when it will buckle, crack, or even delaminate [6–8]. On the other hand, the seam or hole of the W film that is exposed in the gap filling after chemical mechanical polishing (CMP) has a close relationship with the device's reliability. The exposed seam existence will result in several unavoidable problems, such as the organic solvent penetrating into the contact during the following process, and then give rise to device's short, current leakages, or other issues. Therefore, it is necessary to have a smaller seam size in the W-plug to prevent such problems. In this study, the physical properties of W thin film, such as thickness U%, sheet resistance U%, stress, and resistivity were systematically characterized. At the same time, the optimized condition for the high aspect ratio of 16 (contact height: ~740 nm and top diameter ~46 nm) of W gap filling was also investigated by applying the Taguchi method L4 (2^3).

2. Experimental

To study the physical properties of tungsten film, the experiments included several process conditions (ex: WF6 flow rate, pressure, and temperature) on a blanket wafer. A thin layer of TiN film was deposited to prevent the

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occurrence of peeling of the underlying SiO2 and to ensure the tungsten's adhesion to SiO2. After depositing the tungsten material by the SiH4 and H2 reduction of WF6 during the nucleation and VF step (Eqs. (1) and (2)) [9,10], in which the W thickness is 200 nm, the samples were analyzed by PANalytical, KLA (SPECTRA-Fx 100), and KLA (OmniMAP RS-100c) for thickness, sheet resistance, and stress measurements, respectively. The Atomic Force Microscopy (AFM) was used to analyze the surface roughness (Ra). In addition, patterned wafers of A/R of approximately 16 for the contact loop were used to obtain the seam size of the top-view and cross-section to estimate the gap filling ability after CMP treatment using Scanning Electron Microscope (SEM). The design of experiment (DOE) of the Taguchi L4 (2^3), as represented in Tables 1 and 2, was applied to achieve the best W-plug gap filling condition, and was further simulated using a MiniTab R15 analysis. The major steps of implementing Taguchi method are illustrated in Fig. 1 [11,12]. Taguchi method is a technique to design and perform experiments to investigate the processes where the outputs depend on many factors (variables, inputs) without having tediously and uneconomically run the process of utilizing all possible combinations of values. Due to systematically chosen definite combinations of variables it is probable to separate their individual effect [13].

Table 1
Level of process parameters.

Symbol	Factor	Level	
A	**Pressure (Torr)**	**80 (A1)**	**50 (A2)**
B	**Temperature (°C)**	**430 (B1)**	**370 (B2)**
C	**WF_6 flow rate (sccm)**	**150 (C1)**	**50 (C2)**

Table 2
Taguchi's L4 (2^3) orthogonal array.

Exp.	Factor		
	A	B	C
1	**80 (A1)**	**430 (B1)**	**150 (C1)**
2	**80 (A1)**	**370 (B2)**	**50 (C2)**
3	**50 (A2)**	**430 (B1)**	**50 (C2)**
4	**50 (A2)**	**370 (B2)**	**150 (C1)**
5	**80 (A1)**	**370 (B2)**	**150 (C1)**

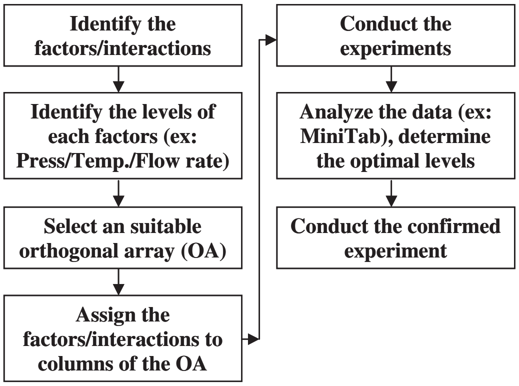

Fig. 1. Scheme of the major steps implementing the Taguchi method and orthogonal array (OA) is the matrix of numbers arranged in columns and rows [12].

$$\text{Nucleation: } 2WF_6+3SiH_4 \rightarrow 2W+3SiF_4\uparrow+6H_2 \quad (1)$$

$$\text{VF (Via Filling): } WF_6+3H_2 \rightarrow W+6HF\uparrow \quad (2)$$

3. Results and discussion

3.1. Studying of physical property of tungsten film

According to the results, the relationships were found between the process parameters and film properties. However, as depicted in Table 3, which includes stress, resistivity (ρ), and uniformity (U%) of thickness and resistance, it displayed various effect levels on the physical characteristics of W thin film. Amongst these, the process pressure increment significantly improved the U% of resistance by 50%, but causes sheet resistance (Rs) to increase oppositely (Fig. 2). Both phenomena are likely due to the reactant gas flow change during the process since pressure is altered, and further affects the behavior of the film deposition. WF_6 partial pressure increments often cause Rs to rise. However, pressure variation has more influence on the Rs uniformity. A lower process temperature or slower WF_6 flow rate seems to bring about better thickness U% as a result of the film's lower growth rate (Fig. 3). Although, if the flow rate of WF_6 is sufficiently large

Table 3
Effect of reactionary parameters on the physical properties of W film.

Parameter	Pressure (Torr) (50- > 80)	Temperature (°C) (370- > 430)	WF_6 flow rate (sccm) (50 - > 150)
THK U%	↑↑	↑↑↑	
Rs U%	↓↓↓		
Stress (MPa)	↑	↓↓	↑↑
Resistivity (μΩ-cm)	↑	↓	

Decrease→ ↓: (> 8%), ↓↓: (> 20%), ↓↓↓: (> 45%), increase→ ↑: (> 5%), ↑↑: (> 18%), ↑↑↑: (> 25%).

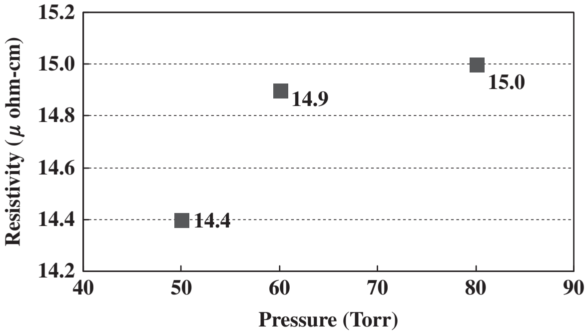

Fig. 2. Effect of process pressure on the resistivity of tungsten film and condition: temperature of 430 °C, WF_6 flow rate of 150 sccm, and W film is 200 nm.