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Evaluation of Mobile Ion Contamination in Tungsten-Gate MOS Process Using Triangular Voltage Sweep Method

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Mobile ion contamination in tungsten (W) gate MOS fabrication is studied using triangular voltage sweep (TVS). It is proved that mobile ionic contaminants in SiO_2 film come from MOS gate electrode or photoresist film in W-gate MOS fabrication. It is found that the change in MOS characteristics due to this contamination is related to the sodium (Na) concentration of electrode material or photoresist film, increased by the electric field induced during ashing in O_2 plasma. A W-gate MOS device free from mobile ion contamination is obtained using a highly purified W sputtering target and reducing the electrical field caused by plasma ashing process.

1. Introduction

Refractory metal has been considered for application to MOS VLSIs because of its low resistivity. The authors have therefore developed a fabrication process for tungsten (W) gate MOS devices[1),2)]. However, there are long-standing problems of mobile ion contamination in metal-gate MOS fabrication.

This paper attributes mobile ion contamination to impurities in MOS gate electrode materials and photoresist film used in photolithography. It also describes a fabrication of W-gate MOS devices free from mobile ion contamination.

2. Experiment

2.1 Evaluation of contaminants from W electrode

W-gate MOS samples are prepared as shown in Fig. 1. The thermal SiO_2 film (20 nm) used in our experiment is grown at 950℃ in dry O_2 atmosphere on 4-inch silicon wafers. These wafers are positive-type (100) oriented and have 9-12 ohm·cm resistivity. After oxidation, W film is deposited by DC magnetron sputtering using three W targets with different purities. W(III) is the purest target. W-gate electrode ($1mm^2$) is patterned by wet etching to avoid damage due to dry etching. Mobile ionic contaminants are measured by triangular voltage sweep (TVS)[3),4)] and bias temperature (BT) test.

Mobile ionic contaminants per W target are shown in Table 1. When W(III) is used, the amount of contaminants is below the TVS detection limit ($5 \times 10^9/cm^2$). Thus mobile ion contamination from W electrode is below the detection limit if a highly purified sputtering target is used.

2.2 Contamination caused by photoresist ashing process

Mobile ion contamination caused in CMOS fabrication processes using photoresist for a mask is studied

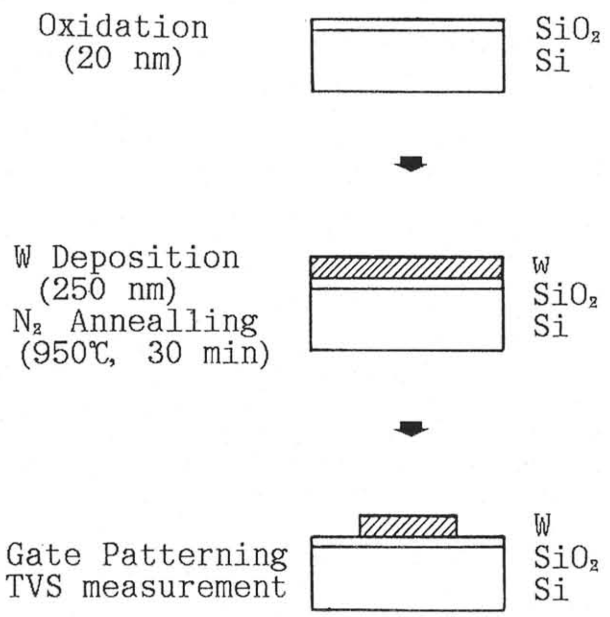

Fig. 1 Sample preparation procedure

Table 1 Evaluation results of mobile ion contaminants from W electrode

Gate electrode	Na concentration (ppb)	Mobile ion (cm^{-2})	
		TVS	BT
W (I)	10	5.0×10^{11}	6.5×10^{11}
W (II)	~0.01	~7×10^{9}	$< 5 \times 10^{10}$ *
W (III)	~0.01	$< 5 \times 10^{9}$ *	$< 5 \times 10^{10}$ *

(* detection limit)

Table 2 Photoresist impurities

Element	Impurity concentration (ppb)
Al	8.4
B	6.4
Ca	8.9
Cr	3.7
Cu	17.8
Fe	324
K	10.8
Mg	18.8
Mn	0.9
Na	762
Ni	6.9
P	267
Ti	1.4
Zn	1.4

using a W-gate MOS fabricated with a highly purified sputtering target. A positive-type photoresist is used. Impurities in this photoresist are analyzed by Inductively Coupled Argon Plasma Spectroscopy (ICPS), as shown in Table 1. Na concentration is 762 ppb. A barrel ashing machine strips the photoresist coating from 4-inch wafers (0.5~1.5 μm thickness) in O_2 plasma. Ashing conditions are 200W, 1 torr, 10 min. Contamination is measured by TVS at 200℃ after heat treatment at 950℃ for 30 min in N_2 atmosphere.

The dependence of mobile ionic contaminant density (D_{ion}) on photoresist thickness is shown in Fig. 2. No contaminants are detected for O_2 plasma treatment alone, without photoresist. However, contaminants are detected when photoresist is used[5]. Furthermore, cotaminants increase as photoresist film thickness increases. It is therefore concluded that these contaminants come from the photoresist materials.

Surface potential change due to O_2 plasma ashing is measured. MNOS capacitor is used in which W, Si_3N_4 and SiO_2 thickness are 250 nm, 50 nm and 2nm respectively. If an electric field forms in SiO_2 during electric charging, the MNOS capacitor C-V curve shifts in voltage axis. Thus the MNOS C-V characteristics indicate surface potential.

D_{ion} dependence on Na concentra-

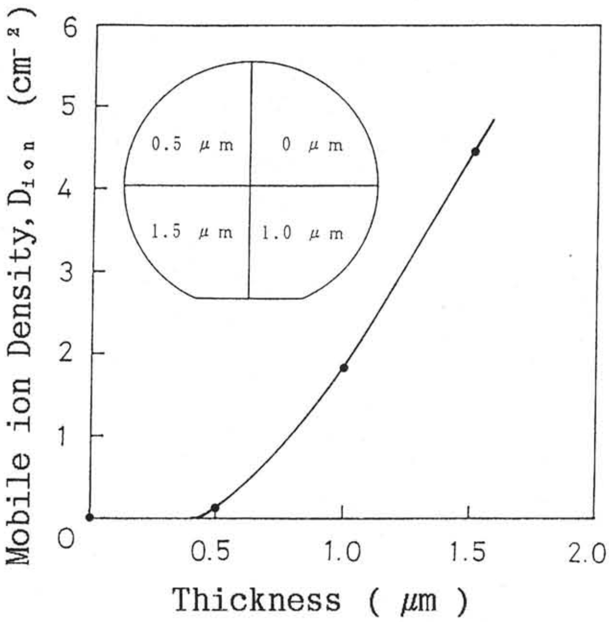

Fig. 2 Mobile ion density, D_{ion}, depending on photoresist film thickness

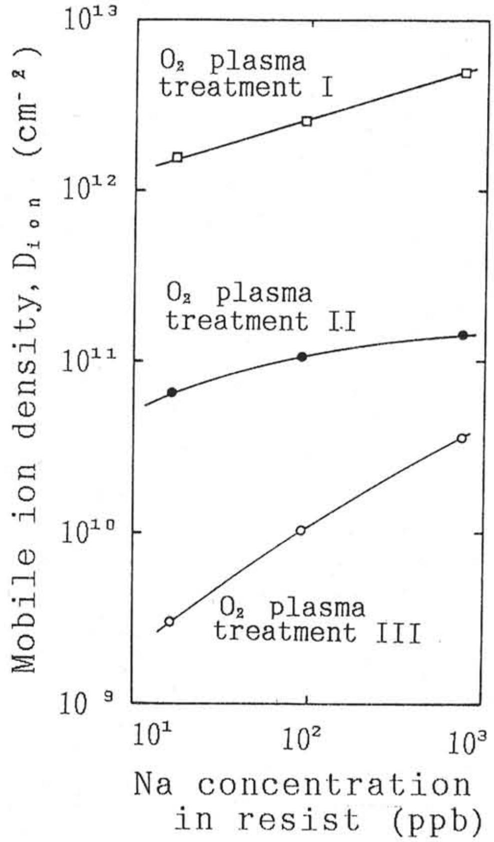

Fig. 3 Mobile ion density, D_{ion}, depending on sodium concentration in photoresist

tion is shown in Fig. 3. Surface potentials caused by O_2 plasma treatments I, II, and III are about 12 (V), 1(V) and below 0.1 (V). In treatment I, D_{ion} value is very high depending on Na concentration in photoresist. D_{ion} increases depending on surface potential during O_2 plasma treatment as Fig. 4 shows. This surface potential is estimated from C-V characteristics. It is very useful to reduce surface potential and to lightly etch the SiO_2 surface to eliminate mobile ionic contaminants.

3. Discussion

As concluded above,. there are two contaminant sources, the metal electrode and the photoresist. Using a highly purified target can reduce contaminants from the electrode to a negligible level.

The mechanism of contamination from the photoresist during plasma ashing is considered to follow these steps: (1) impurities in photoresist cannot be removed and so remain on the wafer surface; (2) these impurities are driven into SiO_2 by electric charging during ashing; (3) these impurities remain in SiO_2 even after light etching with diluted HF. They diffuse through SiO_2 during heat treatment. It is very important to reduce this charging during ashing and to lightly etch the SiO_2 film surface to minimize mobile ion contamination. Contaminant-free W-gate MOS is obtained by using a highly purified W target and reducing surface potential due to plasma ashing.

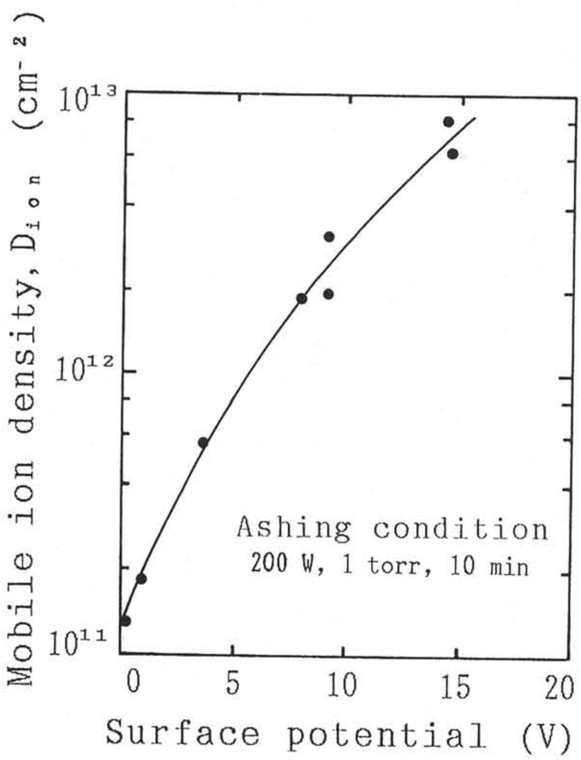

Fig. 4 Mobile ion density, D_{ion}, depending on surface potential due to plasma ashing

4. Conclusion

Studying mobile ion contamination in tungsten (W) gate MOS fabrication reveals the following:

(1) Mobile ionic contaminant density can be reduced below $5 \times 10^9/cm^2$ (TVS detection limit) using a highly purified W target for sputtering in which impurities such as Na are reduced to below 10 ppb concentration.

(2) Mobile ion contamination occurs in W-gate CMOS fabrication during photoresist ashing using oxygen plasma. Mobile ion density strongly depends on Na concentration in photoresist film and on surface potential caused by oxygen plasma.

(3) W-gate MOS devices free from mobile ion contamination are obtained by reducing surface potential caused by plasma ashing.

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