SPUTTERED DEPOSITED TUNGSTEN SILICIDE FILMS FOR MICROELECTRONICS APPLICATIONS

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Key words: Tungsten Silicide films; DC plasma magnetron sputtering; pressure; substrate temperature

Abstract: This paper addresses the effect of substrate temperature and deposition pressure on the electrical properties of Direct Current (DC) plasma magnetron sputter-deposited Tungsten Silicide (WSi) films on silicon substrates. Results from experiments show that, substrate temperature and deposition pressure has exerted significant influence on the electrical properties of the WSi films. The electrical properties of the WSi films are inferior at high deposition pressure and high substrate temperature.

Nanašanje silicidnih filmov WSi za uporabo v mikroelektroniki

Kjučne besede: filmi volframovega silicida, magnetronsko napr̆sevanje v DC plazmi , pritisk, temperatura substrata

Izvleček: Prispevek obravnava vpliv temperature podlage in pritiska pri magnetronskem naprševanju v DC v plazmi na električne lastnosti napršenega volframovega silicida na silicijevih substratih. Rezultati eksperimentov so pokazali, da imata temperatura podlage in pritisk pri naprševanju velik vpliv na električne lastnosti WSi filmov. Le-te so slabše pri visokih pritiskih in temperaturah.

1. Introduction

Polycrystalline silicon (Poly-Si) has been intensively used in the manufacture of integrated circuits in MOS technology, where it is employed as a gate or interconnection material. The achievement of maximal signal transmission in emerging chip and system architectures requires the minimization of high resistance in Poly-Si. High resistance is a major limitation in circuit performance for Ultra Large Scale Integrated Circuits (ULSI) /1/. In order to tackle this problem, alternative materials other than Poly-Si are needed. Several types of silicides of refractory metals have been investigated as a replacement for Poly-Si such as Tantalum Silicide (TaSi), Tungsten Silicide (WSi) and Molybdenum Silicide (MoSi) / 1-4/. Under optimum deposition conditions, WSi has the lowest resistivity of approximately 50 $\mu\Omega$ cm, comparing to others, for example, 70 $\mu\Omega$ cm for TaSi and 80 $\mu\Omega$ cm for MoSi /5/. Furthermore, WSi has high melting point of 2160°C, excellent step coverage of 85% over a vertical step, high thermal stability, low stress and chemical resistance /6/. These properties make WSi an appropriate alternative to Poly-Si as gate or interconnection material. Furthermore, WSi can be applied as barrier liner in copper interconnection, to prevent the diffusion of copper (Cu) into silicon substrate. Cu interconnection is an emerging interconnection scheme employed in microelectronic industries as Cu exhibit better electrical properties than existing aluminum metallization scheme /7/.

In the present study, experiments were carried out to investigate the electrical properties of the Direct Current (DC) plasma magnetron sputter-deposited WSi films on Si substrates as a function of the deposition pressure and the substrate temperature.

2. Experimental

Figure 1 shows the schematic diagram of the magnetron sputtering deposition system. All WSi films were deposited in a DC plasma magnetron (balanced planar magnet-

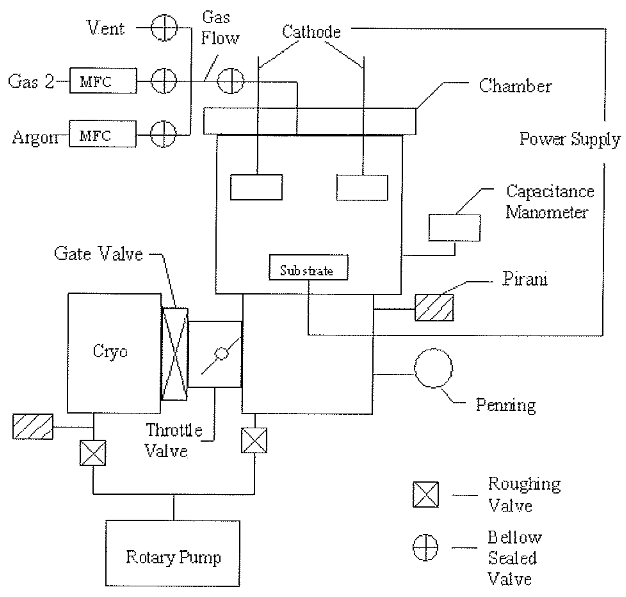

Fig. 1. The schematic diagram of the employed magnetron sputtering deposition system.

ron) sputtering deposition chamber with the base pressure maintained below 10^{-5} Torr. The circular 50.8 mm diameter WSi target was of 99.5% purity. High purity argon (Ar) gas with 99.995% purity was used as working gas in all the sputtering deposition processes. The flow rate of the Ar gas fed into the chamber was controlled by using SEVENSTAR (D07-7A/ZM) mass flow controllers. The magnetron cathode was placed at a distance of about 8 cm from the substrate holder and the substrate. The substrate was grounded during the deposition process in order to improve the efficiency of sputtering. Pressure in the sputtering chamber was measured using Pirani and Penning gauges. The geometry of Si substrates was approximately 6 mm x 12 mm. The electrical measurements of the WSi films were performed with Karl Suss four-point probe at room temperature. The deposition conditions of the WSi films presented in this study are summarized in Table 1.

Table 1. Deposition details of experiments

Target	WSi
Substrate	p-type Si
Target-substrate distance	8 cm
Ar Flow Rate	18 -20 (sccm)
Deposition duration	30 minutes
Deposition Power	50 Watt
Deposition pressure	12 mTorr to 25 mTorr
Substrate temperature	27 °C to 200 °C

3. Results and discussion

Figure 2 shows the measured I-V curves of the WSi films deposited with different pressures ranging from 12 mTorr to 25 mTorr. From the I-V curves, the voltage to current ratio (V/I) is higher when the deposition pressure is increased.

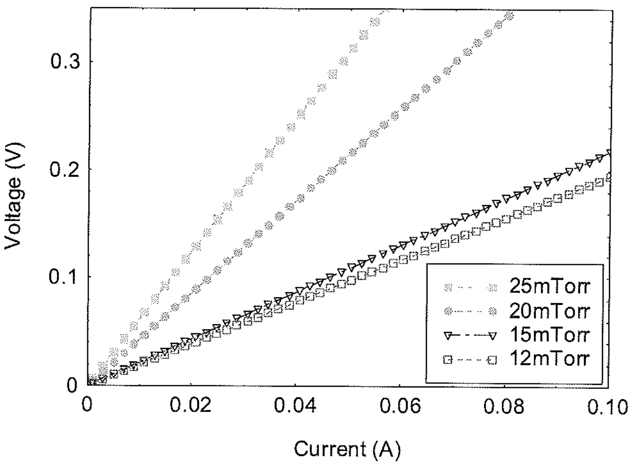

Fig. 2. WSi films at difference deposition pressures.

Referring to figure 2, the resistance, R, of the WSi films can be expressed as /8/:

$$R = V / I, \qquad (1)$$

where V and I represent the voltage and current, respectively. Increase in the deposition pressure causes the film resistance to increase. The sheet resistance, R_S, can be correlated to film resistance, R. The R_S can be estimated using following equation /9/:

$$R_S = C.F.\ (V/I), \qquad (2)$$

where C.F. is the correction factor, depending on sample geometry, which accounts for the sample size, shape and I-V probe tip spacing /10/. In this investigation, all samples geometry was kept constant. The measured film resistance of the WSi films is proportional to the sheet resistance, R_S, of the WSi films.

The film resistivity, ń, can be correlated to sheet resistance, R_S. The film resistivity can be expressed as /11/:

$$\rho = R_S\, t, \qquad (3)$$

where t represents the thickness of the deposited WSi films. Change in the deposition pressure has no significant effect on the thickness of the deposited WSi films /12/. Therefore, the film resistivity of the WSi films can be suggested as proportional to the sheet resistance. Therefore, it can be suggested that the electrical resistivity of the deposited WSi films increases when the deposition pressure is increased.

The reason for the electrical properties of the WSi films become inferior at high deposition pressure can be explained in the following. Hara et al. /13/ have pointed out that the composition of WSi (Si/W ratio) increases when the deposition pressure is increased, because the atomic mass of the W is larger than Si. The electrical conductivity of W is higher than Si. Godbole et al. /14/ reported that film resistivity increases when the composition of WSi (Si/W ratio) increases. Si is a lighter element, so it tends to scatter more than W in the sputtering process /14/. Therefore, with the increase in the deposition pressure, resistance and resistivity of the WSi films grown on Si substrates also increase.

Figure 3 shows the electrical properties of the WSi films deposited with difference substrate temperatures ranging from 27 °C to 200 °C. The result from experiments show that the I-V curve is higher when the substrate temperature is increased; indicating a higher WSi films resistivity is obtained when a higher substrate temperature is used. This is true as the film thickness does not depend on the substrate temperature.

This result is corroborated by the research work carried out by Liang et al. /15/ on WSi films. According to Liang et al., the Si/W ratio increase when annealing temperature for the WSi films is increased up to 400 °C. Additionally, Horiuchi et al. /16/ also discussed about the film resistivity increases with the increases of the annealing tempera-

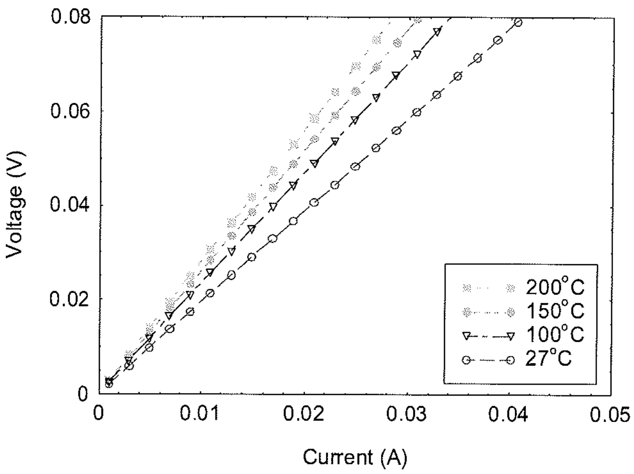

Fig. 3. WSi films at difference substrate temperatures.

ture up to around 575 °C for Titanium Silicide (TiSi) thin films. Karmed et al. reported that higher value of film resistivity is related to the change in the crystalline phase of the deposited WSi films with increasing temperature. Therefore, with the increase in the substrate temperature, resistance and resistivity of the WSi films had grown on Si substrates also increase.

4. Conclusions

In this work, the effects of the deposition pressure and substrate temperature on the electrical properties of the DC plasma magnetron sputter deposited WSi films were demonstrated. The experiment results show that the deposition pressure and substrate temperature significantly influence the electrical properties of the WSi films. The lower deposition pressure and lower substrate temperature favor the growth of WSi films with low resistivity.

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