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Planarization Mechanism in Flowage Bias Sputter Method

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An aluminum planarization mechanism in a Flowage Bias (FB) sputter method is described. Planarization by plastic deformation, which is revealed by marker motion experiments, is caused by the force generated by surface tension at the step edge. Enhanced diffusion of Si observed in irradiated Al film indicate excess vacancy generation which can decrease deformation resistance of Al at the growth temperature. High quality Al film with low Ar content has been obtained using FB sputter method.

1. Introduction

Planarized metal deposition has become very important for the shrinkage of pattern size of LSIs. Planarized deposition of Al by rf bias sputtering using re-sputtering phenomenon has been reported [1]. However, planarization by re-sputtering has problems such as slow deposition rate and Ar trapping in Al film. Recently, we have proposed a new Al planarization method [2]. In this FB sputter method, planarized Al film has been achieved, either by exposure to the plasma atmosphere of deposited Al films (bias treatment), or by sputter deposition under application of negative substrate bias (bias deposition). In this method, planarization caused by plastic deformation of Al has enabled high speed formation of high quality Al films.

In this paper, the Al planarization mechanism in the FB sputter method is discussed in relation to the force generated by surface tension and deformation resistance.

2. Experimental

The FB sputtering system is shown schematically in Fig.1. This system was equipped with a dc magnetron cathode and an rf bias substrate table. The target-to-substrate separation was about 4.5 cm. FB sputtering took place in an Ar ambiance at 0.8 Pa pressure. The vacuum chamber was pumped down to 1.3 X 10^{-5} Pa before introducing Ar. The substrate table can be heated up to 500 °C. Wafer temperature was measured by sheet conductivity changes of Au-Pt laminated films due to Pt diffusion into Au [3]. The wafer temperature is calculated by the equation:

$$1/R_{Au} - 1/R_{AuPt} = K\sqrt{Dt}$$

where R_{Au} is resistivity of Au, R_{AuPt} is resistivity of Au-Pt, K is constant, D is diffusion constant of Pt into Au and t is the time. Trapping Ar concentration into Al film was measured by X-ray fluorescence analysis (XFA).

3.Results and Discussion

A. Planarization mechanism

In the flowage bias sputter method, planarization occurs through plastic deformation of Al films. This is clearly observed by marker motion experiments. The results are shown in Fig 2. First, 1.5 μm thick Al films were deposited on a SiO_2 substrate with 1 μm steps. Spin-coating silicate films were coated on the entire surface of the substrates and etched by CF_4 plasma RIE so that silicate film was left only at microcracks in the groove as shown in Fig.2a. Fig.2c shows a cross section obtained after the sample shown in Fig.2a was irradiated for 5 min. of bias treatment at -1600V. The silicate marker has moved upwards, clearly showing that Al has flowed into the valley. These results clearly demonstrate the viscous flow of Al film and the only possible cause of the deformation is surface energy. However, surface tension has not previously been regarded as the dominant reason for viscous flow of crystalline metal. Mullins simulated the deformation of a solid surface by surface energy taking account of the effects of surface diffusion, volume diffusion, vapor phase diffusion by evaporation-condensation and viscous flow [4]. In his work, viscous flow in crystalline metal was neglected mainly based upon the paper by Herring [5]. Recently, using bias sputter equipment, planarization by surface diffusion has been reported by some authors [6]. V. Hoffman calculated the surface self-diffusivity of Al/1%Si at about 500 °C as $7X10^{-5}$ cm^2/sec [7]. To explain this observed plastic deformation, the situation where the surface energy can cause the viscous flow of Al will be discussed.

Fig.3 shows the schematic drawing of Al film deposited on a step edge. Taking the radius of curvature at the Al edge as r, the force applied per unit area of edge P is expressed as:

$$P = \gamma / r$$

where γ is surface tension of clean Al surface which is obtained as 1800 dyne/cm (averaged value for Al(111) and Al(100), calculated from heat of sublimation at 20 °C) [8]. The r dependence of P is plotted in Fig.4. In Fig.2a, the radius of curvature at the edge is seen to be about 0.5 μm. Using this value for r, the force caused by surface energy P becomes about 0.37 Kg/mm^2. To check whether this force is enough for plastic deformation or not, we can compare this value with the deformation resistance R of Al which is defined as the force required to cause plastic deformation at a certain deformation rate. According to a paper on hot press processing [9], R is about 1.1 Kg/mm^2 and 0.8 Kg/mm^2 for 1%/sec a deformation rate at 450 °C and 500 °C respectively. In a typical planarization condition (bias treatment at -1400V) average substrate temperature is supposed to be about 450 °C measured by Pt diffusion into Au at the backside of the substrate. The R value obtained for this temperature region seems even higher than above obtained P value which suggest that plastic deformation would not occur solely because of the raised temperature. At a higher temperature or at a smaller radius of curvature, deformation can occur because of the temperature.

To explain plastic deformation observed in FB sputtering, it is necessary to consider the decreased deformation resistance due to ion bombardment. For this purpose ion bombardment effect was measured using Al-polysilicon interdiffusion. The sample structure is shown in Fig.5a. Al film was deposited on polysilicon using a conventional sputtering method. A part of the Al surface was covered by polyimide film. After the sample was bias treatment at -1000V for 5 min, Al was removed by wet etching. The polysilicon surface is shown in Fig.5b. Al-polysilicon interdiffusion is observed only at the region not covered by polyimide film. The wafer temperature is kept the same in both areas. These results indicate that Si diffusion in Al is enhanced by ion bombardment. The excess vacancy generation observed by enhanced diffusion in Al is thought to be the cause of the decrease it deformation resistance.

B. Properties of FB sputtered Al film

Due to the difference in planarization mechanism, films deposited by FB sputter show characteristics quite different from those deposited by conventional re-sputter methods. In re-sputter planarization of Al films, the substrate must be kept at a low temperature and deposited films have a fine grain structure and high concentration of trapped Ar. Therefore, film resistivity is high and reliability is reduced because of void formation. In FB sputter method, the substrate is heated above about 400°C deposited films have a large grain structure and a low concentration of trapped Ar. Some properties of FB sputter Al films are listed in Table. 1. FB sputter Al film is deposited at a substrate temperature of 400°C and bias voltage -300V. Ar concentration into Al film is 0.14 at.%. The resistivity is 3 μ Ω·cm, as same as bulk Al. The reflectivity is about 62%. High quality Al film is obtained by using FB sputter method.

4. Conclusion

Planarization mechanism in flowage bias sputter has been explained in terms of surface tension, deformation resistance and the effect of ion bombardment. This new mechanism led to a method that has provided higher quality Al films comparable to sputter deposited Al films. Further improvement of the film structure will be achieved by optimizing the alloy components.

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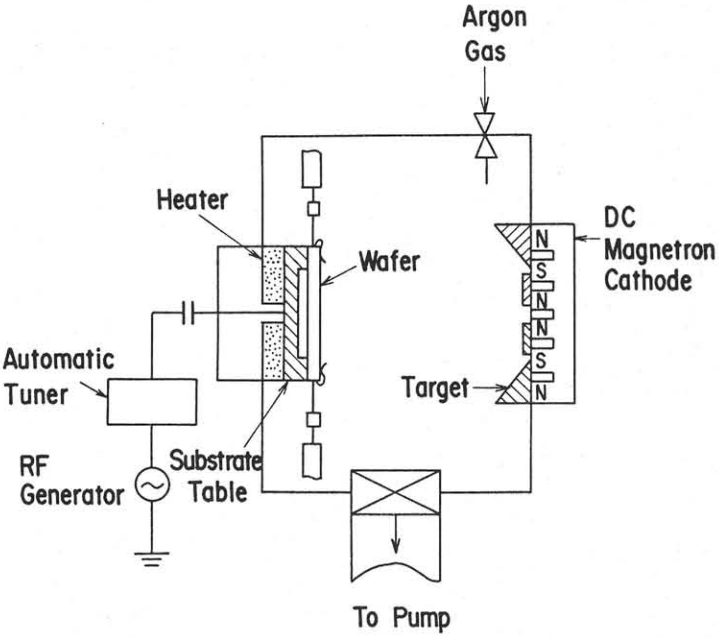

Fig.1 F B sputtering system.

Table.1 Characteristics of FB sputter Al film

Ar concentration	0.14 at.%
Resistivity	3.0 μ Ω.cm
Reflectivity	62 %

Sputtering Condition	Bias Voltage	-300 V
	Sub. Temp.	400°C
	Ar Pressure	0.8 Pa

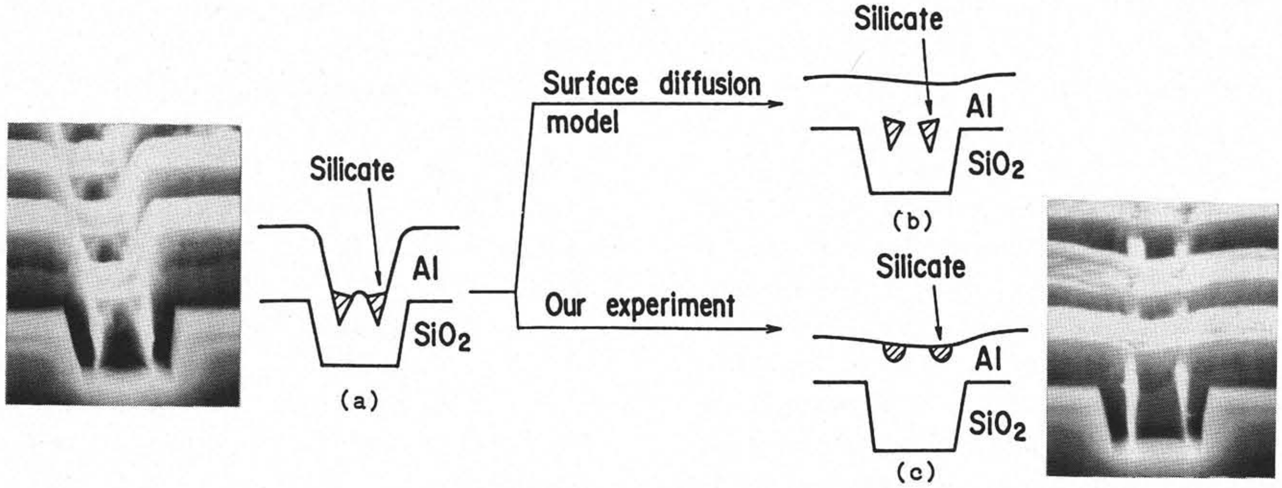

Fig.2 Movement of silicate markers after Al coverage.
(a) before bias treatment and
(b) surface diffusion model and
(c) samples after bias treatment.

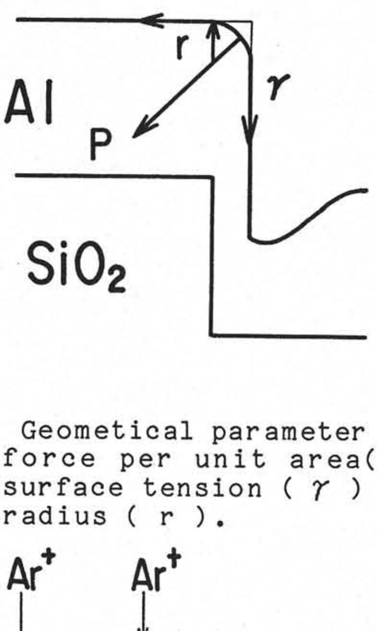

Fig.3 Geometical parameter of the force per unit area(P), surface tension (γ) and radius (r).

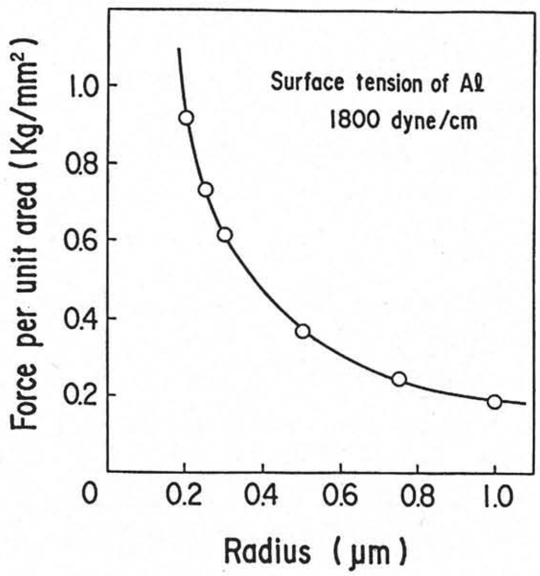

Fig.4 Force per unit area as a function of radius.

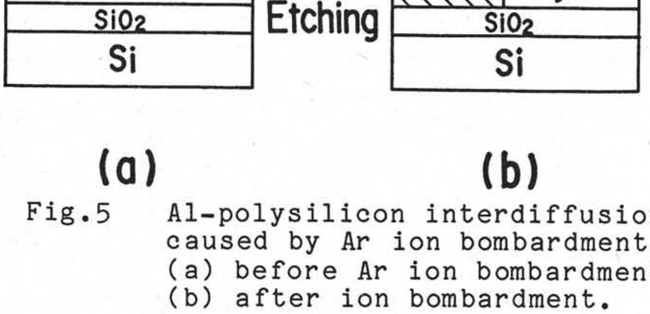

Fig.5 Al-polysilicon interdiffusion caused by Ar ion bombardment.
(a) before Ar ion bombardment
(b) after ion bombardment.

Poly Si surface not covered by polyimide

Poly Si surface covered by polyimide