Extended Abstracts of the 19th Conference on Solid State Devices and Materials, Tokyo, 1987, pp. 455-458

Effect of Stress on Electromigration MTF in Al Based Interconnections

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Effect of the thermal stress caused by passivation processes on electromigration MTF in Al interconnection is examined for three passivation conditions i.e. high temperature deposition (CVD PSG), low temperature deposition (sputtered SiO_2), and no passivation. Al interconnection passivated at low temperarure has longer MTF than unpassivated one and MTF increases with decrease of line width in both cases reflecting the change of grain morphology into bamboo structure. On the contrary the MTF of interconnection passivated at high temperature has strong decreasing tendency in the submicron regime with decrease of line width. Both the line width dependence of interconnection stress and the change in electromigration activation energy due to stress are supposed to be responsible for these results.

1.Introduction

As scaling down of device dimensions to submicron sizes, the requirements on highly reliable interconnection technology have become more and more stringent because of the increasing current density and the possible enhancement of thermal stress effect. In this situation, serious reliability degradations of interconnections such as void formations due to electromigration[1] and stress induced migration[2] have been current issues. In this paper we discuss the effect of the stress on the electromigration MTF(mean time to failure) by comparing line width dependences of interconnections passivated at different stress conditions.

2.Experimental

Pure Al films were sputter-deposited onto oxidized Si surface at 200°C to a thickness 0.8um. The mean grain size as deposited is 0.6um. The lines were patterned by standard photolithographic technics and reactive ion etching (RIE) process to the line length1220um. Line widths between 0.4 to 2.6um were chosen in order to examine the line width dependence of MTF. Then all lines were annealed at 450°C for 15minutes in N_2/H_2 atmosphere. Three passivation conditions were chosen for comparison;

(1) CVD PSG passivated(400°C)

(2) Sputtered SiO_2 Passivated(150°C)

(3) unpassivated.

Cases (1) and (2) are in the below reffered as high temperature passivation (HTP) and low temperature passivation (LTP) respectively. MTF accelerated testing were performed at current density $2x10^6 A/cm^2$ and temperature 200°C by using ten samples for each condition of passivation and line width.

Scanning electron microscopy (SEM) was used to observe the failure shape and the grain structure. Samples after testing were dry etched to remove the passivation layer. For the evaluation of the grain structure, the numbers of triple points and of bamboo like grain boundaries were counted over the length 160um in the sample (1).

In order to measure the stress of Al stripe, X-ray diffraction technic was used. The stress was determined by an elastic change in lattice constant of (222) plane.

3.Results and discussions

The stresses of differently passivated Al interconections with the line width 1.15um measured at room temperature(25^{o}C) are shown in Fig.1. The stress is decomposed into x,y, and z components corresponding to parallel, perpendicular, and vertical directions to the stripe respectively. The interconnection with HTP indicates very high tensile stress, which is several times larger than the yielding stress of a bulk Al. The interconnection with LTP has rather weak tensile stress and the unpassivated interconnection has the weakest tensile stress. These results indicate that the stress of interconnection is mainly determined by the thermal stress.

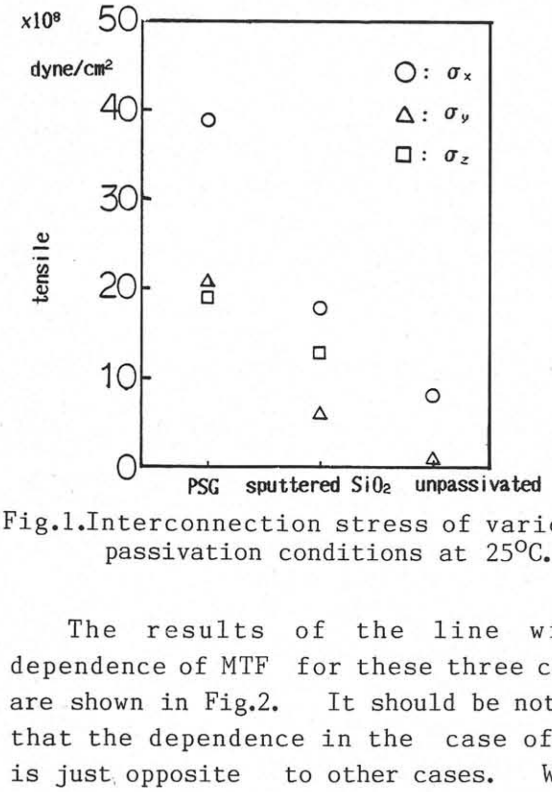

Fig.1.Interconnection stress of various passivation conditions at 25^{o}C.

The results of the line width dependence of MTF for these three cases are shown in Fig.2. It should be noticed that the dependence in the case of HTP is just opposite to other cases. While both LTP and unpassivated cases have longer MTF with decreasing line width, the HTP case has shorter MTF with decreasing line width. By taking the unpassivated case as an reference, it can be said that the effect of HTP on MTF changes at the line width 0.85um from elongation to shortening with the decrease in line width. On the other hand, LTP elongates MTF very effectively through whole range of line width.

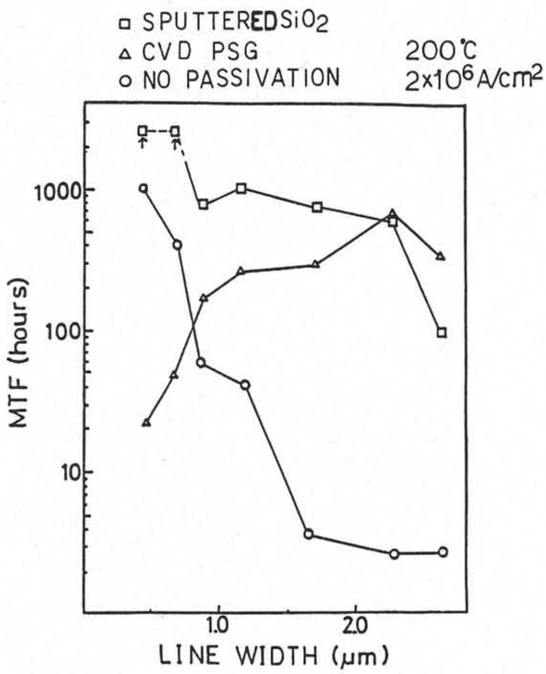

Fig.2. Line width dependences of electromigration MTF for various passivation conditions.

Observations of failure shapes by SEM are shown in Fig.3 and 4. The outstanding difference can be seen between unpassivated and passivated cases at rather wide(>1um) line widths. In the case of no passivatiion, a fatal void growth is accompanied by a hillock which grow anode side of it when the line width is wide as shown in Fig.3-a, where a large amount of Al moved away and the void shape is intricate reflecting a complicated grain morphology. On the other hand, no hillock formation is observed in the passivated lines as shown in Fig.4-a where the void is small. When the line width is nallower than 1.0um (Fig.3-b and 4-b), the grain structure becomes bamboo-like and the fatal voids are slit shaped irrespective of passivated or unpassivated cases.

The results of MTF shown in Fig.2 are complicated because MTF can also be affected by other factors such as the grain morphology and the effect of mechanical coating by passivation. First we refer to the change in grain morphology which is caused by the annealing after patterning. As the line width shrinks comparably to the as-deposited mean grain size, grains tend to

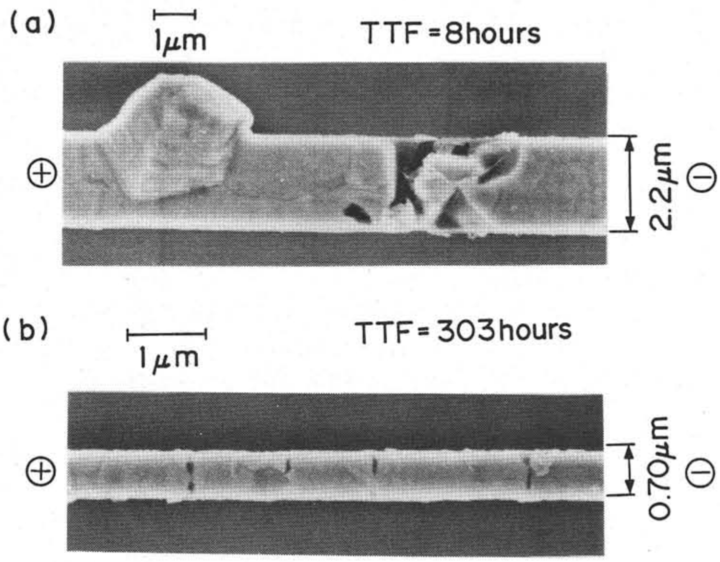

Fig.3. Electromigration induced void formation observed in unpassivated pure Al interconnection. (a) line width W = 2.2um, (b) W=0.70um. (TTF=time to failure)

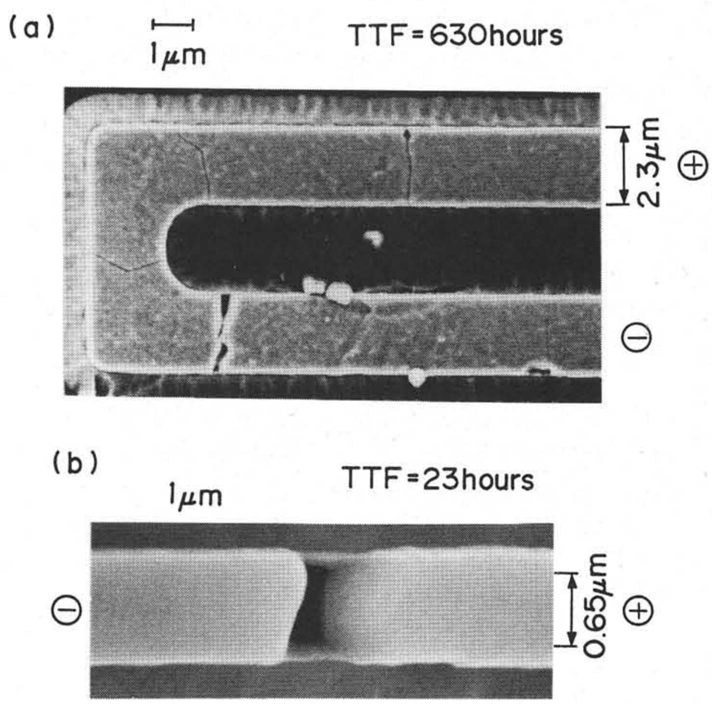

Fig.4. Electromigration induced void formation observed in pure Al interconnection passivated with CVD PSG(1.2um).
(a) W=2.3um, (b) W=0.65um.

form the "bamboo" structure where triple points never exist and grain boundaries intersect almost perpendicularly to the line edge. We have counted the numbers of the grain boundary triple points and the bamboo grain boundaries for various line widths(Fig.5). It is clearly shown that the change in grain morphology occurs between the line width 1.0um and 2.0um. This region of line width well coincide where the MTF begins to increase remarkably in the case of no passivation. The bamboo structure has so high homogeneity that the void formation caused by the flux divergence of electromigrating Al atoms is suppressed, which results in the elongation of MTF[3),4),5)]. However, this is not the case for the HTP where the decrease in MTF occurs in the submicron regime.

The decrease in MTF in the submicron regime in the case of HTP is well explained by taking two assumptions into account.

(1) The tensile stress of interconnection covered with the passivation film increases with decreasing line width.

(2) The compressive stress acts to elongate MTF, and the tensile stress acts to shorten MTF.

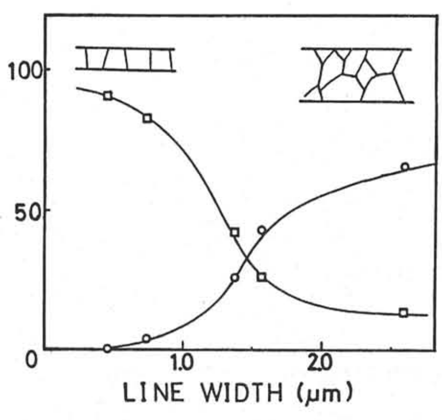

Fig.5. Line width dependence of grain morphology.
□; number of bamboo grain boundary,
○; number of triple point.

The assumption (1) leads that the stress at the testing temperature 200°C is tensile in the submicron regime of HTP and compressive in other cases. Stresses of line width 1.15um measured at 200°C are shown in Fig.6. The stresses are weakly compressive; unpassivated, HTP, and LTP in the increasing order.

It should be noticed that the values of MTF at 1.15um are also the same in increasing order, so that it can be said that MTF increases when the compressive stress is increased. Figure 7 shows the stress of HTP lines at 25°C. It shows a tendency to increase when the line width is decreased. Since the stress of encapsulated lines behave nearly elastic with increase in temperature, the tensile stress decreases and it turns compressive at a certain temperature Tc higher than 25°C. The higher Tc is, the larger the tensile stress is at 25°C, so that it is deduced that the stress is tensile in the submicron regime of HTP at 200°C.

So far, there has been little understanding for the assumption (2). On considering the diffusion process of Al atoms, it is well known that the compressive stress acts to increase the activation energy[6]. When the tensile stress acts, the activation energy is expected to decrease on account of lowering of electrostatic potential.

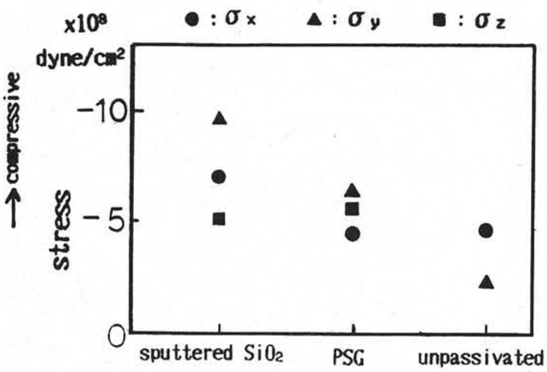

Fig.6. Interconnection stresses of various passivation conditions at 200°C.

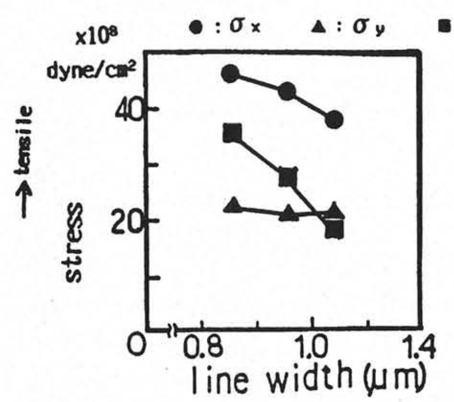

Fig.7. Line width dependence of stress in HTP interconnection at 25°C.

However, a fine measurement of electromigration activation energy at certain stress condition is further required.

There have been several works which have reported the elongation of MTF by the effect of mechanical coating with passivation film[7,8]. The suppression of hillock formation by the passivation film observed in Fig.4 suggests the mechanism of elongation. However, this does not work when the grain structure becomes bamboo structure, where MTF of interconnection with HTP decreases rapidly.

4. Conclusion

From our experimental work, the following conclusions are obtained.

(1) The electromigration MTF is strongly dependent on thermal stress caused by passivation process.

(2) The interconnection passivated at high temperature(>200°C) has MTF which gets seriously shorter with decreasing line width in the submicron regime.

(3) The interconnection passivated at the temperature below 200°C has fairly long MTF even in the submicron regime.

Ackowledgement

The authors would like to thank T.Moriya and M.Kashiwagi for their encouragements and suggestions.

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