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Taper Etching of Molybdenum Films Sputtered in Neon and Neon-Argon Ambients

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Molybdenum (Mo) films sputtered in low-pressure neon (Ne) are taper-etchable with a hydrogen peroxide solution. The reason is that films Ne-sputtered at low pressure have a disordered structure and include an amorphous-like phase due to strong peening effect. However, Ne-sputtering has a lower deposition rate than sputtering in ambient argon (Ar), and Ne-sputtered films have higher resistivity than Ar-sputtered ones. Sputtering in a Ne-Ar mixture improves the deposition rate and the film resistivity without sacrificing the taper-etchability.

1. INTRODUCTION

Taper etching is effective at eliminating step coverage problems in multilevel interconnections of micro-electronic devices. Active matrices of flat panel displays, such as liquid crystal displays (LCDs), must be fabricated using low temperature deposition processes such as plasma chemical deposition (PCVD), because of the limits of the substrate glass. Low temperature deposition produces a coarse film structure, especially on steep side walls. These regions are very vulnerable to wet etchant attack.

Mo is a high-temperature tolerant low-resistivity metal which is suitable for use in active matrices. However, conventional Mo films sputtered in ambient Ar exhibit perpendicular edge profiles after simple wet etching, due to the columnar structure which is common in sputtered metal films[1]. On the other hand, Mo films formed by Ne-sputtering at low pressure show excellent taper etching characteristics[2].

However, the deposition rate in ambient Ne is lower than in Ar, and the film resistivity of Ne-sputtered films is higher than that of Ar-sputtered. Furthermore, discharge instability has been observed in low-pressure Ne. To overcome these problems, sputtering in a Ne-Ar mixture was investigated. Taper etching was found to be possible with a high deposition rate and low film resistivity.

This paper presents results for taper etchability of sputtered Mo films in Ne or Ne-Ar ambients and discusses related mechanisms.

2. EXPERIMENTS

Mo films were deposited by RF magnetron sputtering of a 99.98% pure Mo target. The substrate holder was a carrousel that was rotated during a deposition. The substrate holder was water-cooled, and the substrates were .ot heated. Typical RF power was 2 kW for the 5" x 15" Mo target.

After conventional photolithography using a commercially available positive photoresist, the Mo films were etched with a hydrogen peroxide solution. Mo has extremely poor durability against oxidation. Thus, an oxidizing solution can easily etch Mo film to produce water-solvable oxides or hydro-oxides. We used hydrogen peroxide solution for the Mo etchant. This etchant dose not attack the other constituents of the active matrices such as amorphous silicon or silicon-nitride insulator. Therefore, the etching is very selective.

The characteristics of the taper-etchable Mo films were examined from film stresses, resistivity, Transmission Electron Microscope (TEM) images, incorporated gas contents and Reflective High Energy Electron Diffraction (RHEED) patterns.

3. RESULTS AND DISCUSSIONS

Ne ambient

An excellent taper edged profile of Ne-sputtered Mo film is shown in Fig. 1. The taper angle is around 10°. The films deposited in low-pressure Ne show taper etched profiles with edge angles less than 45°. On the other hand, films sputtered in Ne at high pressure and Ar-sputtered films showed perpendicular edge profiles.

Ne-Ar ambient

Mo films were sputtered in a Ne-Ar ambient at low pressure around 0.5 Pa to investigate taper etchability. Figure 2 shows the ratios of the deposition rate and film resistivity against the Ar content of the mixture. The deposition rate of the Ne-sputtering is about half that of Ar-sputtering, and the resistivity of Ne-sputtered films is 1.7 times larger than that of Ar-sputtered. The deposition rate and resistivity can both be improved by increasing the proportion of Ar in the mixture. The taper-etchability of the films sputtered in a Ne-Ar mixture was observed for low Ar mixtures (under 30% Ar). This means that the deposition rate and film resistivity can be improved without sacrificing the taper-etchability.

FILM STRUCTURE AND RELATED MECHANISMS

The common feature in the taper etchable Mo film characteristics is high compressive stress. Figure 3 shows the film stresses of the Ne-sputtered and Ar-sputtered films. The film stresses of the Ne-sputtered films vary from highly compressive to tensile stress according to the gas pressure. On the other hand, Ar-sputtered films have low tensile stresses, which do not depend on the gas pressure. Figure 4 shows the stresses of films sputtered in the Ne-Ar ambient. The film stress decreases as the proportion of Ar in the mixture increase. Taper etching was observed for

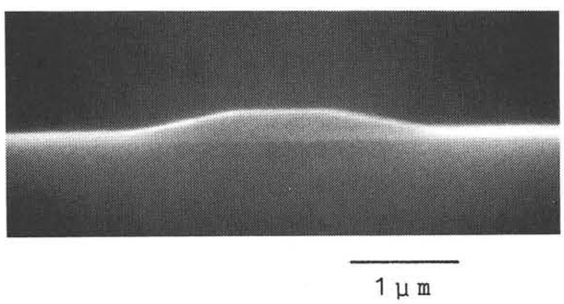


Fig. 1 Taper edged profile of Mo film sputtered in low-pressure Ne.

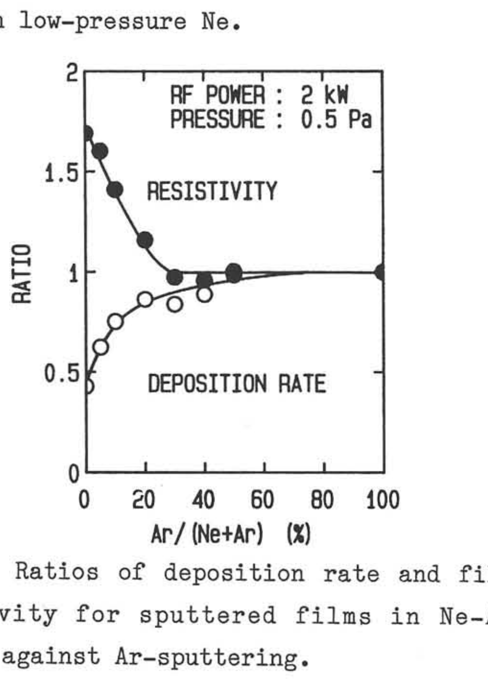


Fig. 2 Ratios of deposition rate and film resistivity for sputtered films in Ne-Ar ambient against Ar-sputtering.

highly compressive films (over 1 GPa).

The gas pressure dependence of the film stress for sputtered Mo films has been investigated[3]. If a lower mass gas, such as Ne, is used for sputtering, the transition pressure P_t from compressive to tensile stress shifts to higher pressure, similar to Fig. 3. The compressive stress in sputtered metal films has generally been believed to result from the peening effect[4]. The peening effect is due to neutralized sputtering gases reflected from the target surface striking the films. This means that the highly compressive films experience a strong peening effect.

Figure 5 shows cross-sectional TEM dark images of Ne-sputtered and Ar-sputtered Mo films. The Ar-sputtered film has columnar structure, so the columns grow continuously from the substrate to the surface. However, low-pressure Ne-sputtered film shows a more disordered structure than the Ar-sputtered film.

The RHEED pattern of the Mo film sputtered in low-pressure Ne, about 1 Pa, includes a halo, which indicates the existence of an amorphous phase in the film structure[2].

These results show that the taper etchable Mo films have a disordered structure and include an amorphous-like phase due to strong peening effect. This makes the taper etching of Mo films possible.

To clarify the reason for the high resistivity of Ne-sputtered Mo films, the incorporated gas content in the films were measured. The Ne or Ar gas content sputtered in Ne or Ar ambient is almost constant and independent of the gas pressure. The Ne content in the films is extremely high, over 1 at%. On the other hand, the Ar content is extremely low, under 0.1 at%. The resistivity of the Ne-sputtered films is

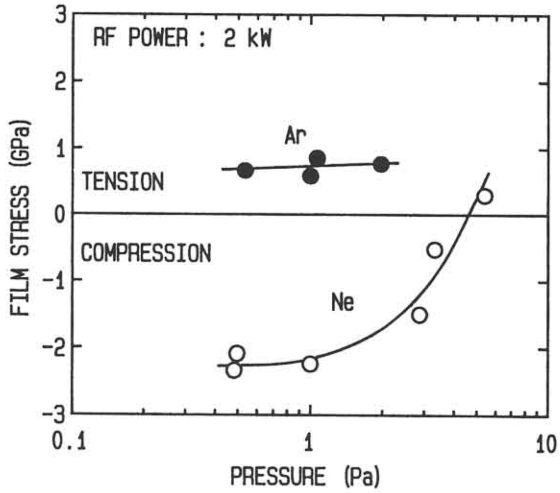


Fig. 3 Film stress versus gas pressure for sputtering in Ne and Ar.

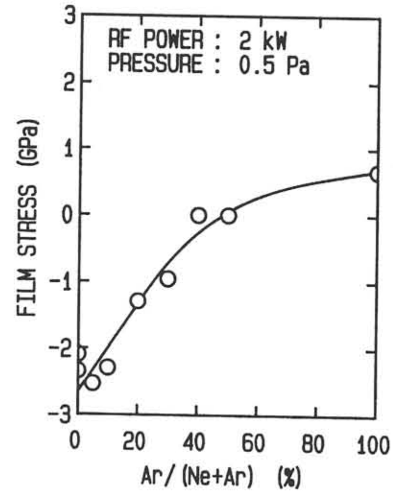
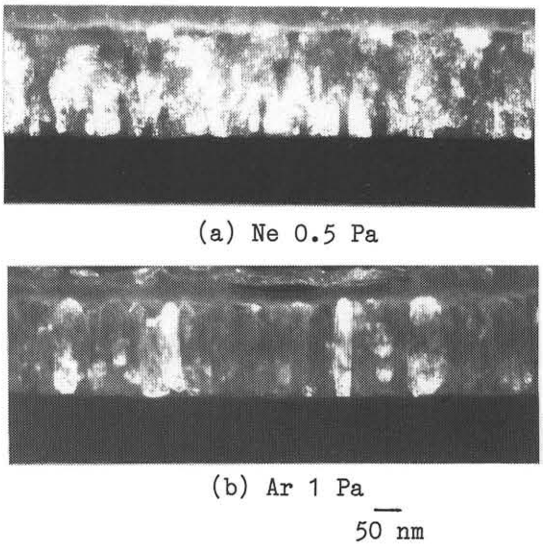


Fig. 4 Film stress sputtered in Ne-Ar ambient.



(a) Ne 0.5 Pa

(b) Ar 1 Pa

50 nm

Fig. 5 Cross-sectional TEM dark images of Ne-sputtered and Ar-sputtered Mo films.

higher than that of the Ar-sputtered ones, and independent of gas pressure.

Figure 6 shows the relationship between the resistivity ratio and the Ne content for the films sputtered in the Ne-Ar ambient. This figure implies that the Ne content of more than 0.3 at% strongly affects the film resistivity. This tendency has been observed for the dependence of the Ne-sputtered film resistivity on the RF power. Higher RF power causes higher resistivity with higher Ne content.

As a result, the resistivity of Ne-sputtered Mo films is determined by the highly incorporated Ne content. The most effective way of to reduce the Ne content, in order to decrease the resistivity, is to use Ne-Ar ambient for sputtering. This is because low-power sputtering is insufficient for the taper-etching, due to the weak peening effect.

4. CONCLUSION

Ne-sputtered Mo films are taper etchable if the Ne pressure is low and a hydrogen peroxide solution is used.

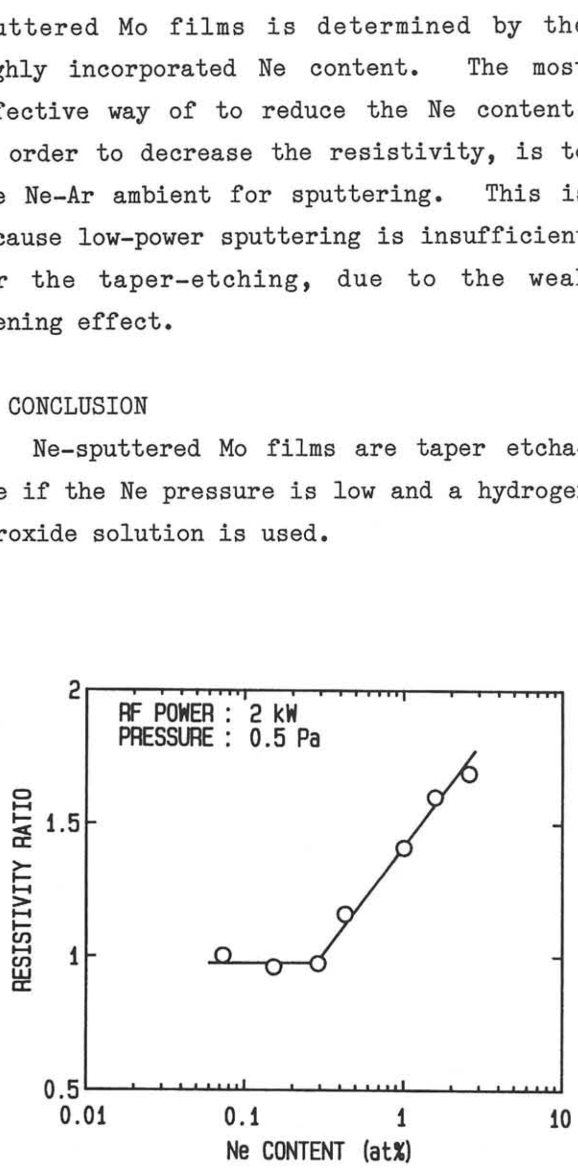


Fig. 6 Incorporated Ne in Mo films sputtered in Ne-Ar ambient against resistivity ratio.

Low-pressure Ne-sputtering causes structural changes in Mo films so as to include an amorphous-phase by the strong peening effect. This makes the taper etching of Mo films possible in the same way as amorphous materials. However, the resistivity of the Ne-sputtered Mo films is higher than that of the Ar-sputtered ones. This has been observed to be due to highly incorporated Ne gas, more than 1 at%. The Ne content must be reduced in order to improve the film resistivity without sacrificing the proper peening effect for the taper-etchability. Sputtering in a Ne-Ar ambient is extremely effective, with the additional benefit of improving the deposition rate.

Taper etched profiles ensure step coverage of the over-coated films and prevent failures caused at the cross-points in the multilevel interconnections.

This technique is very simple so it is applicable to active matrices and other micro-electronic devices.

5. ACKNOWLEDGMENT

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