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Effects of gas ring position and mesh introduction on film quality and thickness uniformity

Seungbum Hong [a,*], Eunah Kim [a], Zhong-Tao Jiang [a], Byeong-Soo Bae [a], Kwangsoo No [a], Sung-Chul Lim [b], Sang-Gyun Woo [b], Young-Bum Koh [b]

[a] *Department of Materials Science and Engineering, KAIST, Yusong-gu, Kuseong-dong, Taejon, South Korea*
[b] *Samsung Electronics, Yongin-city, Kyongki-do, South Korea*

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Abstract

Chromium oxide films were deposited using DC reactive magnetron sputtering system with different gas ring positions. It was found that the film quality was improved, while film thickness deviation over 2″ area of silica wafer increased, as the distance between the target and the gas ring increased. To improve both the film quality and the thickness uniformity, a method of mesh insertion was tried and verified to meet the purpose. Introduction of mesh produced stable plasma and resulted in more uniform and smooth planar film without any contamination from the mesh. These phenomena were explained in terms of gettering and scattering effects of the mesh. © 1997 Elsevier Science S.A.

Keywords: Reactive magnetron sputter; Chromium oxide film; Uniformity; Morphology

1. Introduction

Recently, the deposition of oxide films by reactive magnetron sputtering has received a considerable interest for various applications. They can be used as a dielectric layer in capacitors [1], as a transparent conductor in displays [2] and as a phase shifting layer in phase-shifting mask [3]. Especially, among the main film properties, the film thickness uniformity as well as the film quality are crucial factors in optical applications, since they are directly relevant to the optical properties of the film. A thorough understanding of the relationship between the main film properties and the deposition parameters is required to control the process more efficiently.

In this study, the gas ring position was chosen as the primary variable among the deposition parameters, and the film thickness uniformity and the film morphology were studied. Also, the mesh was introduced beneath the gas ring to improve the film thickness uniformity and quality and its effects were investigated.

2. Experiment

Chromium oxide films were deposited using planar circular type DC magnetron reactive sputtering system with a disc-shaped 4″ Cr target. The Cr target (99.95% purity, Cerac) was 1/4″ thick and mechanically clamped to a water-cooled copper electrode. The films were deposited at the condition of power of 120 W, total chamber pressure of 1.3 Pa and room temperature for 10 min on soda-lime glass substrates. The target to substrate distance was fixed to be 132.4 mm. The distance between the target and the gas ring was varied with 30, 65, 100 mm to investigate the gas ring position effect on film properties. The $Ar + O_2$ gas outlet in the gas ring was directed 45° downward with respect to the horizontal line. The ring size was 130 mm in diameter.

Insertion of mesh beneath the gas ring (Fig. 1) with grounded configuration caused decrease in deposition rate due to the scattering and shadowing effect of the mesh. Thus, the deposition time was doubled for mesh introduction while other deposition parameters were fixed. The cathode was held at the voltage of 390 V with discharge current of 0.31 A, while the substrate was grounded as the mesh was. The gas

* Corresponding author.

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ring position was fixed to be 30 mm below the target for comparison of the films deposited with and without the mesh.

Film morphology was observed by scanning electron microscopy (SEM). The film composition was examined by Auger electron spectroscopy (AES) to detect possible contamination by mesh introduction. The film thickness was measured by profilometer (Tencor alpha step).

3. Results and discussion

Fig. 2 illustrates the slanted cross section SEM micrographs of the films deposited with different gas ring position. It is found that the surface of all films show some small particles embedded with rough morphology. However, the number of small particle and surface roughness decreased with increasing the distance between the target and the gas ring. Moreover, it was observed that as the distance increased, the frequency of arcing decreased which resulted in more stable plasma. It is known that arcing may be due to the charge build-up on the oxide layer forming on the areas of the target where the current density is lower [4]. The arcs may cause the ejection of small particles of Cr_2O_3 or Cr which are embedded in the growing film as shown in Fig. 2. There are known some possible reasons reported for rough film surface [5–7]. The most probable reason is thought to be the energetic oxygen ions formed in the glow discharge which causes damage in the film [5]. The concentration of the oxygen ion may be proportional to the oxygen concentration inside the glow discharge region which is near the target region. Because the pumping port is located on the bottom of the chamber, the oxygen coming out the gas ring has preferred directionality downward. Therefore, as the distance between the target and the gas ring increases, the oxygen concentration of the upper part near the glow discharge region should be lowered which results in smaller amount of energetic oxygen and less damage in the film surface.

Fig. 3 shows the thickness uniformity of the films deposited with different gas ring positions. The film thickness deviations was measured along the line passing through the center of the substrate. It was defined to be the percentage of the standard deviation over the average film thickness of 11 points taken along the line of 2″ in equi-distance of 5 mm. The embedded particles were excluded when measuring the thickness of each point. One of the physical origins of the macroscopic nonuniformity of the film thickness comes from the fact that the target is mainly sputtered along the etch track to yield nonuniform flux of Cr with circular symmetry [8]. However, the role of the background gas becomes more important to the film thickness profile for the reactive sputtering process. It was found that as the

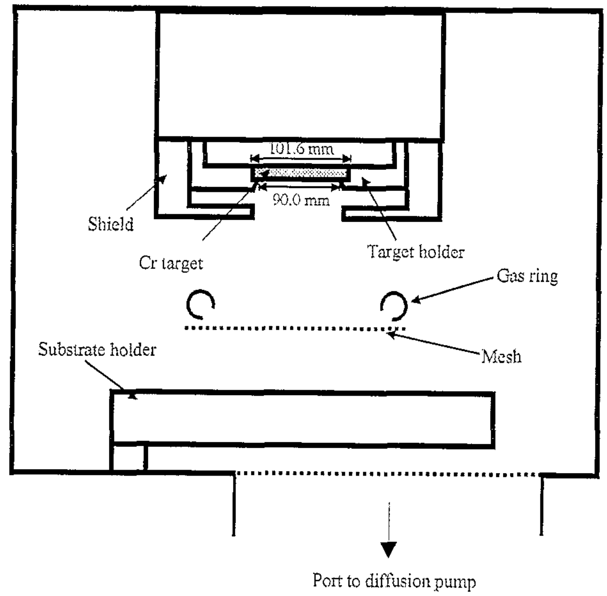

Fig. 1. Schematic diagram of DC magnetron reactive sputtering system.

distance between the target and the gas ring decreased, the film thickness deviation decreased (Fig. 3) while the surface becomes rougher with more embedded particles

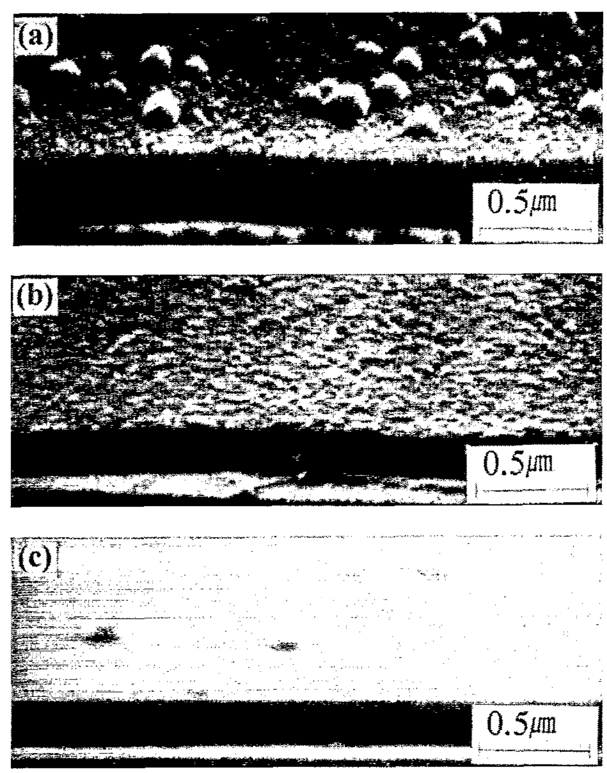

Fig. 2. Slanted cross-sectional SEM micrographs of the films deposited with different gas rings positions. The target to gas ring distances are (a) 30 mm (up), (b) 65 mm (middle) and (c) 100 mm (down).

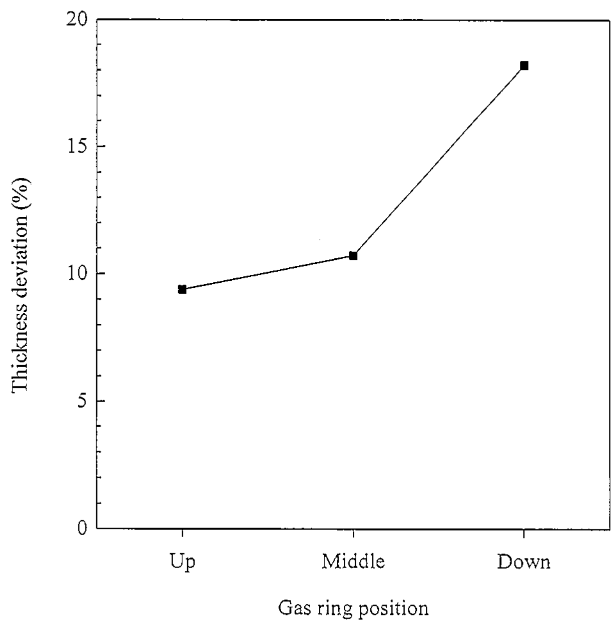

Fig. 3. Thickness uniformity of the films deposited with different gas ring positions. The target to gas ring distances are 30 mm (up), 65 mm (middle) and 100 mm (down).

(Fig. 2). This trend suggests that the surface roughness may not be the major factor to contribute to the thickness deviation when the amplitude of the surface roughness is very small in comparison with the average film thickness. The trend of the film thickness deviation may rather be explained in terms of collisions between the sputtered Cr atoms and the background gas such as argon and oxygen atoms. As the Ar and O_2 concentration along the path from target to substrate increases (as is the case with decreasing target to gas ring distance mentioned above), the Cr atoms experience more collisions with the background gas to make more macroscopically uniform film even though the film surface is rougher in microscopic view.

As a summary, embedded particle density increased, surface roughness increased and overall film thickness deviation decreased as the gas ring moved toward the target as shown in Fig. 4. Therefore, the variation of the gas ring position would not result in both smooth film surface and uniform thickness distribution. In this paper, we are going to suggest another powerful method to enhance both film quality and film thickness uniformity. We have used a steel mesh with hole size of about 130 μm to enhance scattering and gettering effects. The films deposited using a steel mesh were examined by AES and found to be impurity free within the detection limit of the AES. The deposition rate was reduced by a factor of two when the mesh was introduced probably due to its shadowing and scattering

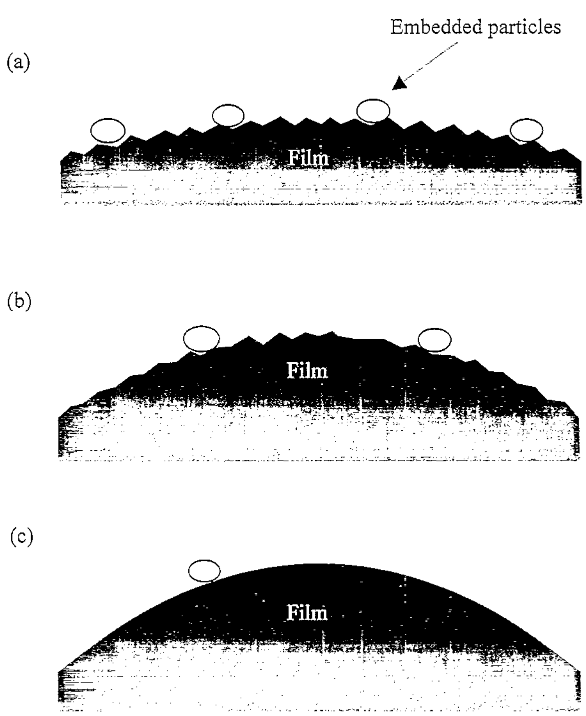

Fig. 4. The schematic diagram of the film morphology variation with gas ring position. The target to gas ring distances are (a) 30 mm (up), (b) 65 mm (middle) and (c) 100 mm (down).

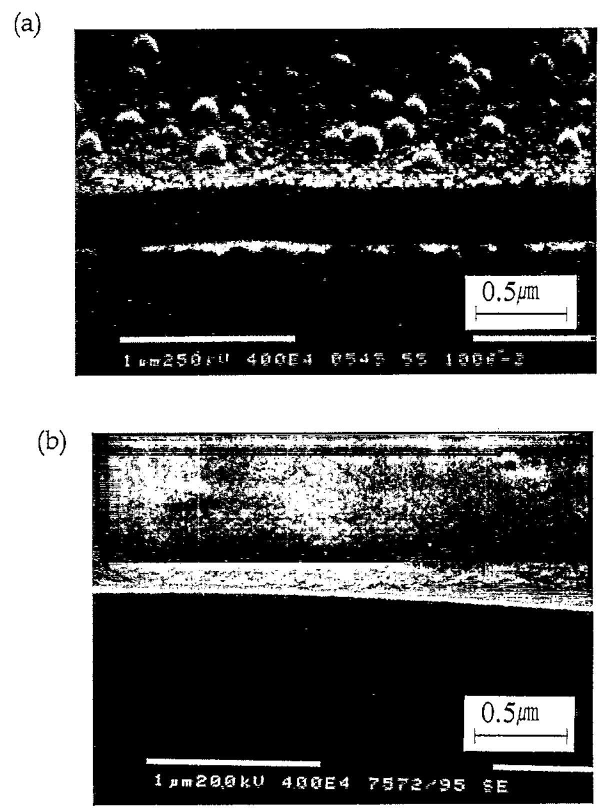

Fig. 5. Slanted cross-sectional SEM micrographs of the films deposited (a) without mesh and (b) with mesh. The distance between the target and the gas ring was fixed to be 30 mm.

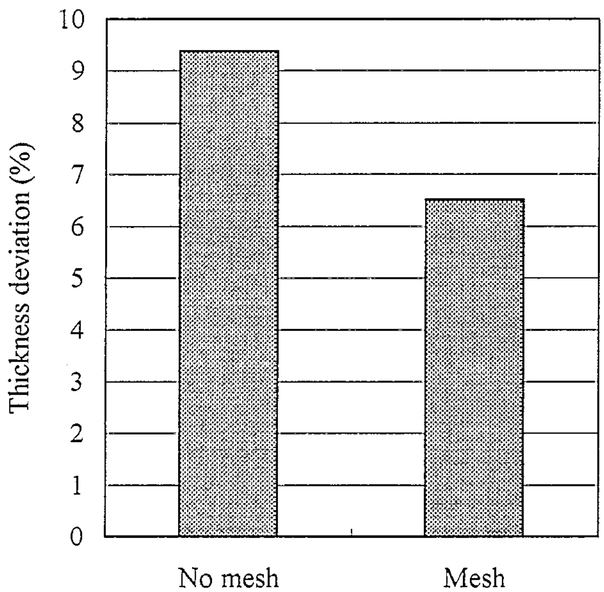

Fig. 6. Thickness uniformity of the films deposited without and with mesh.

effects. Therefore, for the sake of comparison, the deposition time was doubled to deposit the film with the same thickness. The effects of the mesh were investigated through SEM observations and film thickness deviation measurements as shown in Fig. 5 and Fig. 6, respectively. The gas ring position was taken to be 'up' (target to gas ring distance 30 mm) near the target for comparison. The use of the mesh increased oxygen gettering which eliminated arcing on the target surface and stabilized the plasma. No arcing ensured less ejected particles and almost no embedded particles were found on the film as shown in Fig. 5(b) just by the insertion of the mesh between the target and the substrate. Also, it is thought that high energy oxygen is gettered and scattered by the mesh which is consistent with the smooth film surface observed in the SEM micrograph shown in Fig. 5. Moreover, the scattering effect of the mesh is thought to be the main reason of the decrease in thickness deviation as shown in Fig. 6. The insertion of the mesh between target and substrate enhanced both film quality and film thickness uniformity which are essential in optical applications where optical properties should be accurately controlled.

4. Conclusion

The relationship between the film morphology and the gas ring position has been investigated. There was a trend that the film quality was improved while the film thickness deviation increased as target to gas ring distance increased. It was suggested in this study to use mesh for enhancement of both the film quality and the film thickness uniformity. It was found that the use of the mesh enhanced oxygen gettering and scattering of gaseous atoms to improve the film quality and the film thickness uniformity.

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