Effect of Sputtering Power on the Properties of TaN Thin Films Prepared by the Magnetron Sputtering

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ABSTRACT: Objective To research the effect of sputtering power on the deposition rate, structure and surface roughness of TaN thin films prepared by the magnetron sputtering that directly bombardment the TaN target. Methods In this paper, TaN thin films were deposited on SiO2 substrates by a reactive radio frequency magnetron sputtering system that directly bombardment the TaN target under different sputtering powers at room temperature. The thickness of the films is obtained by cross-sectional scanning electron microscopy (SEM) views. The phase structure and surface roughness of TaN film is investigated by X-ray diffraction and atomic force microscopy. Results The results show that the film deposition rate increases with the increasing sputtering power, and sputtering power expresses a good linear relationship with deposition rate. X-ray diffraction (XRD) results showed that the film is amorphous when the sputtering power is 100W, and crystallization effect will be getting better with the increasing power without heat treatment. Also, the films display excellent (111) crystalline orientation compared with the conventional reaction sputtering. Atomic force microscope (AFM) results showed that the effect of sputtering power on the surface roughness of the films is complicated. When the putting power is less and greater than 200W, the surface roughness increases with increasing power. However, the surface roughness is relatively small when the power is 200W. Conclusion The film prepared by magnetron sputtering is compact and smooth, and exhibits fine adhesion. Sputtering power has an important influence on the deposition of TaN films. When the sputtering power is 200W, films with good performance can be obtained.

1 INTRODUCTION

TaN film material is widely used in many fields because of its excellent performances [1-6]. In the semiconductor industry, TaN film is used as a copper diffusion barrier layer mainly due to its high electrical conductivity and good thermal stability. In the microelectronics industry, TaN has a good compatibility with high K material and the function can be regulated by controlling the proportion of Ta and N provide the feasibility of TaN as a metal gate material. In biomedicine, TaN is considered to be a promising material applied in the surface modification of artificial heart valve due to its excellent mechanical properties and good compatibility with blood. In the mechanical field, TaN is used as high temperature hard coating because of its high hardness and good toughness at high temperature. In recent years, there are more and more researches on TaN thin films at home and abroad. G R Lee et al[7] prepared TaN film on Si (001) substrate through ICP-assisted magnetron sputtering and they studied the effect of sputtering power on the hardness of TaN thin films. S K Kim et al[8] deposited TaN thin film on SKD11 tool steel substrate by DC magnetron sputtering. The effects of N2 and Ar flux ratio on the structure, hardness, adhesion and wear resistance of the films were studied. There are many methods for the preparation of TaN film such as physical vapor deposition (PVD) [9], chemical vapor deposition (CVD) [10-11] and atomic layer deposition (ALD) [12]. In the CVD method, the material to be deposited is volatile, and the film is prepared on the substrate by the chemical reaction of volatile material and external gas. There are many shortcomings in the preparation of TaN film by chemical vapor deposition. The main disadvantage is that the precursor is easy to react with oxygen and moisture in the air what is change its own structure, so it is difficult to get the film needed. Preparation of TaN thin film by ALD method also has many shortcomings. The density of TaN film prepared by ALD method is usually relatively small, and the surface of film often has certain gaps, also the film "aging" phenomenon often occurs. As a physical gas phase deposition (PVD), sputtering has become the main method for the
preparation of TaN thin film for its simplicity and good reproducibility. Meanwhile, we can get thin film with excellent performance for the effect of this method on grain refinement.

In the present study, the reactive sputtering method is the main method to prepare TaN film. High pure Ta target is bombarded in vacuum chamber, at the same time N2 and Ar mixed gas is passed into the vacuum chamber. Finally, TaN film can be obtained on the substrate surface through reaction. However, this method requires the step of charged with nitrogen. Also, in reactive sputtering, there is a large amount of active N atoms in the sputtering atmosphere as N2 is used as a reaction gas which leads to N atoms can easily react with Ta atoms on the target surface to form complex compounds. This phenomenon is known as the target poisoning phenomenon[13]. Target poisoning is more likely to occur with the increase of nitrogen flow rate in the sputtering atmosphere and makes the deposition rate drop sharply.

Like other parameters (sputtering pressure, substrate temperature etc.), sputtering power has an important influence on the properties of the prepared films in RF sputtering[14-17]. In this paper, TaN thin films were deposited onto commercial polished SiO2 substrates by RF magnetron sputtering, which bombarded the TaN target directly (99.99% purity). The effect of sputtering power on deposition rate, surface roughness and structure of TaN film is investigated by SEN, X-ray diffraction and atomic force microscopy.

2 EXPERIMENTAL PROCEDURES

TaN thin films were deposited onto commercial polished SiO2 substrates (10mm × 10 mm × 1 mm) by magnetron sputtering of the TaN target(Φ50mm × 4mm with purity of 99.99% ) at various sputtering power(100W-300W). The sputtering gas is argon (99.99%). The base vacuum is 4.6 × 10−4 Pa. The distance between the target and the substrate, the sputtering pressure, the substrate temperature and the argon gas flow are 80 mm, 1.0 Pa, room temperature and 30sccm respectively.

In the experiment, there will be thin film deposited on the surface dusts of the substrate if the surface cleanliness is too poor which can cause the exfoliation of film easily. So, SiO2 substrates are cleaned by ultrasonic cleaning for 20 minutes with acetone, anhydrous alcohol and DI water respectively. Before sputtering, 30-minute sputtering in argon atmosphere at 100 W was performed to remove the surface impurities of the target. The thickness of the films is obtained by cross-sectional SEM views. The phase structures of the samples were explored by X-ray diffraction (XRD) with CuKα radiation. The surface profile of the samples was explored by Atomic Force Microscope (AFM) respectively.

3 RESULTS AND DISCUSSION

3.1 Deposition rate

Fig. 2 shows the deposition rate for various power during sputtering. As it can be seen, the rate increases with increasing RF power almost linearly. Sputtering power has been varied within a wide range, from 100w up to 300 W, corresponding to the increase of the growth rate from 9.17 to 24nm/min(thicknesses are 550nm, 810nm, 965nm,1170nm, 1440nm respectively). This because higher density of the sputtered particles coupled with more energetic ions impinging on the substrate surface. In addition, high-energy particles can cause defects in the impact point on the surface of the substrate. Compared with other areas, these defective areas have a higher adhesion energy what
cause them become a priority of nucleation points to help accelerate the growth rate of the film.

3.2 XRD

The X-ray patterns of the films prepared with different Sputtering-power are shown in Fig. 3 where peaks of 20 angle at 35.16°, 59.29° and 71.30° correspond to cubic TaN patterns of (111), (220) and (311), respectively. It can be seen from the figure, during the process of the sputtering power from 100w to 300w, the structure of the film changed accordingly. We found that TaN films show the formation of a crystalline film only at high sputtering power. When the sputtering power is 100w, the film is amorphous. (111) diffraction peak begins to appear when the power is 150w and the intensity of (111) peak increase with increasing sputtering power. Aryasomayajula [18] found the same phenomenon when they used pulsed DC magnetron sputtering technique deposing tantalum nitride thin films coated at room temperature (300 K) on various substrates. In our work, we also observed (220) and (331) diffraction peaks. However, the intensities of these two peaks have no significant increase with increasing sputtering power.

Wang et al.[19] deposited TaN thin films on Al2O3 substrates by DC reactive magnetron sputtering and found the microstructure of films is very sensitive to the process parameters. Various structures can be formed on the substrate under different parameter conditions. Compared with the traditional reactive sputtering, we can get TaN films with a good (111) orientation.

3.3 Surface roughness

In many fields, the surface roughness of the thin film is strictly required. Fig. 4 gives the AFM images of the TaN films deposited at different sputtering power. To study the surface features of TaN films.

3.4 Conclusions

A series of TaN films with thicknesses in the range of 550-1440nm were deposited on SiO2 substrates. RF power applied to target has been varied in the range100 – 300 W. Deposition rate, structural and surface roughness were investigated by SEM, X-ray diffraction and atomic force microscopy.

In our study, analysis reveals TaN films show the formation of a crystalline film only at high sputtering power and the intensity of (111) peak increase with increasing sputtering power. Under the premise that films have a crystal structure, we can obtain a small surface roughness when the power is 200w.

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