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Study on the low leakage current of an MIS structure fabricated by ICP-CVD

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Abstract. As the dimensions of electric devices continue to shrink, it is becoming increasingly important to understand how to obtain good quality gate oxide film materials with higher carrier mobility, lower leakage current and greater reliability. All of them have become major concerns in the fabrication of thin film oxide transistors. A novel film deposition method called Inductively Coupled Plasma-Chemical Vapor Deposition (ICP-CVD) has received attraction in the semiconductor industry, because it can be capable of generating high density plasmas at extremely low temperature, resulting in less ion bombardment of the material surface. In this work, we present the results of crystallized silicon dioxide films deposited by inductively coupled plasma chemical vapor deposition technique at an extremely low temperature of 90°C. The value of the refractive index of the crystallized ICP-CVD SiO2 film depends on the r.f. power of the ICP system, and approximates to be 1.46. This value is comparable to that of SiO2 films prepared by thermal oxidation. As the r.f. power of ICP applied more than 1250 Watts, still only the (111) diffraction peak is observed by XRD, which implies a very strong preferred orientation or single crystal structure. Too low or too high r.f. power both produces amorphous SiO2 films. From the I-V curve, the MIS device with a SiO2 dielectric film has a lower leakage current density of 6.8×10^{-8}A/cm² at 1V as the film prepared at 1750 watts. The highest breakdown field in this study is 15.8 MV/cm. From the FTIR analysis, it was found that more hydrogen atoms incorporate into films and form Si-OH bonds as the r.f. power increases. The existence of Si-OH bonds leads to a poor reliability of the MIS device.

1. Introduction

With the advance of information technology, the flat panel display (FPD) industry has experienced rapid growth in recent years [1-2]. Thin film transistors (TFT) made by high quality semiconductor films can be used in active matrix liquid crystal displays (AMLCD) [3-4]. Low-temperature fabrication of high-quality gate oxide film is one of the key issues for further development of TFT [5]. Some alternate processes to the conventional thermal oxidation are chemical vapor deposition (CVD), low pressure CVD (LPCVD) [6] and plasma enhanced CVD (PECVD). The plasma-enhanced CVD (PE-CVD) process is widely used nowadays [7-10]. While it can be applicable to large area surface

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deposition, the ion bombardment and contamination in the films with unwanted bonding groups derived from the direct plasma excitation of all the process gases leads to poor film quality.

A novel film deposition method called Inductively Coupled Plasma-Chemical Vapor Deposition (ICP-CVD) has become an important tool in the semiconductor industry because it is capable of producing high density plasmas at extremely low temperature, resulting in less ion bombardment of the substrate surface. How to minimize substrate damage and produce high quality SiO₂ films is important for various electronic devices. The ICP-CVD can provide the following technological improvements: (i) complete separation of film deposition from plasma, (ii) low temperature deposition, and (iii) uniform film deposition on a large substrate.

In this work, we study the properties of silicon dioxide films prepared by the inductively coupled plasma chemical vapor deposition (ICP-CVD) technique from silane and oxygen gas mixtures at extremely low temperature. The microstructure and optical properties of these films on Si substrate were studied in detail.

2. Experimental Details

In this study, the silicon dioxide films were deposited by using inductively coupled plasma chemical vapor deposition (ICP-CVD) with silane and oxygen mixtures as reactant gases. The substrate was radiatively heated by plasma to about 90°C. Before deposition, the chamber was evacuated to the background pressure of 10⁻⁶ torr to avoid any contamination. The substrate was cleaned with trichloroethylene and acetone to remove grease and any possible organic contamination on the substrate surface. The r.f. power was set in the 1000~2000 watts range. The thickness of films was well controlled by keeping the deposition time to approximately 100nm film thickness.

The film thickness was measured using a surface profiler detector (Alpha-step 200). The refractive index was determined with an ellipsometer. The crystal structural of silicon dioxide thin films were analyzed by X-ray diffraction (XRD) with a Shimadzu XD-1 diffractometer using monochromatic high intensity Cu Kα radiation (λ= 1.54052Å), operating at 30kV with 20mA current, and a scanning speed of 3 degrees per minute. The surface morphologies and surface roughness were examined with an atomic force microscope (AFM). In order to obtain information about the electrical properties in the structures, the oxides were incorporated in metal oxide semiconductor (MOS) capacitors formed by vacuum evaporation of Al dots. To create a contact to the Si backside, a continuous Al film was evaporated. Information about the lower leakage was obtained from analysis of the leakage current-voltage (I-V) characteristics of the metal-oxide-Si structures.

3. Results and Discussion

Fig.1 showed the deposition rate of silicon dioxide films deposited at various r.f. powers. The results show that deposition rate is an approximately linear function with increasing r.f. power. When the r.f. power increases both the silicon radicals generated from the decomposition of SiH₄ and the arriving probability of the silicon atoms on the substrate increase which lead to high growth rate.

Fig.2 showed the refractive index of silicon dioxide films with r.f. power. In this reaction system, the oxygen radicals in the plasma are so active that they can immediately react with the products from the deposition of SiH₄ and go on to from the SiO or SiO₂ film. The results shown in Fig.2 reveal that at high r.f. power the film approaches the stoichiometric silicon dioxide, with n about 1.46 [11]. From the variation of refractive index, we may deduce the SiO₂ film formation mechanism from the decomposition of SiH₄ to the formation of SiO₂ in the plasma.
Figure 1. The deposition rate of SiO$_2$ films deposited at various r.f. powers.

Figure 2. The refractive index ($n$) of SiO$_2$ films at various r.f. powers.

Fig. 3 shows X-ray diffraction (XRD) spectra of the SiO$_2$ films as a function of r.f. power. Only the (111) diffraction peak was observed in the range from 30~40 degree, while r.f. power was above 1250 watts. This reveals that all the deposited films were polycrystalline and of high quality. At 1000 watts r.f. power conditions the silicon dioxide films were amorphous, which may be attributed to a too low deposition rate. However, the intensity of (111) was depressed to a lower value when 2000 watts was applied. This result may due to a strong hydrogen etching effect at high r.f. power conditions.

Figure 3. X-ray diffraction patterns of SiO$_2$ films deposited at various r.f. powers.

Fig. 4 shows the surface morphology of the SiO$_2$ films measured with an atomic force microscope (AFM). The roughness decreases with increasing r.f. power, and in the range of 2.1~2.6nm. It can be seen that the SiO$_2$ films prepared in this study were atomically smooth. At 2000 watts of r.f power, the root mean square (RMS) rapidly increases, which may be due to the strong ion bombardment effect in the plasma, which enhances the hydrogen etching effect of the film.
Fig. 4. The roughness of SiO₂ films deposited at different r.f. powers (a) 1000W (b) 1250W (c) 1500W (d) 1750W (e) 2000W

Fig. 5 shows the leakage current of silicon dioxide films for the gate dielectric layer deposited at various r.f. powers. From the I-V curve it can be seen that the SiO₂ thin film has a good electric property as prepared at 1750 watts. The larger leakage current at 2000 watts that may be due to defects or weaker bonding caused by ion bombardment in the SiO₂ films. The lowest leakage current of silicon dioxide films at the gate voltage of 1 V is about $8.2 \times 10^{-8}$ A/cm², and the breakdown field which can be obtained is 15.8 MV/cm at 1750 watts, as shown in Fig.6.

Fig. 5. The leakage current density of SiO₂ films at 1500W, 1750W and 2000W.

Fig. 6. The breakdown field of SiO₂ films at 1500W, 1750W and 2000W.

Typical FTIR absorption spectra are shown in Fig. 7. The strong peak at 2200 cm⁻¹ corresponds to the stretching mode Si–OH bond, and its integrated intensity increases with increasing plasma power density. From the results, we may deduce that the existence of Si-OH bonds leads to poor reliability of the MIS device. The SiO₂ films prepared at high r.f. powers suffer a strong hydrogen etching effect.
4. Conclusions

Crystallized silicon dioxide (SiO$_2$) films were successfully prepared by inductively coupled plasma chemical vapor deposition at an extremely low temperature of about 90°C. In this study, only the (111) diffraction peak is observed, while the r.f power is above 1250 watts. The surface roughness of SiO$_2$ films prepared in this study was in the range of 2.1~2.6nm, which is in the atomically smooth scale.

From the I-V curve it can be seen that the SiO$_2$ thin film has a good electric property as prepared at 1750 watts. The lowest leakage current of silicon dioxide films at the gate voltage of 1 V is about 8.2×10$^{-8}$ A/cm$^2$, and the breakdown field of is 15.8 MV/cm was obtained in this study.

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