FABRICATION OF ULTRA THIN SIN FILM AT LOW TEMPERATURE BY USING ECR PLASMA

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Abstract. SiN thin film has been fabricated using ECR plasma irradiation. Ar/N_2 mixed plasma irradiation at a low temperature of 400°C was carried out for the growth of the film. It is found that the nitrogen partial pressure has decisive effect on the film quality. A Si nitride film having a structure nearest to stoichiometric construction is obtained by precise control of N_2 mixing ratio at 60%. Under the optimum condition, the as-grown SiN film shows a leakage current more than three orders of magnitude lower than that of thermal grown SiO_2 having the same equivalent oxide thickness. High-resolution transmission electron microscope micrograph shows an atomically flat interface of Si and SiN film.

1. Introduction

SiO_2 films are widely used in the fabrication of integrated circuits. SiO_2 is native to Si and with it forms a low defect density interface. Further advantages of SiO_2 include the high receptivity, excellent dielectric strength, a large band gap, and a high melting point [1]. However, with the scaling of the MOSFET for high performance (speed), low static power and low cost devices, SiO_2 gate dielectrics thickness of several atomic layers is required. As the physical thickness of SiO_2 gate oxide approaches less than 2 nm, the leakage current density increases because of direct tunneling effect. Thus, SiO_2 cannot be used for low power ULSI in the future. To solve this problem and extend the limit of gate dielectric, many kinds of metal oxides having a dielectric constant larger than SiO_2 are studied as a replacement of traditional Si dioxide[2]. SiN is one of important gate insulator, which shows a higher permittivity and better barrier for oxygen and boron diffusion relative to SiO_2 having the same equivalent oxide thickness (EOT). Thus, Si nitride film is a reasonable replacement of SiO_2 film as gate dielectric.

In this paper, SiN thin film has been fabricated at a low temperature of 400°C. The growth of the Si nitride film was carried out with Ar/N_2 mixing plasma irradiation in an electron cyclotron resonance (ECR) plasma system. The effect of the N_2 partial pressure on the film quality was studied in detail and it was found that dilution of N_2 plasma with Ar gas having suitable mixing ratio improved the nitrogen radical concentration of the plasma. The bias effects, electrical and structural properties of the Si nitride films were also investigated.

2. Experiment

Si nitride film growth was performed in an ECR plasma system. An n-type (100) Si substrate with a resistivity of 8-12 Ωcm was set on a sample holder at the end of deposition chamber. Before direct nitridation, Si substrate was treated by RCA cleaning process. The substrate temperature was well controlled as low as 400^{0}C during the experiment by adjusting the holder heating power. Microwave power was kept as constant at 500W. The electrical characteristics were measured using MIS capacitors with evaporated Al electrode having an area of 2.25i10^{-4} cm^2 by lithography. To investigate the structure of the Si nitride film, refractive index and thickness of the Si nitride film were measured using an ex-situ spectroscopic ellipsometry (SE). To observe the flatness of the Si/SiN interface, high-resolution transmission electron microscope (HRTEM) measurement was carried out. In addition, X-ray photoelectron spectroscopy (XPS) results elucidated the bonding character of the as-grown film.

3. Results and Discussion

The effect of N_2 partial pressure on film quality was observed in XPS results[3]. The chemical shifted peak position and the full width of half-maximum (FWHM) of N1s signal as a function of N_2 mixing ratio are shown in Fig. 1. In this figure, dash lines also show the peak position and the FWHM of N1s signal from stoichiometric Si_3N_4 film fabricated by thermal CVD as reference. Since it is well known that the position and FWHM of XPS peak are very sensitive to the film bonding structure, it can be seen that a Si nitride film fabricated at the N_2 mixing ratio of around 60% is nearest to stoichiometric structure. When the N_2 mixing ratio was higher than 60%, the film quality became worse. This phenomenon was maybe caused by N_2 molecular incorporation in the film. According to the above discussion, the optimized N_2 mixing ratio for Si nitride growth can be concluded as 60%.

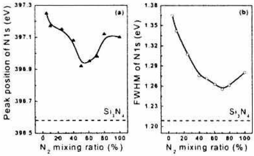

Fig.1. N1s XPS chemical shifted (a) peak position and (b) FWHM as a function of N_2 mixing ratio [N_2/(N_2+Ar)]

The normalized high frequency (100 kHz) C-V characteristic for the Si nitride film is shown in Fig. 2 (a). The film was fabricated at N_2 mixing ratio of 60% for 120 min, where the EOT was 2.46 nm. As comparison, a calculated ideal C-V curve is also shown by a solid line. The interface state density at the flat band was estimated as 6.4i10^{11} eV^{-1}cm^{-2} by using the high frequency capacitance method. The C-V characteristics indicate a Si oxide interlayer is needed between Si substrate and Si nitride film to improve the interface quality. The J-V curve of the same Si nitride film was also shown in Fig. 2 (b). The leakage current density was 4.2i10^{-6} A/cm^2 at +1 V, which were more than two orders of magnitude lower than that of thermally grown Si dioxide film with a given EOT. From the figure, it also can be seen that the breakdown happened at 4.8 V, which was corresponding to a breakdown field of 20 MV/cm.

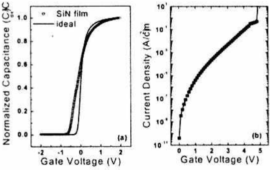

Fig.2. Electrical characteristic of Si nitride films formed in Ar/N_2 plasma

Figures 3 show the film thickness (d), EOT, refractive index and the ratio of the leakage current density at +1V of the SiN film as a function of V_b, where the N_2 mixing ratio was fixed at 60% and the film growth time was fixed at 120 min. The d and n were measured by SE, and EOT was obtained by C-V characteristics. The results can be classified into three types. It shows that the plasma etching caused by the substrate bias application also affected the SiN film quality. The strong negative and positive biases caused the existence of much defects and weak Si-N bonds in the films, respectively, consequently, the leakage current density increased largely. An optimized substrate bias contributed to depressing leakage current density of SiN film by suitable plasma etching effect.

HRTEM measurement indicates that the sample has an atomically flat interface between Si and SiN film. Furthermore, this image indicates that the physical thickness of the film is about 3.9 nm with accuracy. Considering the EOT value of this film, the permittivity of the Si nitride film was calculated to be 6.2, which was 1.6 larger than that of SiO_2

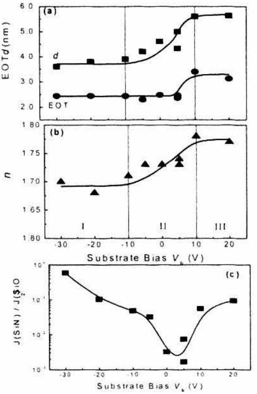

Fig.3. Film thickness (d), EOT (a), refractive index (b) and the ratio of the leakage current density at +1V (c) of the SiN film as a function of V_b.

4. Conclusion

An amorphous Si nitride thin film has been fabricated using Ar/N_2 mixed plasma irradiation in an ECR system at a low temperature of 400^0C. After 120 min irradiation under the optimum condition, a Si nitride film with EOT of 2.46 nm was formed. The as-grown SiN film shows a leakage current more than two orders of magnitude lower than that of thermal grown SiO_2 with a given EOT. An optimized substrate bias contributed to depressing leakage current density of SiN film by suitable plasma etching effect The HRTEM micrograph shows an atomically flat interface of Si and SiN film. It is found that the nitrogen partial pressure has decisive effect on the film quality. A Si nitride film with minimum EOT is obtained by precise control of N_2 mixing ratio at 60%. It implies that the existence of Ar with suitable partial pressure would increase nitrogen radical concentration in the Ar/N_2 mixed plasma. The XPS results also confirmed this point.

References

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