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High Quality Silicon Nitride Film Formed by Microwave-Excited Plasma Enhanced Chemical Vapor Deposition with Dual Gas Shower Head

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1. Introduction

It is required that high quality silicon nitride film is deposited at low temperature and high-speed for performance enhancement of the MOS devices such as a gate sidewall, a interconnect insulator film and a TFT gate insulator film. In this study, a high quality silicon nitride film formed by a microwave-exited plasma enhanced chemical vapor deposition (PECVD) technology in which process gases are introduced to the low electron temperature diffusion plasma region with dual gas shower head at low temperature (400°C) is firstly demonstrated. The silicon nitride film can be deposited at high-speed, and has a stoichiometric composition and excellent electrical characteristics such as a low leakage current and a high breakdown voltage.

2. Experimental Method

The experimental equipment, as shown in Fig. 1, is capable of generating a low-electron-temperature (<1eV) and high-density (>10^{12} cm^{-3}) plasma by 8.3 GHz microwave through a radial line slot antenna (RLSA)[1]. Process gases for the film deposition introduced through the upper gas inlet are $Ar/N_2/H_2$ and the lower gas shower head is SiH_4. The advantage of this equipment is to separate the plasma-excited region and the process region[2]. The SiH_4 is uniformly introduced to the low electron temperature diffusion plasma region for suppressing excess decomposition of SiH_4.

The substrates were n-type (100) 10^{16} phosphorus doped crystal silicon. The substrate temperature, microwave power density, Ar flow rate, N_2 flow rate, H_2 flow rate and SiH_4 flow rate are 400°C, 6 W/cm^2, 237.5 ccm, 40 ccm, 4 sccm and 0.05 ccm, respectively.

3. Results and Discussions

Figure 2 shows deposition rates of the silicon nitride film compared with a conventional high temperature (800°C) LPCVD silicon nitride film and the high quality silicon nitride film formed by plasma direct nitridation at 400°C[3]. Though this silicon nitride film was formed at 400°C, the deposition rate is higher than that of the conventional LPCVD film at 800°C.

The refractive index and the Si/N ratio of the PECVD silicon nitride as a function of the process pressure are shown in fig. 3 and 4. The refractive index and the Si/N ratio approach to a value of the stoichiometric Si_3N_4 at low pressure. With increasing of the pressure, the residence time of SiH_4 gas in camber increases. Longer residence time and higher Ar ions density at higher pressure, more SiH_4 may be dissociated into neutral radicals, which are incorporated in the film and cause Si rich.

Figure 5 shows the dependence of the etching rate on the refractive index. The etching rate was measured in the solution of BHF at 25°C. Generally, refractive index and etching rate are related to the composition and density of the film. This result indicates that the silicon nitride film has the characteristic that is approximate to the thick silicon nitride film formed by LPCVD (800°C).

These good characteristics are owned by the high-density and low electron temperature plasma separated the plasma-excited region and the process region suppressing excess decomposition of process gases.

In electrical characterization, Al-gate MIS capacitors are fabricated with the PECVD silicon nitride film that is stochiometric and its refractive index is 1.98. The high frequency C-V characteristic of the silicon nitride film is shown in Fig. 6. The C-V characteristic exhibits small hysterisis loop with 0.06 V. The fixed charge density of this film corresponds to 1x 10^{11} cm^{-2}.

Figure 7 shows the J-E characteristic of the silicon nitride film that film thickness is 17 nm (EOT is 8.5 nm) compared with the thermal silicon oxide formed at 1000°C that thickness is 9.4 nm and the PECVD silicon oxide formed at 400°C that film thickness is 20 nm[4]. E shows effective electric field and is defined $(V_g\text{-}V_{th})$/EOT. The PECVD silicon nitride film has good characteristics those are low leakage current at low electric field and high brake-down field.

4. Conclusions

The high quality silicon nitride film have been achieved by the PECVD technique in which process gases are introduced by a lower gas shower head to the low-electron-temperature diffusion region of a microwave-excited high density plasma at low temperature of 400°C. This high quality PECVD silicon nitride film can be applied to various insulator films in MOS devices.

References

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[3] T. Goto et al, Jpn. J. Appl. Phys., 42, pt. 1, No. 4B, 2003.
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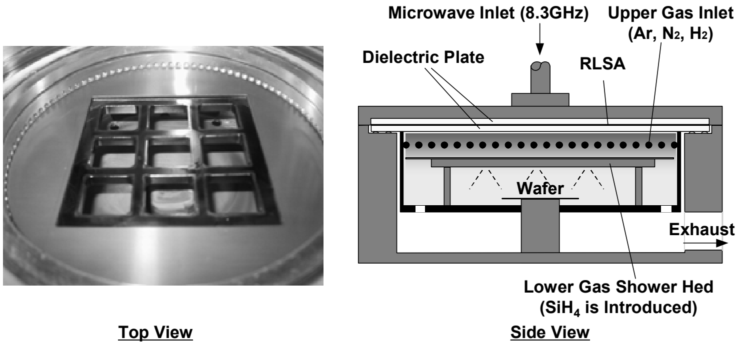

Fig. 1 Schematic of the high density low energy plasma system with lower gas shower inlet. This equipment can separate a plasma exited region and process region. The SiH_4 gas is introduced to the process region of diffusion plasma region by the lower gas shower inlet with low electron temperature (<1 eV) for suppressing excess decomposition of SiH_4 and some undesirable gas phase reactions.

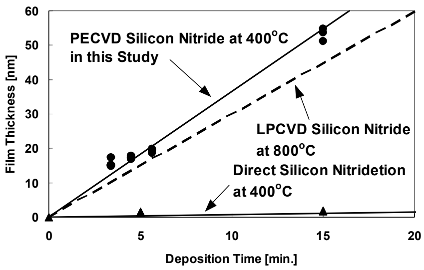

Fig. 2 Deposition rate of the PECVD silicon nitride. The PECVD formed at 400°C, the deposition rate is higher than that of the LPCVD film formation at 800°C and is sufficiently high for practical use.

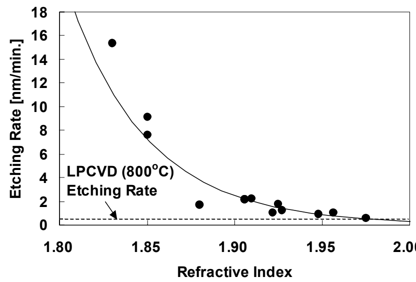

Fig. 5 Dependence of the etching rate on the refractive index. The PECVD silicon nitride film has the characteristic that is approximate to the thick silicon nitride formed by the LPCVD (800°C).

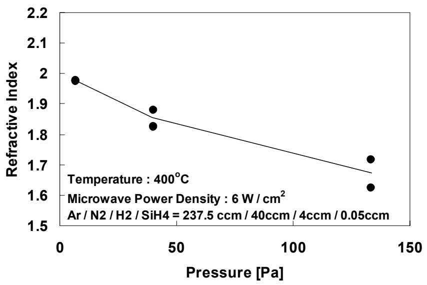

Fig. 3 Refractive index of the PECVD silicon nitride as a function of the process pressure. The refractive index decreases with the increase of the pressure.

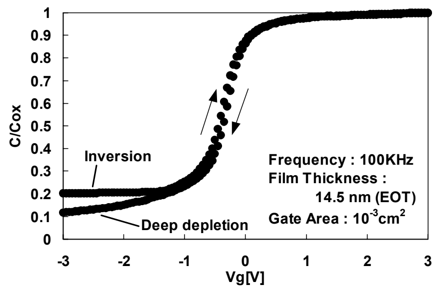

Fig. 6 C-V characteristic of the PECVD silicon nitride. The width of hysterisis loop is small value of 0.06 V. And, the fixed charge density is 1x 10^{11} cm^{-2}.

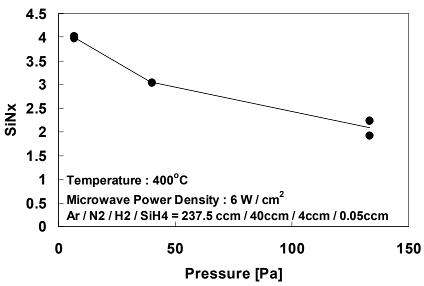

Fig. 4 Si/N ratio of the PECVD silicon nitride as a function of the process pressure. The Si/N ratio decreases with the increase of the pressure.

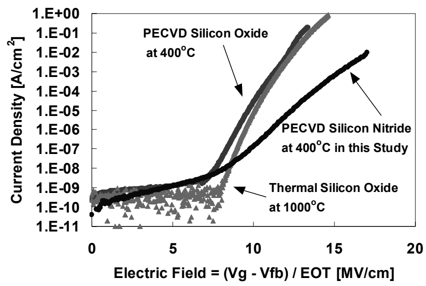

Fig. 7 J-E characteristic of the PECVD silicon nitride. The PECVD silicon nitride film has good characteristics compared with the SiO_2 film formed by the thermal (1000°C) and the PECVD (400°C). Those are low leakage current at low electric field and high brake-down field.