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Radio frequency source power-induced ion energy impact on SiN films deposited by using a pulsed-PECVD in SiH_4–N_2 plasma at room temperature

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ABSTRACT

Using a radio frequency (rf) pulsed-plasma enhanced chemical vapor deposition system, silicon nitride (SiN) films were deposited in a SiH_4–N_2 inductively coupled plasma. Effect of duty ratio and rf source powers on deposition rate at room temperature were investigated in the ranges 50–90% and 600–900 W, respectively. Plasma diagnostics on ion energy was conducted and rf source power-induced ion energy impact on SiN films were studied as well as some correlations between deposition rate and ion energy. High and low energies ranged from 17.8 to 22.6 eV, and from 23.6 to 33.8 eV, respectively. Higher ion energies observed at lower duty ratios or lower rf powers was attributed to a lower plasma density. Ion energy flux variation was opposite to that for ion energy. Meanwhile, the deposition rate increased with decreasing the duty ratio at all powers but 900 W. This was not clear as a function of rf source power. The deposition rate ranged from 17.0 to 26.5 nm/min.

1. Introduction

Due to good thermal stability, good chemical inertness, and high electrical resistivity, silicon nitride (SiN) films are used as a passivation layer in manufacturing solar cells or integrated circuits. A plasma enhanced chemical vapor deposition (PECVD) system has been widely used to deposit SiN films in a SiH_4–NH_3 [1,2], SiH_4–N_2 [3,4], SiH_4–N_2–NH_3 [5] plasmas. Recently, pulsed-plasma enhanced chemical vapor deposition (P-PECVD) has been actively used for SiN deposition [4,6,7] due to a reduced particle in gas phase [6], at high deposition rate, and a reduced substrate heating [7]. A smaller surface roughness was achieved at lower ratio duty ratio [4,8]. The deposition temperature was even lowered to room temperature [8–11]. A higher deposition rate of SiN films at lower radio frequency (rf) source power was reported [9]. In the P-PECVD, the duty ratio is one of important factors that affect film properties. Actually, the duty ratio is strongly involved in the efficiency of energy transfer to plasma, electron or ion energy distributions as well as ionization rate. Using a DC magnetron sputtering system, duty ratio impacts on plasma discharge [12] and film depositions [4,6] were investigated. The influence of duty ratio on SiN deposition was also examined under fixed process parameters. Up to now, the effect of duty ratio on SiN deposition as a function of rf source power particularly at room temperature was not reported. Meanwhile, ion bombardment serving as a surface reaction promoter influences film properties in terms of chemical reactions, bond breakage, or surface densification. Depending on the duty ratio or rf source power, varying degrees of ion energy is expected. Up to now, this concern was not studied. Therefore, certain relationships between rf source power and duty ratio and the impacts of duty ratio on film properties still remain to be explored.

In this study, SiN films were deposited at room temperature in SiH_4–N_2 plasma by using a P-PECVD system (PLASMART™). Effects of duty ratio and rf source power on a SiN deposition rate were examined. A non-invasive ion analyzer (IEA) (PLASMART™) was used to measure ion energy distribution. Relationships between the rf source power and duty ratio and between the duty ratio and deposition rate are investigated.

2. Experimental details

SiN films were deposited on p-type, single side polished Si wafers of (1 0 0) orientation. The thickness and resistivity of wafers

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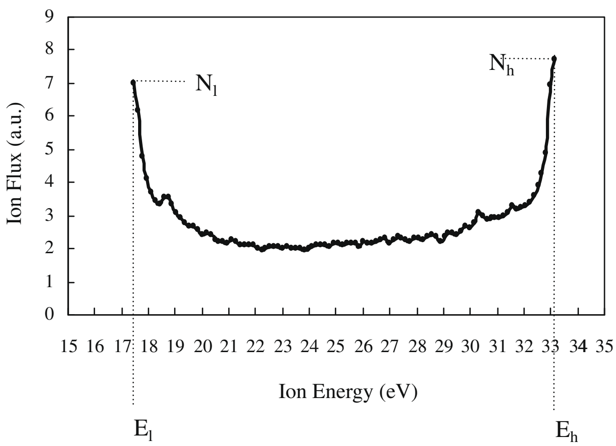

Fig. 1. Ion energy distribution function at 900 W source power and 90% duty ratio.

were about 525 ± 25 μm and 1–30 Ω cm, respectively. Using the P-PECVD system, SiN films were deposited. The equipment was detailed in [9]. Deposition was conducted as a function of source power in the range 600–900 W. The bias power was set to zero. The deposition was conducted in SiH_4–N_2 chemistry. The flow rates of SiH_4 and N_2 gases were set to 8 and 100 sccm, respectively. The deposition time was 5 min. In situ ion energy distribution functions were collected by using the IEA. An illustration of IEA-collected ion energy distribution function is shown in Fig. 1. This was collected at the source power and duty ratio of 900 W and 90%, respectively. Four diagnostic variables are extracted from the distribution function in Fig. 1 and they are a high ion energy (E_h), a low ion energy (E_l), a high ion energy flux (N_h), and a low ion energy flux (N_l). As depicted in Fig. 1, both E_h and E_l represent the location of high and low energy peaks, respectively. The N_h and N_l correspond to the height of high and low energy peaks, respectively. There parameters are useful to evaluate ion bombardment in terms of energy level and flux concentration.

3. Results

3.1. Diagnostics

Fig. 2 shows an E_h as a function of duty ratio and source power. As shown in Fig. 2, the E_h is seen to increase with decreasing the duty ratio at all rf powers but 600 W. Higher E_h is observed at lower powers and this is clear at shorter duty ratios of 50% and 60%. This is identical to the energy variation reported in the deposition of SiN in a SiH_4–NH_3 plasma [9]. From the increase in E_h, another increase in potential drop across the plasma sheath is expected. The increased potential drop is closely related to a decreasing source power-induced DC bias. In addition, the DC bias is inclined to increase as the plasma density lowers. This implies a lower plasma density at lower duty ratios or at smaller source powers. The relationship between the plasma density and source power is well supported by other experimental reports [3]. However, another relationship between the high ion energy and source power variations in view of plasma density was not clear in previous studies. In other words, lower plasma density at lower duty ratio is identified as the main contributor for higher E_h. This phenomenon is consistent with those noticed in the plasma density variation under the constant-current mode in the pulsed-DC magnetron discharge [12]. In Fig. 2, the E_h ranges from 23.6 to 33.8 eV for all variations in duty ratio and powers. Fig. 3 shows an E_l as a function of duty ratio and source power. In Fig. 3, the E_l variation with the duty ratio is quite complex. The E_l variation with the duty ratio at 900 W is very little. In contrast, the E_l at 700 and 800 W increases with the duty ratio. The most complex E_l variation occurs at 600 W. All these features are much different from those observed in a SiH_4–NH_3 plasma [13]. For the power variation, as observed in the case of E_h, higher E_l is achieved at lower power in the duty ratio range 50–70%. This dependency is conspicuous at 50% and 60%. Fig. 3 shows that in general decreasing either the duty ratio or the source power is likely to increase the E_l. It should be noted that this is true of E_h. In Fig. 3, the E_l ranges from 17.8 to 22.6 eV for all variations in the duty ratio and power. This range is smaller than that for E_h as stated earlier. This indicates that E_l is less affected

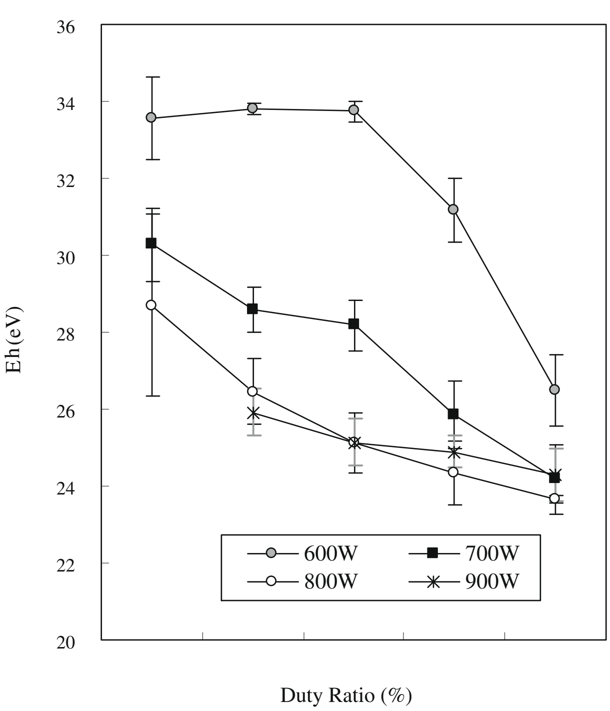

Fig. 2. High ion energy as a function of duty ratio and rf source power.

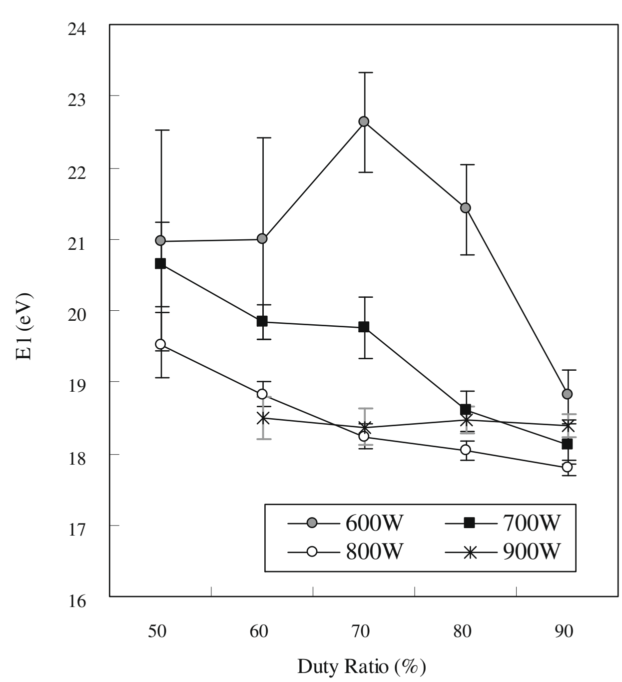

Fig. 3. Low ion energy as a function of duty ratio and rf source power.