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The Passivation of GaAs Surface by Laser CVD

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In order to passivate the GaAs surface, silicon-nitride films were fabricated by using laser CVD method. SiH_4 and NH_3 were used to obtain SiN films in the range of 100~300℃ on P-type (100) GaAs substrate. To determine interface characteristics of the metal-insulator-GaAs structure, electrical measurements were performed such as C-V curves and deep level transient spectroscopy (DLTS). The results show that the hysteresis was reduced and interface trap density was lowered to 1,012 ~ 1,013 at 100 ~ 200℃. According to the study of surface leakage current, the passivated GaAs has less leakage current compared to non-passivated substrate.

Key Words : Laser CVD, Passivation, DLTS method, GaAs surface

1. INTRODUCTION

III-V compound materials, including GaAs, offer the high electron mobility and excellent optical characteristics which can not be obtained from Si material[1,2]. Therefore high speed devices which are fabricated using these materials are applied to optical communications and high frequency systems. The development of the GaAs device has thereby gained considerable interest in recent days[3,4].

In order to develop GaAs devices, it is necessary to form insulators for passivation with good chemical stability, dielectric and interface properties on the GaAs surface. However, in GaAs, good quality insulator for passivation was not reported yet as good as SiO_2 on silicon process. Therefore, more extensive studies on forming several oxides and insulating films on GaAs are now required for surface passivation and planar technology. The conventional insulating films deposition methods such as thermal CVD method, plasma CVD method and anodic oxidation were not satisfied in view of chemical stability and interface properties[5-7].

On the other hand, laser CVD method has advantages such as low temperature process and no-surface damage. For these reasons, good chemical stability and interface properties can be obtained by laser CVD method[8,9].

In this work, we examined properties of GaAs passivation films formed by laser CVD method. The SiN films formed on GaAs surface had good masking effect against O_2. The chemical depth profiles between 500 ~ 1500Å thick SiN films were obtained using Auger spectroscopy combined with Ar ion milling. C-V curve and DLTS analysis were carried out to study the interface properties and the influences of SiN passivation film on leakage current between electrodes.

2. EXPERIMENT AND ANALYSIS

The P-type (Na = 7 x 1,016) GaAs wafers, doped with Si, were used in this work. The wafers were cleaned in ultrasonic bath containing acetone and then rinsed in DI water. To remove metal ions and native oxide on the surface, the wafers were then etched in aqueous solution of NH_4OH and H_2O_2.

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Figure 1 shows the schematic diagram of a laser CVD system which is composed of a vacuum chamber with two windows, a light source, an optical equipment, a reactant gas supplier, a substrate heating equipment and vacuum system. Two windows in the vacuum chamber are made up of quartz which has good transmittance for the laser beam of the 193㎚ wavelength. The ArF excimer laser is irradiated parallel to the substrate through the lens with 50㎝ focal length. The distance between the beam and wafer in the experiment was fixed to 0.3㎜ to limit the diffusion length of reactive species to within 1㎜.

To remove moisture and residual gas, the wafer holder was heated at 400℃ for about an hour. The wafer was then placed in the chamber. The chamber was exhausted to 10^{-2} Torr.

The laser beam was irradiated parallel to the substrate under constant pressure. The reactant gases used in this experiment consist of SiH_4(95%), NH_3(99.996%), and buffer N_2 gas, made by Takachio.

The deposition conditions for laser CVD SiN are presented in Fig.1. 6.4 Watt of laser power and 2 Torr of chamber pressure were used in this processing. We varied substrate temperature 100, 200, 300℃. And gas ratio of SiH_4, NH_3, N_2 were 20, 80, 100 sccm.

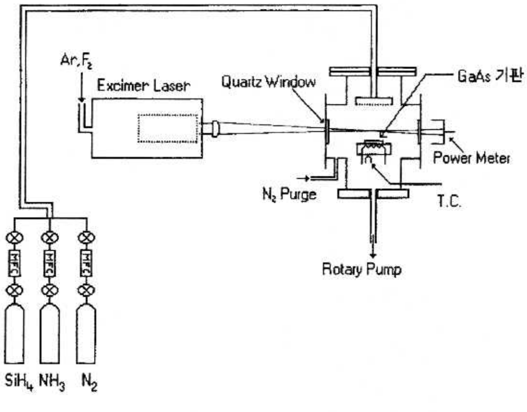


Fig. 1. Schematic diagram of laser CVD system.

3. MEASUREMENTS

Nanoscope and ellipsometer were used to measure thickness and refractive index of SiN films as functions of temperature. The chemical depth profile of SiN film and temperature varied spacial atomic distributions were estimated from Auger spectroscopy though 500 ~ 1500Å range.

The Al was evaporated on SiN films to make MIS structure. The C-V curve and DLTS were examined to obtain hysteresis effect and interface trap density as a function of temperature. The surface leakage current was measured before and after passivation.

Figuge 2 shows the sample with semi-insulating substrate and Au/Ge opposite electrodes to measure the surface leakage current before and after passivation.

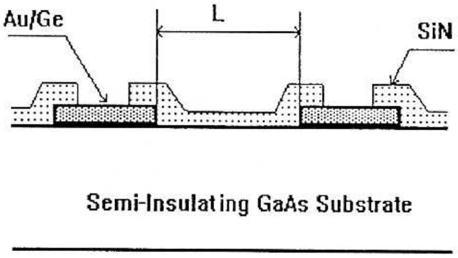


Fig. 2. Sample for measurement of surface current.

4. RESULTS AND DISCUSSIONS

Figure 3 shows deposition rate and refractive index of SiN films as a function of substrate temperature. The deposition rate increases as substrate temperature increases, which is due to enlargement of thermal dissociation effect of source gas and increase of reaction rate between reactive species and substrate. The refractive index increases as substrate temperature increases, too. This is due to the increasing of film density with substrate temperature.

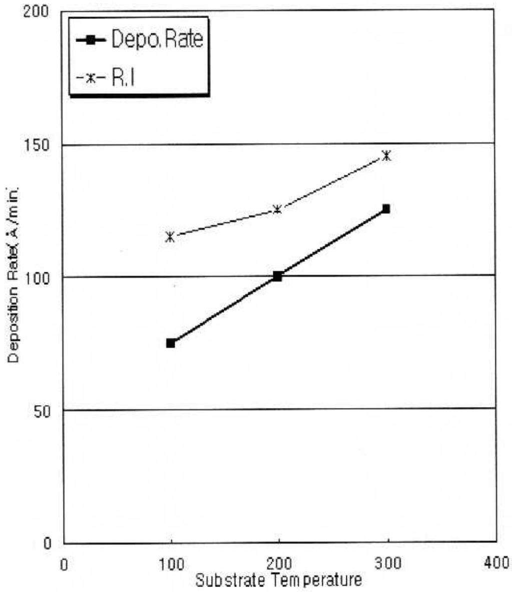
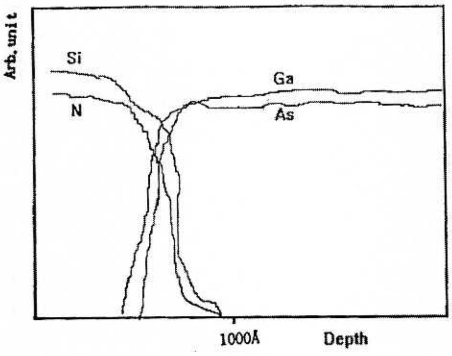
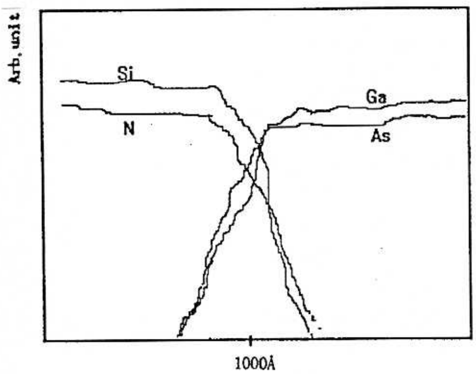


Fig. 3. Deposition rate and refractive index of SiN films as a function of substrate temperature.

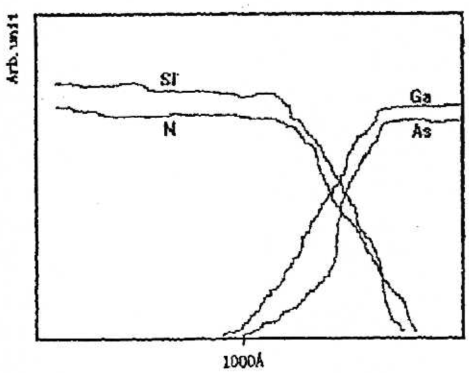
Figure 4 shows Auger depth profiles of SiN films obtained at each temperature. The diffusion of GaAs atoms through SiN films increases with increasing temperature. This diffused atoms influences the C-V curve and its hysteresis effect. The hysteresis effect of MIS structure is not desirable to devices characteristics. As a result, low temperature processed sample showed the better device properties.



(a) 100℃



(b) 200℃



(c) 300℃

Fig. 4. Auger depth profiles of SiN films as function of substrate temperature.

Capacitance versus applied gate voltage VG, measured at 1㎒ in MIS structure, are represented in Fig. 5.

The C-V curves for GaAs-SiN MIS structure show clockwise hysteresis which is due to charge injection effect. The hysteresis loop is expanded as substrate temperature increases, which is caused by increase of Ga, As ion diffusion from substrate to films with increase of substrate temperature. This is suggested that low temperature process should be effective on prevention of hysteresis effect. On this studies, hysteresis effect is not so serious at the substrate temperature range of 100 ~ 200℃. We can expect that it will be well suited to practical devices.

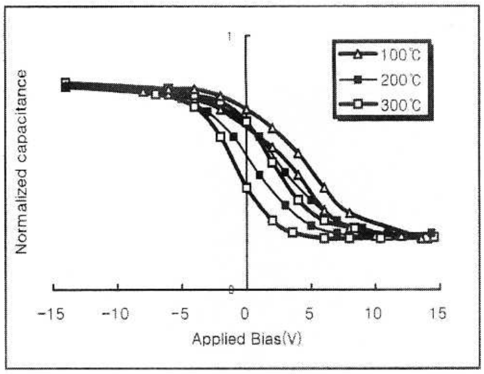


Fig. 5. C-V curves as a function of substrate temperature.

Figure 6 shows DLTS signal of SiN film formed at 200℃, from which extract the interface trap density. Briefly, DLTS is a high frequency capacitance transient thermal scanning method useful for observing a wide variety of traps in interface. The height of these peaks is proportional to their respective trap concentration, the sign of each peak indicates whether it is due to a majority or minority carrier trap, and the position, in temperature, of the peak is uniquely determined by the thermal emission properties of the trap.

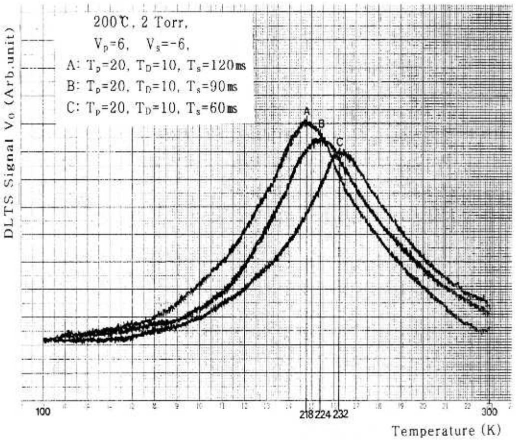


Fig. 6. DLTS signal of SiN films formed at substrate temperature 200℃.

The interface trap density as a function of substrate temperature extracted from the DLTS signal by calculation of traditional equation is shown in Fig. 7. The interface trap density peak is located at 0.24 eV from the valence band edge Ev. And interface trap density decreases as substrate temperature increases, which is due to increment of atom's surface migration and which form more stable bonding between N, Si atom and GaAs with temperature. However, it is shown that satisfactory interface density can be obtained even between 100 to 200℃.

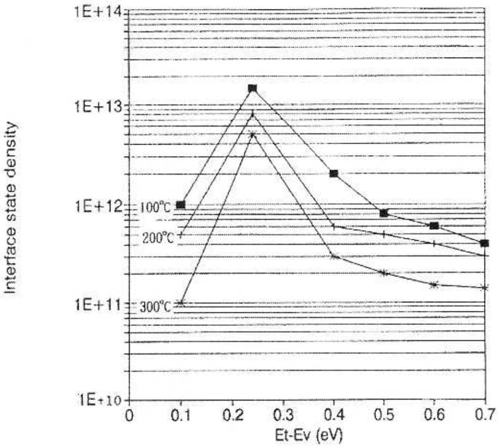
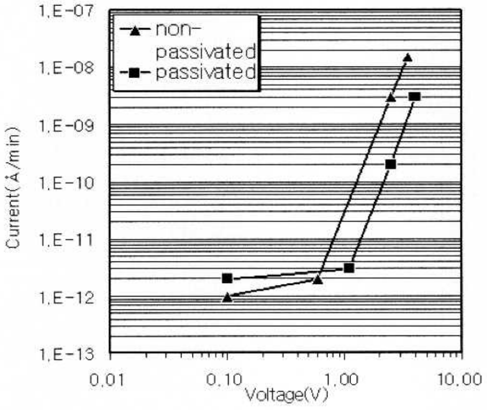


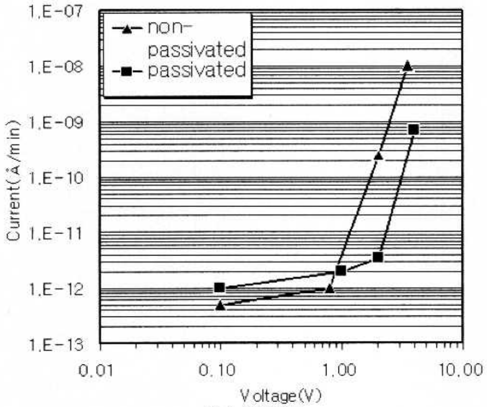
Fig. 7. Interface trap density as a function of energy state at each substrate temperature.

Figure 8 shows I-V characteristics of surface leakage current between two opposite electrodes before and after passivation at the substrate temperature of 100, 200 and 300℃. In low electric field area I-V characteristics followed the ohmic rule prior to surface passivation. But, the current increase abruptly about 4~6 order above some voltage Vth.

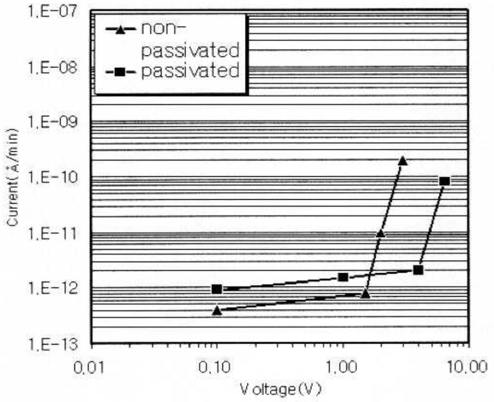
After making surface passivation films, in low electric field region, the trend of I-V curve is similar to non passivation. However, current surge voltage Vth of passivated samples is larger than that of non-passivated ones. It demonstrates that electrical activation of surface atom is greatly attenuated after surface passivation.



(a) 100℃



(b) 200℃



(c) 300℃

Fig. 8. I-V characteristics of surface leakage current between two opposite electrodes before and after passivation at the substrate temperature of 100, 200 and 300℃.

5. CONCLUSION

The results of SiN passivation films formed by laser CVD are as follows.

1) The deposition rate of SiN films increases as substrate temperature increases. This is due to generation of more reactive species with substrate temperature. The refractive index increases as substrate temperature increases, which is due to the accompanying increase film density.

2) Upon the inspection of the C-V curve, we noticed that, although the hysteresis effect is diminished at 100~200℃, hysteresis generally becomes more serious with substrate temperature. This is probably due to the increased diffusion of Ga, As.

3) The measurement of interface trap density from DLTS signal shows that interface trap density decreases as substrate temperature increases. However, it is shown that satisfactory interface density can be obtained even in substrate temperature range of 100~200℃.

4) The surface leakage current properties between two opposite electrodes are improved by passivation. That is, current surge voltage is larger in passivated GaAs than non-passivated GaAs.

In summary, the results of this studies indicated that SiN passivating films formed on GaAs by laser CVD technique at substrate temperature 100~200℃ exhibit good interface properties, reduction of hysteresis effect and reduction of surface leakage current. Accordingly, stable device properties are expected when this method is applied to device fabrication.

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