AlGaAs/InGaAs HEMTs Passivated with Atomic Layer Deposited SiO_2 using Aminosilane Precursors

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Abstract—**Atomic layer deposited SiO_2 has been applied to AlGaAs/InGaAs high electron mobility transistors (HEMTs) for surface passivation employing bis(ethylmethylamino)silane (BEMAS) and tris(dimethylamino)silane (3DMAS). The BEMAS SiO_2 HEMT has achieved a lower on-resistance, as compared to the 3DMAS. This suggests excellent termination of surface dangling bonds by BEMAS.**

Keywords-AlGaAs/InGaAs; high electron mobility toransistor (HEMT); surface passivation; SiO_2; atomic layer deposition (ALD); bis(ethylmethylamino)silane (BEMAS).

I. Introduction

AlGaAs/InGaAs high electron mobility transistors (HEMTs) which show excellent performances including a low on-resistance and a high current gain cut off frequency are used for low noise amplifiers of direct broadcast satellite TV services. For obtaining the performances, SiO_2 is deposited on a device surface commonly by the chemical vapor deposition (CVD) method [1]. However, termination of dangling bonds by CVD is restricted due to its deposition mechanism of gas phase reaction. Dangling bonds on the semiconductor surface near the gate electrode act as trapping defects. Electrons trapped at the defects enhance the surface potential of the HEMT, thus decreasing an electron concentration in the channel. As a result, a channel current decreases. In this study, we characterized the effects of SiO_2 passivation films on HEMTs by the atomic layer deposition (ALD) method which shows excellent capability for termination of dangling bonds using aminosilane precursors [2], [3].

II. Experimental Procedures

SiO_2 films were formed at a substrate temperature of 150 °C by the plasma enhanced ALD, where bis(ethylmethylamino)silane (BEMAS: $H_2Si[N(C_2H_5)(CH_3)]_2$) and tris(dimethylamino)silane (3DMAS: $HSi[N(CH_3)_2]_3$) [3] were employed as precursors. The plasma enhanced ALD-SiO_2 can be deposited using an alternate supply of precursor and oxygen plasma. A procedure of the film formation is as follows; the Ar flowed constantly at 100 sccm during the entire cycle as diluted and purge gas. The precursor was firstly introduced to the reactor to be absorbed on a semiconductor surface during 0.4 s with a vapor pressure at a room temperature. Five seconds later, remote oxygen plasma generated by a 13.56 MHz RF power of 300 W was exposed to react with precursor absorbed on the surface for 20 s. These two steps were repeated to form the SiO_2 film.

TABLE I. Growth Rate per Cycle and Etching Rate of ALD-SiO_2 Films using BEMAS and 3DMAS

	Growth rate per cycle [nm/cycle]	Etching rate [nm/s]
BEMAS SiO_2	0.14	16.2
3DMAS SiO_2	0.08	31.5

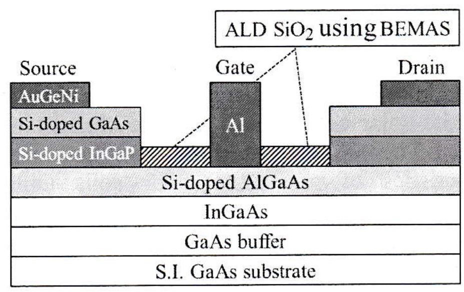

Figure 1. Schematic cross section of the AlGaAs/InGaAs HEMT.

The ALD-SiO_2 using BEMAS and 3DMAS were evaluated by a growth rate per cycle (GPC) and an etching rate in buffered hydrofluoric acid (HF : NH_4F = 1 : 5). The results of the GPC and the etching rate are shown in Table 1. The GPC of BEMAS SiO_2 film was about 2 times higher than that of 3DMAS. This is due to the larger number of Si-H bonding of BEMAS. In addition, the etching rate of BEMAS is half of 3DMAS SiO_2. These results imply that BEMAS is more reactive than 3DMAS, thus resulting in tightly bounded SiO_2.

The structure of a fabricated AlGaAs/InGaAs HEMT is schematically illustrated in Fig. 1. Epitaxial layers were grown on a semi-insulating GaAs substrate by the molecular beam epitaxy method. For fabricating HEMTs, mesa isolation was firstly achieved with the wafer. Then, AuGeNi was deposited on the patterned wafer for source and drain electrodes by the vacuum evaporation method, and the wafer was annealed at 430 °C for 60 s. Next, a recessed gate structure was formed utilizing InGaP as an etching stopper layer by a self-aligned technique [4]. Then, Al was deposited by the evaporation method, and gate electrodes were formed employing the lift-off technique. Continuously, SiO_2 with 3 nm thick was deposited on the

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HEMTs individually using BEMAS and 3DMAS by the plasma enhanced ALD method at 150 °C, as shown above. The HEMTs with a gate length of 1.2 μm and a gate width of 100 μm were successfully fabricated. The length of the recess region was 0.3 μm. DC performances were measured employing the EPS150TRIAX probe station with the 4200-SCS parameter analyzer.

III. Results and Discussion

The drain-source current (I_{ds}) versus the drain-source voltage (V_{ds}) characteristics for the fabricated HEMTs are shown in Fig. 2. On-resistances (R_{on}) of the HEMTs with BEMAS SiO_2, 3DMAS SiO_2 and without passivation were measured to be 13.0, 13.8 and 17.2 Ω·mm, respectively (with I_{ds} at V_{ds} of 0.5 V). The transconductance (g_m) versus the gate-source voltage (V_{gs}) characteristics is presented in Fig. 3. The peak transconductance of the HEMTs with BEMAS SiO_2, 3DMAS SiO_2 and without passivation were 95, 90 and 81 mS/mm, respectively. It should be noted that the R_{on} reduced by 24 %, thus resulting in transconductance enhancement by 17 % for the HEMT with BEMAS SiO_2, compared to the HEMT without passivation. On the other hand, the 3DMAS SiO_2 less improved the HEMT performances.

The source resistance (R_s) was defined as

$$R_s = R_c + R_r = \frac{R_{on} - R_{ch}}{2}, \qquad (1)$$

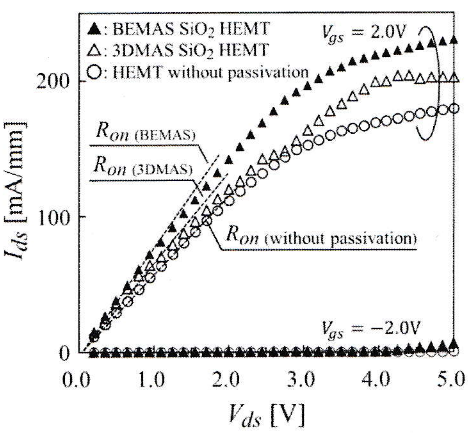

Figure 2. Measured *I-V* characteristics of the fabricated HEMTs.

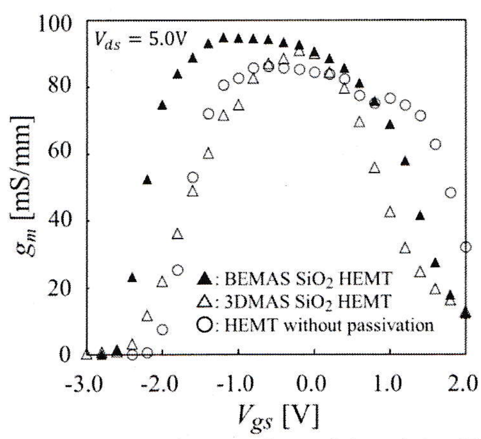

Figure 3. Measured transconductance characteristics of the fabricated HEMTs.

TABLE II. Transistor Performances and Resistance Parameters Analyzed for Fabricated HEMTs

	R_{on} [Ω·mm]	R_r [Ω·mm]	g_m [mS/mm]	g_{mi} [mS/mm]
BEMAS SiO_2 HEMT	13.0	1.6	95	137
3DMAS SiO_2 HEMT	13.8	2.0	90	133
w/o passivation HEMT	17.2	3.7	81	142

where R_c is the contact resistance, R_r is the channel resistance under the recess region and R_{ch} is the channel resistance under the gate electrode. The R_c was derived employing the transmission line method, and determined to be 1.6 Ω·mm. The R_{ch} was estimated with the sheet concentration (1.6×10^{12} cm^{-2}) and the mobility of electrons (7200 $cm^2/V \cdot s$) which were obtained by the van der Pauw method with Hall measurement devices on the HEMT wafer. Additionally, the intrinsic transconductance (g_{mi}) in the saturation region is given as

$$g_{mi} = \frac{g_m}{1 - R_s \cdot g_m}, \qquad (2)$$

where g_m is the measured transconductance [5]. The transistor performances and resistance parameters are summarized in Table 2. Surface passivation would affect neither R_{ch} nor R_c, and it does affect the channel resistance under the recess region, i.e. R_r. The R_r of BEMAS HEMT is less than half as compared to without passivation one. The reduction of R_r suggests an increase of the electron concentration in the channel under the recess region, which implies decreasing of electron potential at the recess surface.

IV. Summary

The AlGaAs/InGaAs HEMTs were successfully fabricated with plasma enhanced ALD-SiO_2 as passivation films employing BEMAS and 3DMAS. The performances were characterized comparing with transistor parameters. The BEMAS SiO_2 significantly reduced the resistance under the recess region passivated. It implies that dangling bonds of the AlGaAs surface are well terminated by BEMAS.

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