InGaP/GaAs HBT 적용을 위한 높은 절연강도의1000Å 실리콘 질화막 MIM capacitor 제작과 특성 분석

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Analysis of Properties and Fabrication of 1000Å silicon nitride MIM capacitor with High Breakdown Electric Field for InGaP/GaAs HBT Application

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Abstract

For InGaP/GaAs HBT applications, we have developed characterized MIM capacitors with thin 1000Å PECVD silicon nitride which were deposited with SiH_4/NH_3 gas mixing rate, working pressure, and RF power of PECVD at 300℃ and had the capacitance density of 600 pF/mm^2 with the breakdown electric fields of 3073 MV/cm. Three PECVD process parameters were designed to lower the refractive index and then lower the deposition rate of silicon nitride films for the high breakdown electric field. At the PECVD process condition of gas mixing rate (0.92), working pressure (1.3 Torr), RF power (53 W), the AFM Rms value of about 1000Å silicon nitride on the bottom metal was the lowest of 0.662 nmand breakdown electric fields were the highest of about 73 MV/cm.

Key Words : MIM capacitor, InGaP/GaAs HBT, Silicon Nitride, PECVD

1. Introduction

Silicon nitride thin films are used widely in GaAs-based compound semiconductor and plate panel display industry. The former applications include device passivation of metal-semiconductor field-effect transistors (MESFETs) [1], high-electron-mobility transistors (HEMTs) [2,3], and heterojunction bipolar transistors (HBTs) [4-6], dielectric layers for metal-insulator-metal (MIM) capacitors [7], and glassivation to prevent chips from mechanical damage during the large-volume assembly. Also, the latter application is the blocking layer of impurities diffused from glass substrate to active layer [8].

Because the MIM capacitors occupy a large fraction of the die area in power amplifier and other monolithic microwave integrated circuits (MMICs), the insulator thickness at MIM capacitors has to be reduced to increase the capacitance. However, it becomes more difficult to maintain the breakdown electric field and the reliability of the MIM capacitors, as the insulator thickness is reduced. These problems are because the effect of particles and other defects becomes more dominant.

In this study, MIM capacitors with 1000Å PECVD silicon nitride were manufactured by SiH_4/NH_3 gas mixing rate, working pressure, and RF power of PECVD process at 300℃. At MIM capacitors, the surface roughness of insulator layer which is 1000Å silicon nitride and is located on the bottom metal/1000Å silicon nitride is analyzed by Atomic Force Microscopy (ASM). Also, the refractive index of this silicon nitride is measured by ellipsometer, and the wet-etch rate was obtained by the wet-etch in Buffered Oxide Etching (6:1, BOE). We had the good MIM capacitor which their breakdown electric fields were very high (73 MV/cm) and could applied at mass production because of the good uniformity of the capacitance and the breakdown electric fields in 6 inch wafer.

2. Experimental

To improve the breakdown electric field and the capacitance of MIM capacitor using on the InGaP HBTs, silicon nitride was deposited at 300℃ on bottom metal/1000Å PECVD silicon nitride/n-type 6 inch GaAs substrate by PECVD whose process factors were SiH_4/NH_3 gas mixing rate, working pressure, and RF power, and its thickness was about 1000Å. The three PECVD process condition of insulator layer (silicon nitride layer) was summarized at table 1. The refractive index and the surface roughness of the silicon nitride thin films deposited by three conditions were respectively measured by ellipsometer and AFM, their wet-etch rate was obtained by the wet-etch in Buffered Oxide Etching (6:1, BOE).

Our MIM capacitors whose size is 100m × 100m are being used at the true InGaP HBT power amplifiers. The first silicon nitride whose thickness is about 1000Å was deposited to insulate between the bottom metal of MIM capacitors and the substrate which is 6 inch n-type GaAs wafer. After bottom metal site was developed by the first photolithography, the first seed metal used at Au plating was deposited by DC sputtering about Ti/Au (500Å/1500Å). Non-cyanide, sulfite-based gold plating solution was used in this study. At MIM capacitors, the bottom electrodes were made by the first Au plating, and then the

Table 1. PECVD process condition to deposit the silicon nitride thin films.

PECVD process condition		Condition A	Condition B	Condition C
PECVD process Parameters	Gas mixing rate	1.307	0.925	0.920
	Working pressure	2.7 Torr	2.7 Torr	1.3 Torr
	RF power	40 W	40 W	53 W
	Substrate Temperature	300 ℃		

insulator layers, the second silicon nitride thin films were deposited by PECVD whose conditions were three and were indicated at table 1. The thickness of these silicon nitride thin films was about 1000Å. The second seed metal was deposited by DC sputtering and Ti/TiW/Au (500Å/500Å /1000Å) after photolithography. The second Au plating was performed to make the top electrode pad and the air bridge at our MIM capacitors.

To analyze electrical and RF properties for our MIM capacitors, micro probe station (cascade 12000series) was interfaced with semiconductor parameter analyzer (Agilent 4156C), vector network analyzer (Agilent 8722ES) and impedance analyzer (Agilent 4284A) by which the breakdown electric field, the self resonance frequency and the capacitance of our MIM capacitors were respectively identified.

3. Results and Discussion

3.1. The properties of 1000silicon nitride on bottom metal/silicon nitride/n-type GaAs substrate

To investigate the physical and the optical properties of insulator layers (silicon nitride thin films) at MIM capacitor, 1000Å silicon nitride thin films were deposited on bottom metal/1000Å PECVD silicon nitride/n-type GaAs substrate by PECVD whose conditions are indicated at table 1. The properties of these insulator layers are show in table 2. Also, their deposition rates and thickness during PECVD process are recorded in table 2.

Table 2. The properties of silicon nitride on bottom metal/silicon nitride/n-type GaAs substrate.

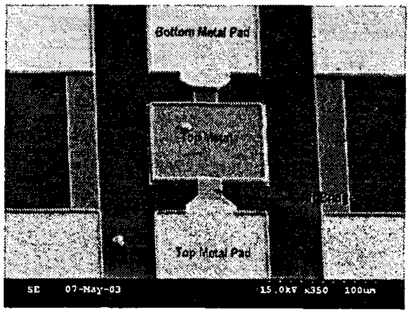
PECVD process condition		Condition A	Condition B	Condition C
Thin film features	Deposition rate	1.21nm/sec	1.23nm/sec	0.83nm/sec
	Thickness	995Å	1000Å	1010Å
Physical Properties	Refractive index	2.0	1.9	1.9
	Wet-etch rate	4.42nm/sec	8.96nm/sec	1.30nm/sec
	Rms	0.995nm	0.977nm	0.662nm
Electrical Properties	Breakdown electric field	3.2MV/cm	5.0MV/cm	73MV/cm
	Q factoor	209	168	105

The refractive index and Rms of condition B is smaller than these of condition A. We think that these changes are because of the increase of Si-H bonding as NH_3 gas increases. To decrease Rms value (to improve surface roughness) and increase the density of silicon nitride film, 1000Å silicon nitride was deposited by condition C whose SiH_4/NH_3 gas mixing rate is 0.920which is the similar rate of condition B and working pressure is lower and RF power is higher than condition B. The Rms and the wet-etch rate of condition C were lower than those of others. This implies that the density of silicon nitride films deposited at condition C was improved and also surface roughness was reduced. Figure 1 shows the surface images measured by AFM.

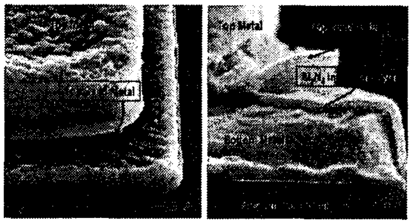
3.2. MIM capacitor at true HBT power amplifier

Our MIM capacitors were manufactured by the fab process, and their SEM (scanning electron microscopy) images are indicated at figure 2. Bottom and top electrodes consist of seed metal and plating metal, and 1000Å PECVD silicon nitride is located between bottom plating metal and top seed metal. Also, there is air-bridge which connects top metal and top metal pad.

Figure 3 shows the current-voltage curves of MIM capacitors fabricated by condition A, B, and C. These curves are to interpret the breakdown electric field of MIM capacitors at 100 nA leakage current. The breakdown voltages of condition A and B are respectively about 32 V and 50 V at 100 nA. The breakdown voltage and the incipient leakage current at condition B has higher than those at condition A. This means that MIM capacitor of condition B improves the breakdown electric field, but there is reliability problem because the incipient leakage current is very high, so that MIM capacitor is subjected to a continuous electrical stress that lead to a continuous leakage current and a resultant Joule heating which degrades MIM capacitors at biased voltage or current. MIM capacitors of condition C have very highest breakdown voltage and lowest leakage current at pre



(a) top view



(b) side view

Fig. 2. Scanning electron micrographs of MIM capacitors

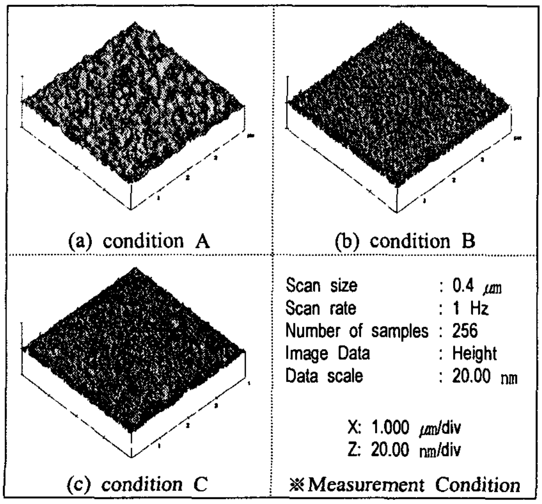


Fig. 1. The images of AFM analysis for the roughness of silicon nitride thin films.

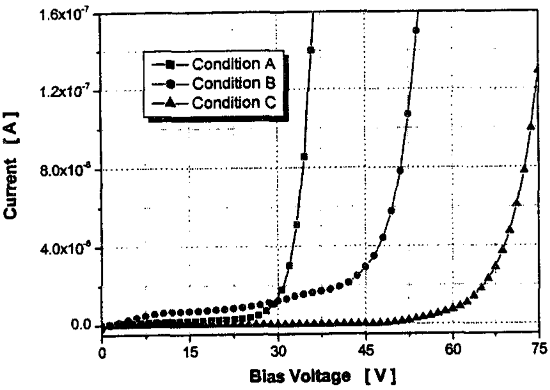


Fig. 3. The current-voltage curves of MIM capacitors fabricated by condition A, B, and C.

break down region than the others. Their breakdown electric field is about 7.0~7.5 MV/cm, for the silicon nitride thickness of condition C is about 1010Å and breakdown voltage is about 73 V. Table 2 summarizes the breakdown electric fields and Q factors which were measured at 2 GHz by vector network analyzer for all conditions.

Figure 4 shows the frequency characteristics of MIM capacitors for condition A, B, and C. The resonant frequencies are located from 6.2 GHz to7.2 GHz, and capacitances are about 6 × 10^{-12}F for all condition. Therefore we reveal that these capacitors can be applied to InGaP HBT at below 5 GHz.

4. Conclusion

At PECVD process of this study, to manufacture the MIM capacitor with the high breakdown electric field, the refractive index of silicon nitride was decreased by SiH_4/NH_3 gas mixing rate and then the density of silicon nitride was increased by working pressure and RF power. As the SiH_4/NH_3 gas mixing rate is decreased, the Rms values of silicon nitride thin films are decreased and the breakdown electric fields are improved at MIM capacitor. These imply that breakdown electric field depends on the surface morphology and the Si-H bonding of silicon nitride thin films. However, the incipient leakage current will be increased if work pressure and RF power be optimized at PECVD process, because the incipient leakage current at condition B is higher than one of condition A at our study.

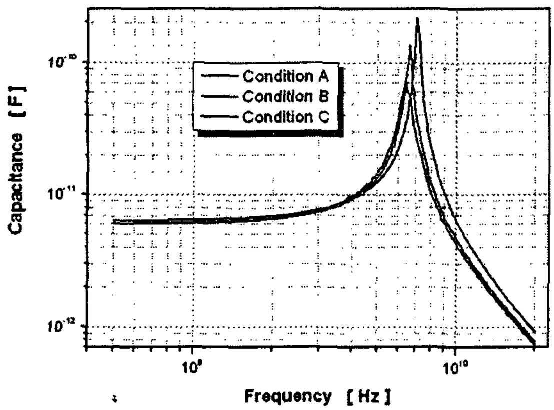


Fig. 4. The frequency characteristics of MIM capacitors for condition A, B, and C.

In this study, we fabricated the excellent MIM capacitors of 1000Å silicon nitride with high breakdown electric field for InGaP/GaAs HBT Applications. There breakdown electric field and capacitance had about 7.3 MV/cm and about 620.565 pF/mm^2 respectively. Also, these MIM capacitors are applying at the mass production of our company and property-yield is about 98%.

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