Highly C-Axis-Oriented AlN Film Using MOCVD for 5GHz-Band FBAR Filter

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***Abstract* -** We have successfully developed to deposit highly c-axis-oriented aluminum nitride (AlN) film using metal-organic-chemical-vapor deposition (MOCVD). Full-width at half-maximum (FWHM) of the deposited AlN(0002) film whose thickness was 1μm has found to be 2.98^o. The value of FWHM means the deposited film has the electromechanical coupling coefficient (K^2) of 6.4%. The conditions of deposition were substrate temperature of 1050^{o}C, pressure of 20Torr, and V-III ratio of 25000. Film-bulk-acoustic resonator (FBAR) band-pass filter for 5GHz orthogonal -frequency-division multiplexing (OFDM) wireless local area network (WLAN) system has been designed using the c-axis-oriented AlN film. The designed band-pass filter has the sufficient bandwidth of more than 100MHz, which is evaluated from Butterworth-Van Dyke (BVD) equivalent circuit model of FBAR.

I. INTRODUCTION

Recently, demands of higher data rate wireless local area network (WLAN) systems using orthogonal-frequency-division multiplexing (OFDM) communication system in 5GHz band are increasing. In order to implement equipments of 5GHz OFDM system, radio frequency (RF) band-pass filter is one of important devices. The requirements of the RF band-pass filter are wide bandwidth, low insertion loss, flat group-delay, small-size, easy fabrication and low fabrication cost. For example, center frequency of 5.2GHz and bandwidth of 100MHz are required for IEEE802.11a system in Japan.

For conventional wireless system such as cellular phone, surface-acoustic wave (SAW) filter was usually used for RF band-pass filter. However, it is difficult to fabricate interdigital transducers (IDTs) for 5GHz SAW filter. For example, using 128YX-$LiNbO_3$, line&space of the IDTs is less than 0.2μm because of SAW velocity of 128YX-$LiNbO_3$. Furthermore, insertion loss was increasing, because the propagation loss of SAW proportionally increases with square of increasing operation frequency.

RF band-pass filter based on film-bulk-acoustic resonator (FBAR) is fabricated simply. Since the propagation direction of acoustic wave is the direction of film thickness, the frequency can control by film thickness. The film thickness is possible to control less than 0.1μm, commonly.

Because the substrate of FBAR is silicon (Si), FBAR can make monolithic microwave integrated circuit (MMIC). FBAR has an economically attractive because it has advantages of small size, low cost by mass production and compatibility with semiconductor process. FBAR filter is suitable for 5GHz RF band-pass filter.

The commonly available thin film piezoelectric material for FBAR are aluminum nitride (AlN) and zinc oxide (ZnO). The temperature coefficient of frequency (TCF) of ZnO of –60ppm/^{o}C is more than twice that of AlN of –25ppm/^{o}C . In addition, since intrinsic quality factor Q of ZnO is less than that of AlN, AlN is suitable for application to RF filter at high frequencies [1].

In order to fabricate wideband FBAR filter, high Q-factor of FBAR is needed. Q-factor of FBAR is decided by K^2 of AlN film. K^2 [2] of AlN film depends on full-width at half-maximum (FWHM) of AlN(0002) film. Thus, c-axis-oriented AlN film is strongly required to fabricate the wideband FBAR filter. Conventional AlN film deposited using

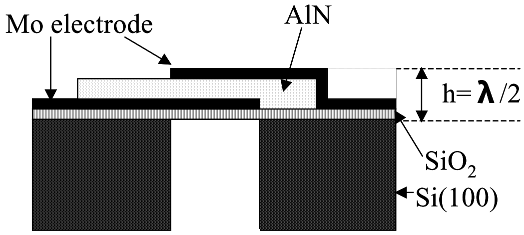


Figure 1 The structure of FBAR.

sputtering method has c-axis-oriented AlN with the thickness of more than 0.5μm.

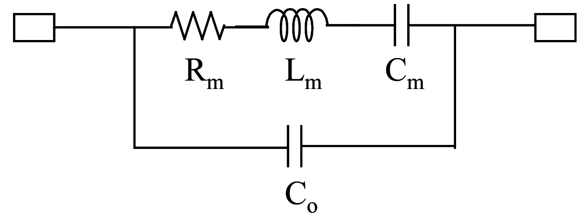
In this paper, we have successfully developed deposition procedure for highly c-axis-oriented AlN film using metal-organic-chemical-vapor deposition (MOCVD). The requirement of K^2 of AlN film was decided by the simulation using BVD equivalent circuit model.

II. MEMBRANE STRUCTURE OF FBAR

Figure 1 shows the membrane type structure of FBAR. FBAR consists of a piezoelectric layer of AlN sandwiched between two electrodes of molybdenum (Mo). The resonant area is released by etching a via through the silicon wafer. The film of SiO_2 is roles of stopper the etching. Resonance frequency (f_s) is $V_a/2d$. V_a and d mean acoustic velocity and thickness of film, respectively. Wavelength is related in thickness of film (h). The thickness of AlN film and the size of resonant area are fixed 1μm and 75x75μm^2 for 5GHz. Because the substrate temperature of MOCVD is above 1000^{o}C, Mo was accepted as electrode material. It has a high-melting point, a low-resistance and an economically attractive.

III. BVD EQUIVALENT CIRCUIT AND ADS SIMULATION

Figure 2 shows the Butterworth-Van Dyke (BVD) equivalent circuit [3]. The BVD equivalent circuit model is not considered the effects of electrode and SiO_2. R_m represents the resistance due to



$$R_m = \frac{\pi\eta\varepsilon_r\varepsilon_0}{8k_t^2\rho A\omega_a V_a} -(1) \quad L_m = \frac{\pi^3 V_a}{8\omega_r^3\varepsilon_r\varepsilon_0 A k_t^2} -(2)$$

$$C_m = \frac{8k_t^2\varepsilon_r\varepsilon_0 A\omega_r}{\pi^3 V_a} -(3) \quad C_0 = \varepsilon_0\frac{a}{d} ------(4)$$

$$k_t^2 = \frac{K^2}{1+K^2} ----(5)$$

$$\frac{2(\omega_a-\omega_r)}{\omega_r} = \frac{C_0}{C_m} = \frac{8k_t^2}{N^2\pi^2} -(6) \qquad f_S = \frac{V_a}{2d} -(7)$$

k_t^2	Electromechanical coupling constant	η	Viscousity
$\varepsilon_r\varepsilon_o$	Dielectric constant	A	Area of resonance
V_a	Phase velocity	ρ	Density of AlN
ω_r	Resonant frequency	N	Harmonic number
ω_a	Anti-resonant frequency	d	Thickness of film

Figure 2 The BVD equivalent circuit [3].

piezoelectric loss. L_m and C_m represent inductance and capacitance of resonance. C_0 represents the physical capacitance of the FBAR. Bandwidth of FBAR filter is decided by the difference between resonant frequency and anti-resonant frequency of FBAR. From Eq.(6) in Fig.2, the difference of resonant frequency and anti-resonant frequency is depending on K^2. Insertion loss of FBAR filter is decided by the R_m. R_m is in inverse proportion to the K^2 from Eq.(1) in Fig.2. Therefore, the increase of K^2 means the decrease of insertion loss and the increase bandwidth of FBAR filter.

Figure 3 shows the simulation results of frequency response of FBAR filter depending on K^2. Advanced design system (ADS) of Agilent Technology was used for simulation. 7th radder filter was assumed. Resonant areas and film thickness of FBAR were

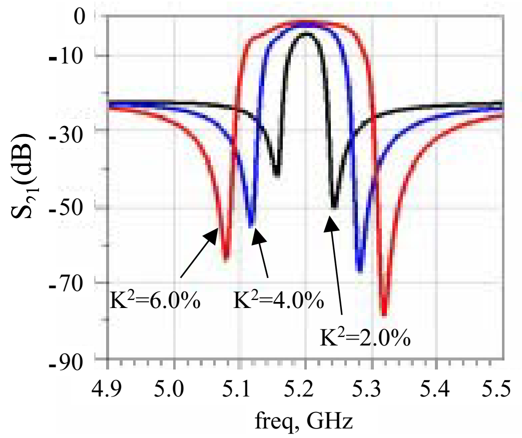


Figure 3 Band Pass Filter characteristic by ADS.

fixed to 75x75μm^2 and 1μm, respectively. The parameters of K^2 were 2.0, 4.0 and 6.0%. In the case of 6.0%, insertion loss and bandwidth are 1.5dB and 137MHz, which results satisfy the 5GHz RF band pass filter for WLAN system.

IV. GROWTH OF AlN FILMS

Interrelation between the full width at half maximum (FWHM) and K^2 were reported from Rajan S.Naik et al [4]. Due to the reported interrelation, the FWHM of AlN(0002) should be less than 4^o in order to obtain K^2 of more than 6%[4].

We have optimized the condition of AlN deposition from a viewpoint of substrate temperature.

AlN film was deposited on Mo/SiO_2/Si(100) using MOCVD. Before the deposition of AlN film, hydrogen (H_2) anneal was done. The conditions of H_2 anneal were fixed as substrate temperature of 1100 ^{o}C, pressure of 20torr. Annealing time was 20min. The conditions of AlN deposition were fixed as pressure of 20torr, ammonia (NH_3) gas of 3 slm, trimethylaluminum (TMA) bubbling of 10sccm, TMA-back-up H_2 gas of 100sccm. The V-III ratio was 25000. Substrate temperature for AlN deposition was changed. The values of substrate temperature were 800, 1000, 1050, 1100 and 1200 ^{o}C, respectively.

Figure 4 shows XRD patterns of AlN on

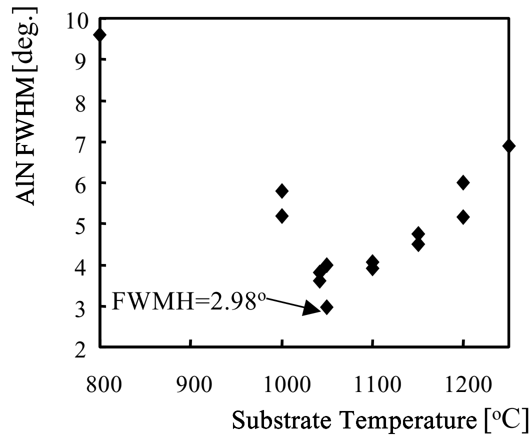


Figure 5 FWHM of (0002) AlN as a function of substrate temperature.

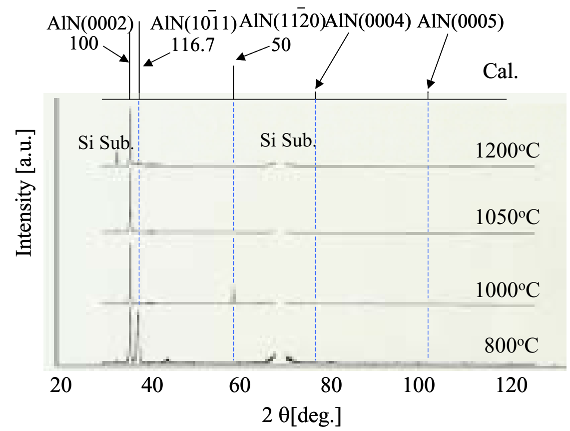


Figure 4 XRD patterns of AlN on Mo/SiO_2/Si.

Mo/SiO_2/Si. The source of X-ray was CuKα1. AlN(10$\bar{1}$1) and AlN(0002) were observed at 800 ^{o}C. AlN(10$\bar{1}$1), AlN(11$\bar{2}$0) and AlN(0002) were observed at 1000 ^{o}C. Only AlN(0002) was observed at 1050 ^{o}C.

Figure 5 shows FWHM of AlN(0002) as a function of substrate temperature. FWHM of AlN(0002) was 2.98 ^{o} at 1050 ^{o}C. This result means that K^2 of 6.4% can be obtained [4]. Figure 6 shows band-pass filter characteristic with ADS at 6.4% of K^2. Insertion loss and bandwidth are 1.4dB and 146MHz at 6.4%. The result of 2.98 ^{o} of FWHM is suitable to 5GHz OFDM band-pass filter by AlN film using MOCVD.

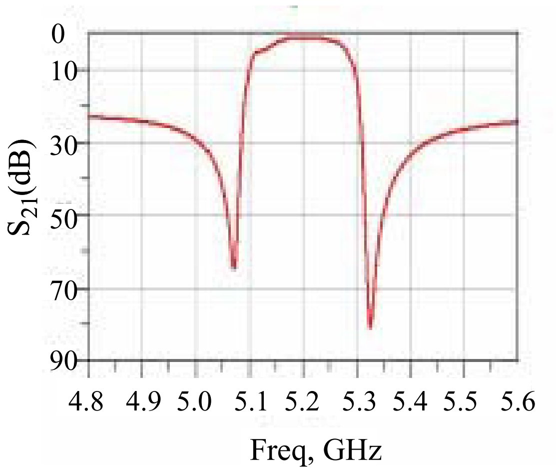


Figure 6 Band-pass filter characteristic with ADS at 6.4% of K^2.

V. CONCLUSION

We have developed a poly-crystalline c-axis oriented aluminum nitride (AlN) film on $Mo/SiO_2/Si(100)$ structure for film-bulk-acoustic resonator (FBAR) using metal-organic-chemical -vapor deposition (MOCVD).

The full-width at half-maximum (FWHM) of AlN(0002) was 2.98°. This film had 6.4% of electromechanical coupling constant (K^2). From advanced design system (ADS) simulation, the insertion loss and bandwidth are 1.4dB and 146MHz respectively at 6.4% of K^2. Then, the result is satisfied 5GHz orthogonal–frequency- division multiplexing (OFDM) radio-frequency (RF) band-pass filter. The result promises the success of the FBAR filter for the wireless local area network (WLAN) using the OFDM system in the 5GHz band, IEEE 802.11a.

ACKNOWLEDGMENT

This work was supported in part by the IT-program (RR2002) of MEXT, Japan.

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