Defense Technical Information Center
Compilation Part Notice

ADP013348

TITLE: Characteristics Analysis of SAW Filter Using Al[0.36]Ga[0.64]N Thin Film

DISTRIBUTION: Approved for public release, distribution unlimited

This paper is part of the following report:

TITLE: Materials Research Society Symposium Proceedings; Volume 720. Materials Issues for Tunable RF and Microwave Devices III Held in San Francisco, California on April 2-3, 2002

To order the complete compilation report, use: ADA410712

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, etc. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP013342 thru ADP013370

Mat. Res. Soc. Symp. Proc. Vol. 720 © 2002 Materials Research Society H3.1

Characteristics Analysis of Saw Filter Using $Al_{0.36}Ga_{0.64}N$ Thin Film

Sun-Ki Kim, Min-Jung Park, Cheol-Yeong Jang, Hyun-Chul Choi, Jung-Hee Lee, and Yong-Hyun Lee
School of Electronic Engineering & Computer Science, Kyungpook National University, 1370 Sankyuk-Dong, Buk-Gu, Daegu, Korea, e-mail : yhlee@ee.knu.ac.kr

ABSTRACT

$Al_xGa_{1-x}N$ sample with x=0.36 was epitaxially grown on sapphire by MOCVD. SAW velocity of 5420 m/s and TCF (temperature coefficient of frequency) of -51.20 ppm/℃ were measured from the SAW devices fabricated on the $Al_xGa_{1-x}N$ sample, when kh value was 0.078, at temperatures between –30 ℃ and 60 ℃. Electro-mechanical coupling coefficient was ranged from 1.26 % to 2.22 %. The fabricated SAW filter have shown a good device performance with insertion loss of -33.853 dB and side lobe attenuation of 20 dB.

INTRODUCTION

AlN, GaN, and their alloys are important piezoelectric Ⅲ-V semiconductors suitable for optoelectric devices as well as blue/green light emitters and surface acoustic wave (SAW) applications [1,2]. Especially AlN is a promising materials for SAW devices because its high SAW velocity which qualifies it for GHz-band applications. Devices working at 2 GHz have already been built [3]. The respective SAW velocities of GaN and AlN are 4800 m/s and 5700 m/s [4]. Theoretical SAW velocity of $Al_xGa_{1-x}N$ is therefore expected to be between these values by varying from x = 0 to x = 1, which indicates that the operating frequency of the SAW can be controllable by simply changing Al-mole fraction.

EXPERIMENTS

The $Al_xGa_{1-x}N$ with x=0.36 piezoelectric thin film was grown on sapphire substrate using MOCVD at 1035 ℃ with TMAl flow rate of 40 μmol/min, H_2/ NH_3 flow of 4/4 slpm, and growth pressure of 50 torr. Prior to the epitaxial $Al_xGa_{1-x}N$ growth, 180Å thick GaN initial buffer layer was grown at 550 ℃ with TMGa flow rate of 30 μmol/min. The surface morphology and crystallinity of the $Al_xGa_{1-x}N$ thin films were characterized using SEM (scanning electron microscopy) and X-ray rocking curve. To estimate the characteristic parameters, SAW filters with unapodized interdigital transduscer/$Al_xGa_{1-x}N$/sapphire structure were used.

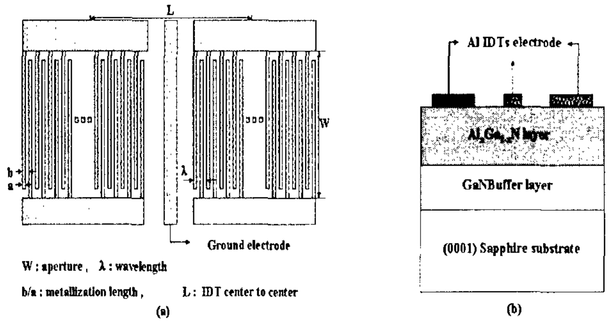


Figure 1. *(a) IDT pattern (b) schematic diagram of the cross-section of fabricated $Al_xGa_{1-x}N$ SAW filter.*

The electrode wavelength of the SAW filter was 20, 40, 60 ㎛. Al electrodes with thickness of 200 nm were evaporated. The patterning of the electrodes for the SAW IDT was performed by a conventional lift-off process. The respective schematic IDT pattern and the cross-section of the devices are shown in Figure 1 (a) and (b), respectively. The detailed specification is summarized Table Ⅰ. The frequency response of the SAW filters was measured using a HP 8753C network analyzer. SAW velocities were calculated by estimating center frequency from the measured S_{21}. Electromechanical coupling coefficient k^2 were also calculated from conductance from the measured S_{11} and the crossed-field equivalent model [5] as in equation (1) and (2).

$$k^2 = (1/8N^2f_c)(G_0/C_s) \quad (1)$$

$$k^2 = (\pi/4N)(G_0/B_0) \quad (2)$$

Here, N is IDT electrode finger pair number, and f_c is the center frequency. G_0, C_s and B_0 are the radiation conductance, capacitance and susceptance of center frequency response [3,6].

Table Ⅰ. SAW IDT pattern specifications.

Wavelength(λ)	20,40,60 ㎛
Aperture(W)	1800 ㎛
IDT finger pairs	160,82,54 pairs
IDT center to center spaces(L)	3650,4100,5000,6800 ㎛
Metallization ratio(a/b)	0.5

RESULTS AND DISCUSSIONS

Analysis of $Al_xGa_{1-x}N$ thin film

Smooth surface was of the $Al_{0.36}Ga_{0.64}N$ is evident in SEM image in Figure 2. A smooth morphology is important to reduce propagation loss of the SAW filter at high frequency. Figure 3 shows X-ray rocking curve of the film with full width at half maximum of 536.76 arcsec, which is reasonable value for $Al_xGa_{1-x}N$ with such a with Al mole fraction[7].

Characteristics of surface acoustic wave

Fabricated SAW filter has the input and output IDTs with 82 split-electrode finger-pairs with wavelength ranger of 20 ~ 60 ㎛. Figure 4 show frequency response of $Al_xGa_{1-x}N$ SAW filter with wavelength 60 ㎛. The center frequency is 90.336 MHz, bandwidth is 1.12MHz, and Q factor is 81.236. Insertion loss is –33.853 dB and side lobe attenuation is 22 dB. Figure 5 shows SAW velocity as a function of kh ($k = 2\pi/\lambda$, h is the thickness of $Al_xGa_{1-x}N$ thin film) value, which was calculated from center frequency. That was decreased from 5510 to 5100 m/s as kh was increased from 0.0628 to 0.167. This is because, as kh value increase, the wave, which travels along the surface of the $Al_xGa_{1-x}N$ thin film with slower velocity than that of the sapphire substrate, becomes dominant [3,4,8].

And Electro-mechanical coupling coefficient was ranged from 1.26 % to 2.22 %.

The temperature coefficient of frequency (TCF) of $Al_xGa_{1-x}N$ SAW filter was measured in the temperature range between –30 ℃ and 60 ℃. The measured TCF was –51.20 ppm/℃.

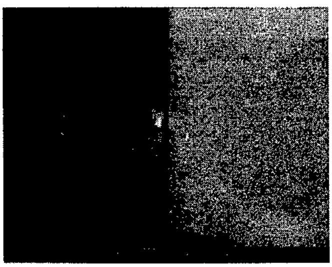


Figure 2. *$Al_xGa_{1-x}N$ thin film SEM image.*

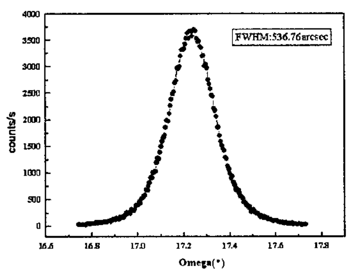
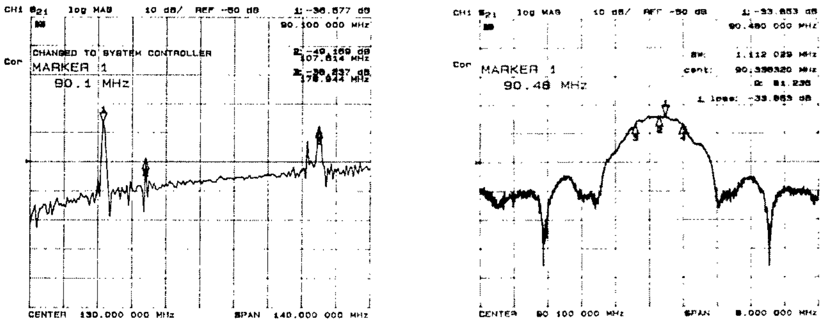


Figure 3. *X-ray rocking curve pattern of $Al_xGa_{1-x}N$ thin film.*



(a) (b)

Figure 4. *Frequency response characteristics of fabricated $Al_xGa_{1-x}N$ SAW filter with wavelength of 60 ㎛. (a)Wide frequency scan including fundamental and harmonic mode and (b) narrow frequency scan mode.*

Figure 6 shows insertion loss as function of input-to-output IDT space width.

The value of propagation velocity, k^2, and TCF for $Al_xGa_{1-x}N$ SAW filter were summarized in Table Ⅱ and they compared to those obtained from other SAW materials[9,10,11]. The propagation velocity and TCF of $Al_xGa_{1-x}N$ SAW filter have lower value than AlN SAW filter and higher value than undoped GaN SAW filter. It seems that the propagation velocity and TCF in $Al_xGa_{1-x}N$ SAW filter was able to be controlled by Al mole fraction [12].

CONCLUSION

MOCVD grown $Al_xGa_{1-x}N$ thin film were grow and investigated for the possible use in high frequency SAW application. Electro-mechanical coupling coefficient k^2 are

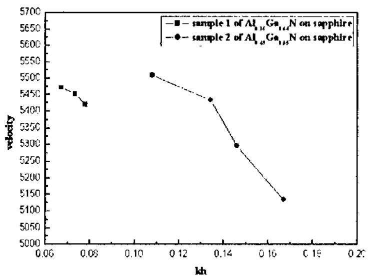


Figure 5. *SAW velocity as function of kh value.*

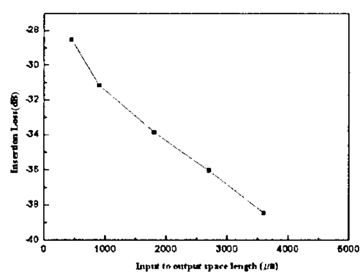


Figure 6. *Insertion loss as function of IDT space length.*

Table Ⅱ. Properties of piezoelectric substrates for SAW filter. All values were cited from [1,10,11,12].(* : measured value in this work)

subrate	Propagation Velocity (m/s)	K^2 (%)	TCF (ppm/°C)
Quartz (ST-X)	3158	0.14	0
$LiNbO_3$ (128º Y-X)	3992	5.3	-75
$LiNbO_3$ (Y-Z)	3488	4.5	-94
$LiTaO_3$ (X-112ºY)	3288	0.6	-18
AlN film	5750-5765	0.15 - 0.8	-55-63
ZnO film(c-axis)	2600	0.6 - 1.9	-25
Undoped GaN film	4900-5500*	0.2 - 4.7*	-60.8*
$Al_{0.36}Ga_{0.64}N$ film	5510-5100*	1.26 - 2.22*	-51.20*
Mg-doped GaN film	5806*	4.3*	-18.3*

from 1.26 % to 2.22 % with changing kh values. Due to its high SAW velocity (larger than 5000 m/s) and the low temperature coefficient of frequency (less than –60 ppm/℃), the SAW filters fabricated on the epitaxial $Al_xGa_{1-x}N$ thin film would have a strong potential for GHz band applications.

ACKNOWLEDGMENTS

This work was supported by grant No. 2000-2-30200-006-2 from the Basic Research Program of the Korea Science & Engineering Foundation.

REFERENCES

1. H. Okano, N. Tanaka, Y. Takahashi, T. Tamaka, K. Shibata, and S. Nakano, Appl. Phys. Lett. 64, 166-168 (1994).
2. M. AsifKhan, X. Hu, G. Sumin, J. Yang, R. Gaska, and M. S. Shur, IEEE Electron Device Letters, Vol. 21, No. 2, 63-65 (2000).
3. G. D. O'Clock and M. T. Morkoc, Appl. Phys. Lett., vol. 23, No. 2, 55-56 (1973).
4. C. Deger, E. Born, H. Angerer, O. Ambacher, M. Stutzmann, J. Hornsteiner, E. Riha, and G. Fischerauer, Appl. Phys. Lett., Vol. 72, No. 19, 2400-2402 (1998).
5. C. K. Campell, Surface Acoustic Wave Devices for Mobile and Wireless Communications. New York : Academic, (1998).
6. K. H. Choi, Jin Yong Kim, Hyeong Joon Kim, Hyung Kook Yang, and Jong Chul Park, IEEE Ultrasonics Symp., 353-356 (2000).
7. D. Brunner, H. Angerer, E. Bustarret, f. Freudenberg, R. Hopler, R. Dimitrov, O. Ambacher, and M. Stutzmann, J. Appl. Phys. 82(10), 15, November (1997).

8. I. S. Didenko, F. S. Hickernell, and N. F. Naumenko, IEEE Trans. Ultrason. Ferroelectr. Freq. Control 47, 179 (2000).
9. S. Tonami, A. Nishikata, and Y. Shimizu, Jpn. J. Appl., pt. 1, vol. 34, 2664-2667, May (1995).
10. T. Sato and H. Abe, IEEE Trans. Ultrason. Ferroelectr. Freq. Contr., vol. 45, Jan (1998).
11. J. G. Gualtieri, J. A. Kosinski, IEEE Trans. Ultrason. Ferroelectr. Freq. Contr., vol. 41, Jan (1994).
12. Suk-Hun Lee, Hwan-Hee Jeong, Sung-Bum Bae, Hyun-Chul Choi, Jung-Hee Lee, and Yong-Hyun Lee, IEEE Trans. Electron Devices, Vol. 48, 524-529 (2001).