Proceedings of Symposium on Ultrasonic Electronics, Vol. 36 (2015)
5-7 November, 2015

Enhancement of Effective Electromechanical Coupling Factor by Mass Loading in Layered SAW Device Structures

層構造 SAW デバイスの実効電気機械結合係数に及ぼす電極膜厚の影響

Gongbin Tang[1, 2†], Tao Han[1], Jing Chen[1], Tatsuya Omori[2], Akihiko Teshigahara[3], Takao Iwaki[3], and Ken-ya Hashimoto[2,1] ([1]Shanghai Jiao Tong University, [2]Chiba University, [3]DENSO CORPORATION)
唐供賓 [1,2†], 韩　韬 [1], 陳　景 [1], 勅使河原明彦 [3], 岩城隆雄 [3], 橋本研也 [2,1]
([1] 上海交通大学,[2] 千葉大学, [3] 株式会社デンソー)

1. Introduction

The effective electromechanical coupling factor K_e^2 is a key parameter to determine the realizable filter bandwidth. Recently, Scandium-doped AlN (ScAlN) films have drawn much attention due to the strong piezoelectricity[1-3)]. The authors reported that large SAW velocity V, small propagation attenuation, and large K_e^2 of about 6.1% are simultaneously achievable when the film is combined with a high velocity base substrate such as single crystal diamond (SCD) and 6H-SiC for the Sezawa mode even for operation in the 3 GHz range [2,3)].

In many cases, K_e^2 of the SAW is much lower than that of the bulk wave even when the same piezoelectric material is chosen. This is because the SAW field distribution does not match well to the electric field generated by the interdigital transducer (IDT), and thus K_e^2 can be sometimes enhanced when heavy electrodes are used and/or the IDT is inlaid in the layered substrate.

This effect is well known also for the bulk acoustic wave (BAW) devices[4)], and is widely used in practical device design.

This paper describes drastic enhancement of K_e^2 by mass loading in layered SAW device structures such as the Cu IDT/ScAlN film/Si substrate structure, and existence of this phenomenon is verified experimentally.

2. Simulation

SAW properties on the Cu electrode/$Sc_{0.43}Al_{0.57}N$ film/Si structure were analyzed by the software SYNCL[5)], which calculates the input admittance of the infinitely long IDT on the structure as a function of the driving frequency f. The $Sc_{0.43}Al_{0.57}N$ film thickness is set at 0.5 λ, where λ is the SAW wavelength. This thickness gives the maximum K_e^2 when the Cu electrode thickness h_{Cu} is zero.

----

† gongbin.tang@chiba-u.jp

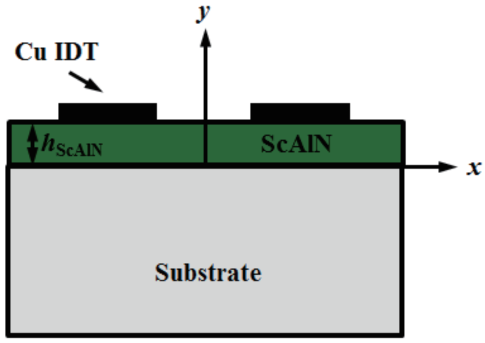

Fig.1. Model structure used for simulation

Fig. 2 shows effective SAW velocity V and K_e^2 as a function of h_{Cu}/λ. These values were estimated using the following formulas:

$$V = \lambda f_r \quad (1)$$

and

$$K_e^2 = (\pi f_r / 2 f_a) / \tan(\pi f_r / 2 f_a), \quad (2)$$

respectively, where f_r and f_a are the resonance and anti-resonance frequencies.

It is seen that V decreases monotonically with h_{Cu}/λ for the fundamental and second modes. On the other hand, K_e^2 for the Sezawa mode increases with h_{Cu}/λ, and takes a maximum value of 9.1% at h_{Cu}/λ~0.15, which is more than three times larger than the value when h_{Cu}/λ~0. In contrast, K_e^2 for the Rayleigh mode decreases with h_{Cu}/λ. This enhancement is caused by variation of the SAW field distribution to fit with the electric field excited by the IDT. Such K_e^2 enhancement also occurs in SAWs on semi-infinite piezoelectric substrates[6)]. But it is more prominent for the present case because only the limited region, i.e., piezoelectric film, is responsible for the wave excitation.

This phenomenon occurs in various layered SAW structures. More calculations can be found in Ref. 7.

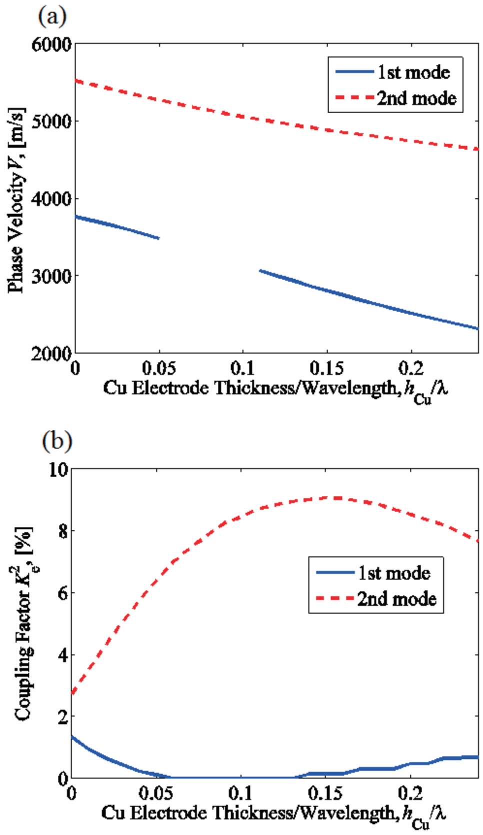

Fig.2. SAW properties on the ScAlN/Si structure when the mass loading is taken into account. (a) Variation of V with h_{Cu}/λ, (b) Variation of K_e^2 with h_{Cu}/λ

3. Experiment

For experimental verification of this phenomenon, a series of one port SAW devices were on the ScAlN film/Si substrate structure[8], and K_e^2 was evaluated using Eq. (2). The device parameters are given in Table I. The Sc content r estimated by the X-ray fluorescence spectrometry was circa 22%.

Table I. Design parameters

ScAlN thickness, h_{ScAlN}	1.6 μm
Wavelength, λ	2, 2.2, 2.4 μm
Finger width, *w*	0.5 μm
Aperture, W	40 μm
Numb. of IDT finger pairs	80
Numb. of Reflector fingers	80
Cu electrode thickness, h_{Cu}	20, 100, 200 nm

Fig. 3 shows variation of K_e^2 of the second mode with h_{Cu}. It is seen that K_e^2 increases monotonically with h_{Cu}, and K_e^2 is about 2% when h_{Cu}/λ~0.1. The value is about three times larger than that when h_{Cu}/λ~0.01. But the value is much smaller than that shown in Fig. 2(b). This is because of low r in the used ScAlN film. It results in not only reduction of the piezoelectricity but increase of the SAW velocity. Larger V tends to increase the Cu thickness giving maximum K_e^2. For example, the Cu thickness of 0.6 λ is necessary for the AlN/Si structure.

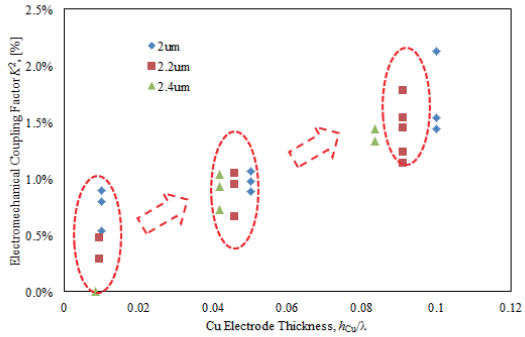

Fig.3. K^2 on the ScAlN/Si structure changing with h_{Cu}/λ

4. Conclusion

This paper describes drastic enhancement of K_e^2 by mass loading in layered SAW device structures.

It is quite interesting about the SAW characteristics on high Sc content Cu IDT/ScAlN film/Si substrate structure.

Acknowledgement The work was supported by the Natural Science Foundation of China (No.11174205, No.11474203, and No. 11404209) and the Ministry of Education of China (NCET-12-0357 and RFDP-20120073110021).

Reference

1. M.Akiyama, et al, Adv. Mater., **21**, 5 (2009) p. 593
2. K.Hashimoto, et al, Proc. IEEE Ultrason. Symp. (2012) p. 1926
3. K.Hashimoto, et al, IEEE Trans. Ultrason., Ferroelec., and Freq. Contr., **60**, 3 (2013) p. 637
4. K.M.Lakin, et al, Proc. IEEE Ultrason. Symp. (2001) p. 827.K.Hashimoto, et al, IEEE Trans. Ultrason., Ferroelec., and Freq. Contr., **56**, 11 (2009) p. 2559.
5. http://www.te.chiba-u.jp/~ken/freesoft.html
6. K.Hashimoto, "8. Simulation of SH-type SAW Devices," in *Surface Acoustic Wave Devices in Telecommunications* (Springer Verlag, Berlin, 2000) pp. 236-270.
7. G.B.Tan, et al, Proc. IEEE Freq. Contr. (2015) p.416
8. M.Sumisaka, et al, Jpn. J. App. Phys., **54** (2015) 07HD06