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Shear Mode Polarity Inverted ScAlN Multilayer for Application to BAW Transformer in Rectifying Antenna

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***Abstract*— Energy harvesting from surrounding environment is required for battery-less sensors. RF-DC conversion with a rectifying antenna (so-called rectenna) is generally used to obtain energy from ambient electromagnetic wave. However, RF-DC conversion efficiency of the diode significantly decreases for ambient electromagnetic wave due to their weak RF power. In this study, we report a new type of bulk acoustic wave (BAW) piezoelectric transformer based on c-axis zig-zag multilayers ScAlN film in order to amplify the RF signal in the rectenna. c-Axis approximately 45º-tilted film exhibit high $k'_{15}{}^2$ without undesired longitudinal wave excitation. The theoretical voltage gain was simulated by Mason's equivalent circuit model considering polarization inversions due to c-axis zig-zag structures. Voltage gain increase with k^2Q value (= FOM) increasing or the number of layers *n* in the output layer increasing. S parameters of a BAW piezoelectric transformer with c-axis zig-zag 4 layers ScAlN film are measured by a network analyzer. As a result, voltage gain approaching + 20 dB with the 4 layers BAW piezoelectric transformer is obtained. This new type of polarization inverted FBAR transformer is attractive for a voltage transformer in the rectenna.**

Keywords—ScAlN, BAW, transformer, rectenna

I. Introduction

Wireless sensors are increasingly placed in order to get a number of information for IoT. These sensors required to be activated without wired energy supply. In order to obtain energy from surrounding electromagnetic wave, RF-DC conversion with a rectifying antenna (called rectenna) is generally used. However, RF-DC conversion efficiency significantly decreases for weak RF signal because weak RF signal cannot activate the diode in the rectenna. Therefore, a Dickson charge pump [1] is generally used to increase the RF voltage in order to obtain high conversion efficiency for a weak signal. However, there are some problems such as low efficiency, poor impedance matching, and large size.

In this study, we introduce a new type of bulk acoustic wave (BAW) piezoelectric transformer for RF energy harvester which based on c-axis zig-zag multilayers ScAlN film in order to overcome this problem. As shown in Fig. 1, an RF input signal can be increased with increasing the number of output layers without inserting intermediate electrode. We demonstrated and characterized the transformer based on 4-layers of c-axis zig-zag polarization inverted ScAlN stack resonators operating around 500 MHz which is used for digital terrestrial television broadcasting (DTB) band. We theoretically predicted the performance of the transformer by using Mason's equivalent circuit model.

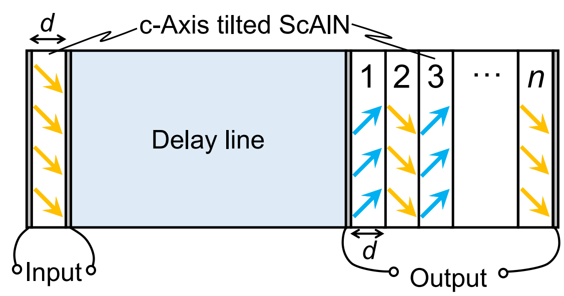

Fig. 1. BAW transformers based on c-axis zig-zag ScAlN stack.

II. Deposition method of c-axis zig-zag ScAlN multilayer

c-Axis tilted ScAlN films were grown on bottom electrode film /silica glass substrate by a glancing angle magnetron sputtering deposition [5]. In this experiment, as shown in Fig. 2, the substrate was set to be 60º from target surface to obtain c-axis approximately 50º-tilted film. ScAl metal alloy ($Sc_{43}Al_{57}$) was used as a target. After the growth of the first ScAlN film, the substrate was rotated by 180º and the following layers were grown. The *n*-layers c-axis zig-zag structure was obtained by repeating this process (*n*-1) times.

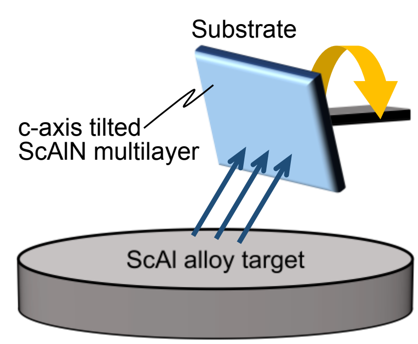

Fig. 2. Deposition method of c-axis zig-zag ScAlNmultilayers.

III. Charactarization

A. *Crystalline orientation of the c-axis zig-zag ScAlN film*

In order to obtain quantitative information of the film, X-ray diffraction analysis was conducted (X-Pert Pro MRD, Philips). Figure 6 shows the (0002) pole figure of 4-layers c-axis zig-zag ScAlN film. Two pole concentrations indicate X-ray diffraction from the odd layers (1,3 layer) and even layers (2,4 layer). Each of X-ray diffraction was observed at approximately ψ=45° as expected.

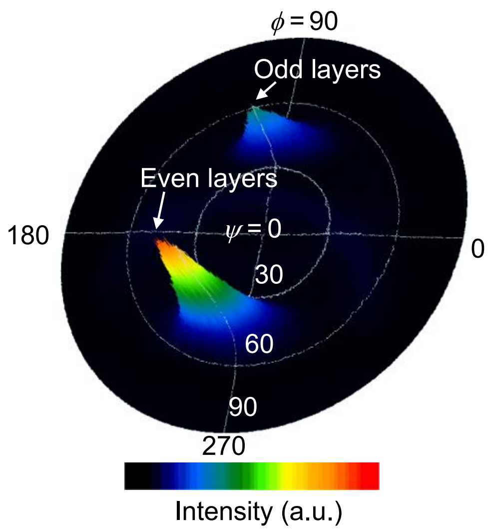

Fig. 3. (0002) pole figure of 4-layers ScAlN film stack.

B. *Electrical characterization*

S parameters of a BAW piezoelectric transformer with c-axis zig-zag 4 layers ScAlN film are measured by a network analyzer (E5071C, Agilent Technologies). As shown in Fig. 4, voltage gain calculated by experimental S parameter approached +20 dB in the 4 layers BAW piezoelectric transformer. The experimental voltage gain agrees well with the theoretical one which calculated by Mason's equivalent circuit model based on polarity inversion (c-axis zig-zag structure) as shown in Fig. 5.

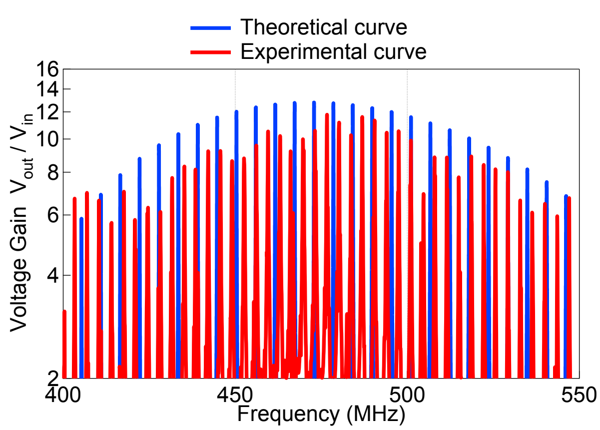

Fig. 4. Voltage gain of the 4 layers BAW transformer.

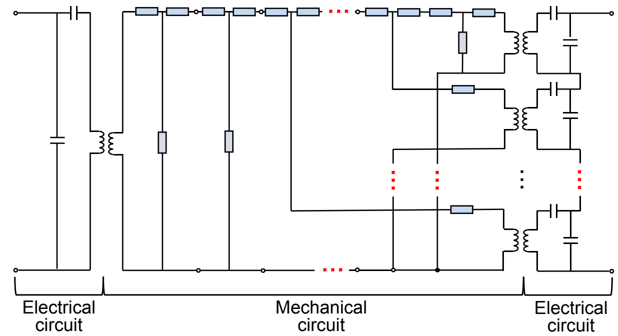

Fig. 5. Mason's equivalent circuit model based on polarity inverted.

IV. Conclusion

We have achieved +20 dB voltage amplification in the BAW piezoelectric transformer based on c-axis zig-zag 4-layers ScAlN film in the 500 MHz range. This new type of polarization inverted BAW transformer makes it possible to realize high voltage operation of the diode and impedance conversion in the rectenna.

Acknowledgment

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References

[1] T.-W. Yoo and K. Chang, "Theoretical and experimental development of 10 and 35 GHz rectennas," *IEEE Trans. Micro. Theory and Tech.*, vol. 40, pp.1259–1266, 1992.

[2] A. N. Parks, A. P. Sample, Y. Zhao and J. R. Smith, "A wireless sensing platform utilizing ambient RF energy," *in Proc. IEEE WiSNET*, no. 6486731, pp. 154–156, 2013.

[3] R. Karasawa and T. Yanagitani, "c-Axis zig-zag polarization inverted ScAlN multilayer for FBAR transformer rectifying antenna," *in Proc. IEEE Ultrason. Symp.*, no. 8091618, 2017.

[4] M. Akiyama, T. Kamohara, K. Kano, A. Teshigahara, Y. Takeushi and N. Kawahara, "Enhancement of piezoelectric response in scandium aluminum nitride alloy thin films prepared by dual reactive cosputtering," *Adv. Mater.*, vol. 21, no. 5, pp. 593–596, 2008.

[5] T. Yanagitani, K. Arakawa, K. Kano, T. Akihiko and M. Akiyama, "Giant shear mode electromechanical coupling coefficient k_{15} in c-axis tilted ScAlN films," *in Proc. IEEE Ultrason. Symp.*, pp. 2095–2098, 2010.

[6] K.-H. Sano, R. Karasawa and T. Yanagitani, "ScAlN thick film ultrasonic transducer in 40–80 MHz," *IEEE Trans. Ultrason., Ferroelectr., Freq. Control*, 2018.

[7] M. Suzuki and T. Yanagitani, "Quasi-shear mode electromechanical coupling k'_{15} and shear wave velocity in c-axis tilted $Sc_xAl_{1-x}N$ films," *IEEE Ultrason. Symp.*, 6G-5, pp.326–327, 2015. [Abstract]

[8] R. Karasawa and T. Yanagitani, "c-Axis zig-zag polarization inverted ScAlN multilayer for FBAR transformer rectifying antenna Shear mode polarity inverted ScAlN multilayer for application to transformer in rectifying antenna," *in Proc. IEEE Ultrason. Symp.,* no. 8580083, 2017.

[9] M. A Caro, S. Zhang, T. Riekkinen, M. Ylilammi, M. A Moram, O. Lopez-Acevedo, J. Molarius and T. Laurila1, "Piezoelectric coefficients and spontaneous polarization of ScAlN," *J. Phys.: Condens. Matter*, vol. 27, pp. 245901, 2015.

[10] M. Moreira, J. Bjurström, I. Katardjev, V. Yantchev, "Aluminum scandium nitride thin-film bulk acoustic resonators for wide band applications," *Vacuum*, vol. 86, no. 1, pp. 23-26, 2011.