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DISTRIBUTION OF LAMB WAVES IN AlScN RESONATOR STRUCTURES

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Abstract. In this paper we present the results of a simulated model of resonator device comprised of AlScN/6H-SiC piezo-layers for use in RF electronic circuits. The device uses the piezoelectric effect and Al electrode gratings to generate Lamb waves with great frequencies. The small mechanical impedance, micrometric size and good electromechanical characteristics make it especially suited for the manufacturing of RF band-pass filters. Moreover, because of the mechanics of the Lamb Wave Resonator (LWR) device, it can allow for multiple resonant frequencies to be used with the same configuration. Here we show the basic characteristics of one such system using $Al_{0,91}Sc_{0,09}N$ piezo-active layer and base layer from hexagonal SiC.

Keywords: AlScN; Lamb wave; Lamb Wave Resonator (LWR); 6H-SiC, resonant frquency

Introduction

In recent years, the need for temperature stable, low noise and low power micro resonator devices, integratable in single RF chip has grown. Among the various MEMS devices used for band pass filters and synchronizing resonators, great promise show precisely the LWR resonators. Enhancing parameters such as Q-factor and electromechanical coupling coefficient k^2 are currently researched (Zou, 2014).

In this paper the results and discussion on Finite Element Analysis (FEA) of LWR resonator using AlScN piezo-active layer will be presented. Former studies (Mayrhofer et al,, 2015; Barth et al., 2014) demonstrate an increase of piezoelectric constants of the crystal with an increase in Scandium (Sc) concentration. Moreira et al. (2011) using AlScN in a Film Bulk Acoustic Resonator (FBAR), reaches better RF parameters, increased Figure of Merit (FOM) and coupling coefficient κ^2, despite a small decrease in the Q-factor. Even more, he shows that controlling the concentration of Sc, adjustment of the resonant frequency band can be achieved.

The data for the elasticity coefficients, electromechanical and temperature parameters are taken from (Mayrhofer et al., 2015; Barth et al. 2014; Moreira et al., 2011). The FEA simulations were generated with COMSOL Multiphysics platform.

General parameters

Overview

Acoustic devices based on piezo crystals are being used for different applications (mostly in filters, synchronizers, sensors etc.). The acoustic waves could be divided in three general groups depending on their propagation in a given media: surface waves, bulk waves and plate acoustic waves. The LWR resonators use Rayleigh-Lamb waves, propagating in a perpendicular direction in the thin layer. Important condition for the excitement of such waves, is the thickness of the resonating thin layer to be close to the wavelength (λ). Different modes exhibit different phase velocities, determined by the parameters of the used material, as well as of their size, geometry and structure. By using this information, it is possible to improve the manufacture error margins when producing such devices, greatly improving the selection for specific operational frequencies.

Some of the piezo materials mostly used in the industry are: quartz (SiO_2), gallium arsenide (GaAs), silicon carbide (SiC), lithium tantalate ($LiTaO_3$), lithium tantalate ($LiNbO_3$), langasite ($La_3Ga_5SiO_{14}$), aluminum nitride (AlN), ZnO, PZT, PVDF (the last on is a polymer). From the displayed materials, AlN exhibits the best balance between electromechanically coupling (κ^2), small acoustic impedance, high acoustic velocity, good heat conductivity, significant elastic modulus and compatibility with the modern CMOS technologies.

An increase of piezoelectric constants of the AlN crystal is observed with an increase in Scandium (Sc) concentration when it is incorporated in it. The resonant modes in monolithic AlScN demonstrate greater phase velocities, but in turn suffer from lower Q-factors and are strongly influenced by temperature variations compared to the quartz based oscillators. One way to counteract this is to grow the AlScN over Si or $SiO_{2,}$ which helps, respectively, to increase the Q-factor or for temperature stability. Another very promising substrate, used in the modern micromachining technologies is the SiC, showing an increased acoustic speed.

The device under study is comprised of 6H-SiC base layer, $Al_{0,91}Sc_{0,09}N$ active piezo layer, Interdigital (IDT) electrodes and two support structures, suspending the whole resonator in air. We choose here the hexagonal polytype 6H-SiC because of its lattice coherence with AlN and thus AlScN (Lin et al., 2010; Karmann et al., 1989).

The IDT electrode material Al is chosen as such due to its low density, low electrical resistance, as well as its compatibility with the popular micromachining technologies. In order to excite a proper Lamb wave, the spacing between the electrodes is equal to quarter of a wavelength (λ/4).

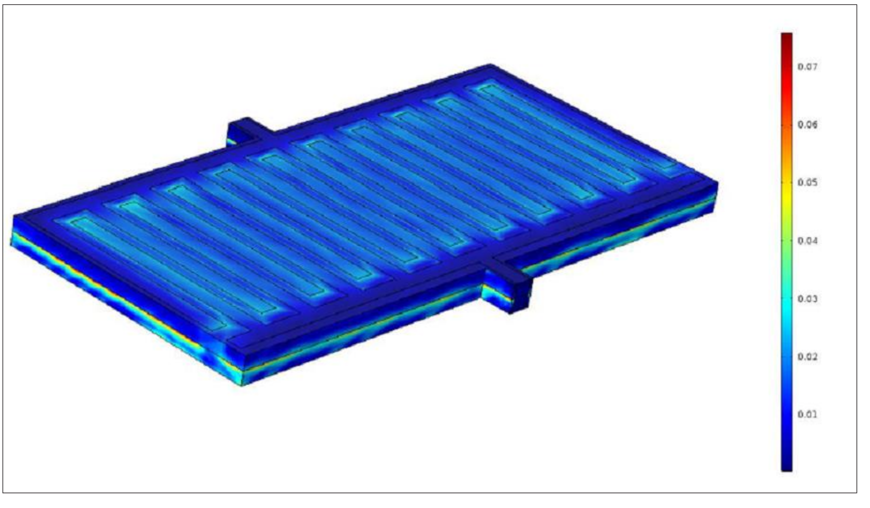

Figure 1. General view of a Lamb Wave Resonator (LWR), the scale presents the mechanical stress distribution (N/m^2)

Device structure

The dimensions of the different parts of the simulated device (Fig.1) are as follows: 6H-SiC thickness – 2.5 µm; $Al_{0,91}Sc_{0,09}N$ thickness - vary between 0.2 and 10 µm for the purposes of the analysis; Al electrode thickness - 0.15 µm; Al electrode width – 2.5 µm; Al electrode spacing – 2.5 µm.

Resonant modes structure

We can divide the modes in two groups, symmetric (S) an asymmetric (A), depending on the direction of wave propagation and the wave's polarization in space. The number of Lamb waves that could be excited in a given film depends mostly on the electro-mechanical factor and the relation of the film thickness to the wave's wavelength.

The higher modes demonstrate greater phase velocity, as well as steeper dispersion, which make them naturally very sensitive towards the thickness of the film and thus harder to manufacture. Hence weak dispersion modes as A_0, S_0, A_1, A_2 are preferred due to their low sensitivity to the film's thickness.

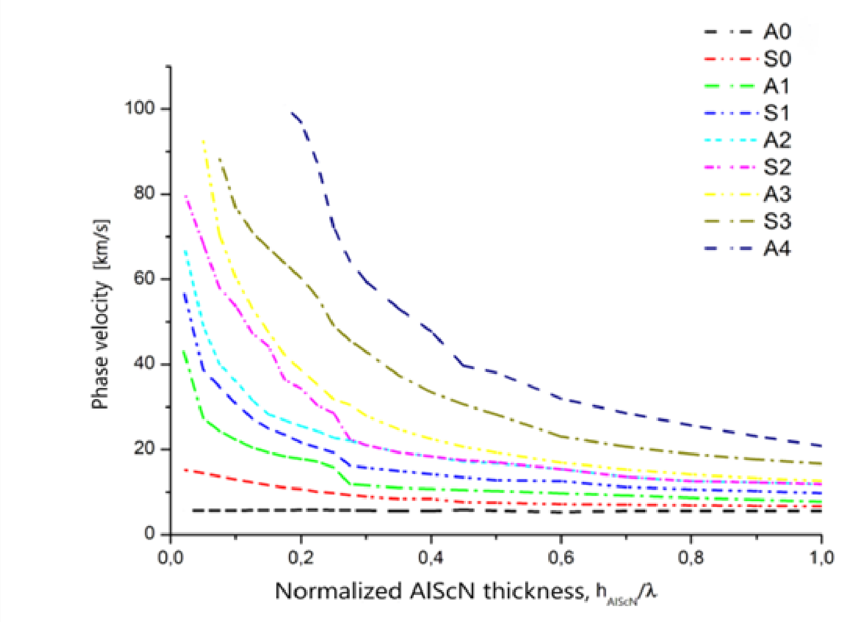

Figure 2. Dispersion of the first 9 resonant modes in thin AlScN film

Phase velocity

We see the first nine modes of the Lamb waves in between frequencies of 0.6 to 10 GHz on Fig. 2. The wave length here is 10 µm. We observe that higher modes demonstrate greater speeds as well as steeper dispersion.

Coupling coefficient

As we see from Fig. 3 the higher modes exhibit very low effective coupling factors, the biggest ones are these of S_0 and A_1 around 2.5%. It is shown (Hashimoto, 2009) that those numbers can be additionally increased by adding a grounded metal layer on the interface between the two piezo layers.

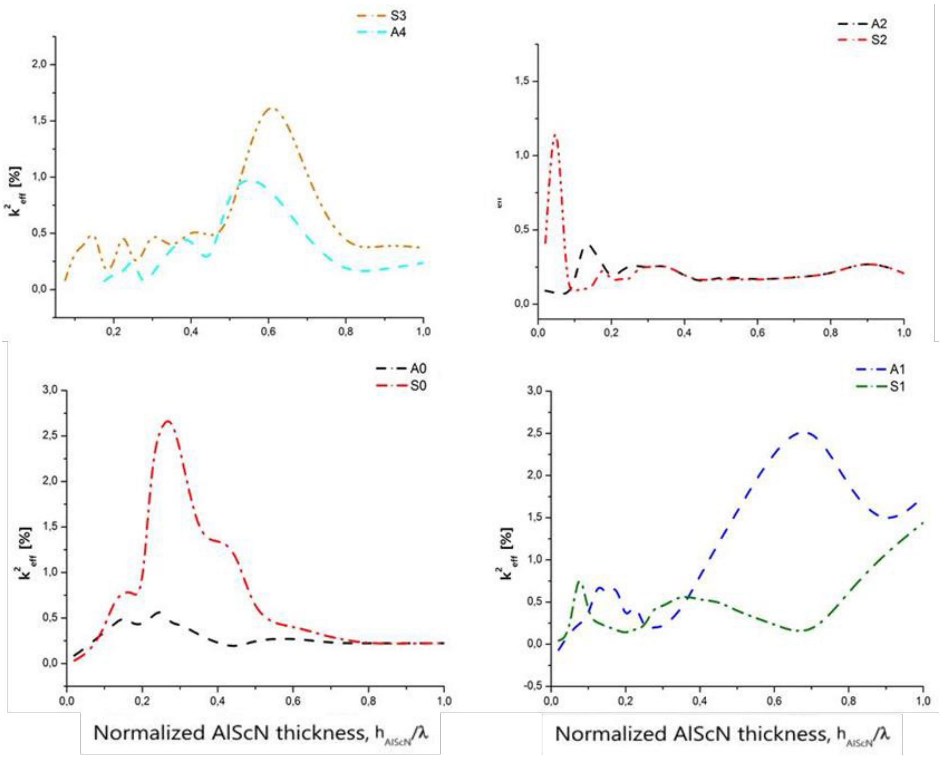

Figure 3. Coupling coefficient as a function of the layer's normalized thickness

Figure of Merit (FOM)

AlScN demonstrates enhanced piezoelectric properties in comparison with AlN. However, it is also a softer material, which is not surprising due to most piezoelectrics being soft materials. This leads to decrease in Q-factor, but increase in the electromechanical constant k^2. When constructing oscillators and filters, often the so called Figure of merit (FOM=κ^2.Q) is used to determine the effectiveness of the device in terms of noise and input losses.

The FOM dispersion becomes less pronounced with every following mode (Figs. 4 and 5). The most significant of them is the S_0 mode around 930 MHz. A_1 and S_1, too possess relatively good FOM factors for respectively 2100 and 3500 MHz, which makes them especially applicable for the 4G and LTE networks.

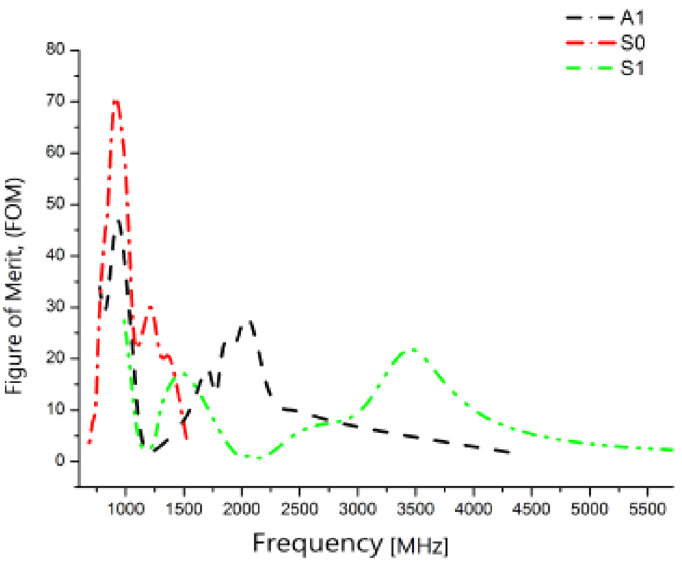

Figure 4. FOM spectrogram of S0, S1 and A1 modes

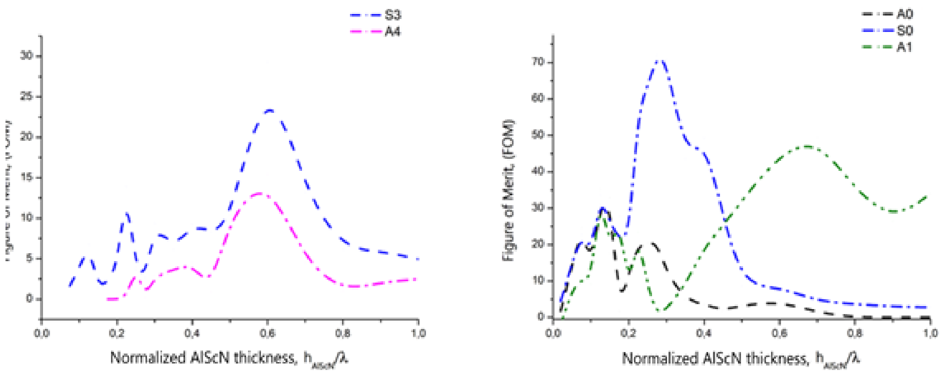

Figure 5. Dispersions of modes with significant FOM

Finally, the simulated frequencies and distribution of the main resonant modes presented in cross-section of the structure SiC/AlScN where d_{AlScN}= 2.5µm and d_{6H-SiC}= 2.5µm are shown in Fig. 6.

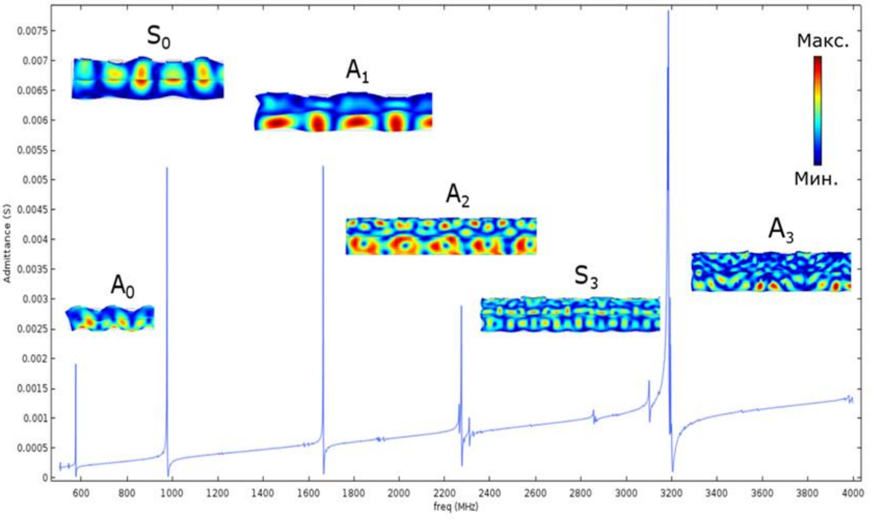

Figure 6. Spectrogram with depicted main resonant modes

Conclusion

Analyzing the simulation results we observe that the phase velocities of the first few modes A_0 to A_3 have a relatively weak dispersion which makes them suitable for manufacturing purposes. This is due to the fact that there exists a certain tolerance for the deposition thickness and small errors in the layer thickness could easily translate into changed resonant range. Thus by decreasing the steepness of the dispersion, the yield may be increased. As it is expected the lower modes demonstrate better resonant characteristics (especially S_1 and A_1), making them especially suitable for filter applications where low losses are preferred.

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