A Piezoelectric Bulk Acoustic Wave Transformer-Filter

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Abstract

A piezoelectric transformer is presented comprising a transducer for generating longitudinal elastic wave and a periodic stack of piezoelectric layers with alternating direction of polarization, the thickness D of the layers of the stack close to half the wavelength λ of the longitudinal acoustic standing wave generated by said transducer.

Motivation

The devices increasing voltage received by antenna to the level necessary for switching of “wake-up” devices are now demanded. Such devices must satisfy a few criteria:
- The device must operate directly at used radio frequency, say in 434MHz or in 868MHz ISM band;
- filtering functionality integrated with voltage transformation is an advantage
- Low loss of the order of 1 dB is a must
- Small size is demanded

Such device can be referred to as piezoelectric bulk acoustic wave “filter-transformer” or “transformer-filter”

Device description

Rosen type piezoelectric transformer [1], Fig.1, is known based on elongated piezoelectric platelet with different polarization in its parts. For RF frequency (for example 434 MHz ISM band) the platelet would be too thin and polarization in two perpendicular directions hardly possible. We present here a piezoelectric bulk acoustic wave (BAW) voltage transformer, with high conversion efficiency at high frequencies, where the electrical impedance is scaled up with the number of the alternating piezoelectric layers connected to the output electrical port. The piezoelectric transformer employs longitudinal BAW, such that the wavelength in area of the multilayered stack, is about twice its thickness D of each layer, Fig.2.

The piezo-layers have alternating polarization in layers. The standing wave excited by the transducer B in Bragg frequency range has the wavelength exactly equal to 2D and the electric fields generated in layers due to piezo-effect are all directed in one direction. That allows accumulation of voltage on the output electrode 17 proportional to the number of layers. As a piezoelectric material thin films of ZnO or AlN used in well-established FBAR technology can be used for RF devices operating at f > 400MHz frequency. For lower frequencies piezoceramic can be used. The interfaces between layers can be metallized, but it is not demanded for operation of device.

The exciting transducer has two electrodes serving an input port of device 9, 10. The thickness of transducer comparable with D must be optimized.

The transformer described here represents a specific extension of the use of multiple alternating piezoelectric layers with opposed polarizations or c-axis orientations as by the teachings in patent [2] by R. Aigner et. al., wherein this structure is used as efficient transducer for overtone frequency.

Device geometry

![Fig.2 Device, schematically](image)

In this example the transducer consist of a 0.8μm thick c-textured aluminum nitride layer 6, sandwiched in between two 0.1μm thick aluminum electrodes 2, 3.

Electrode 3 is a common grounded electrode for the transformer, while input RF electric potential is applied on electrode 2. The piezo stack 7 consists of 10 alternating c-textured 1μm thick AlN layers 8 with a 0.1μm thick aluminum electrode 4, forming the output "high voltage” electrical contact. The frequency of synchronism is about f=5.56GHz. The frequency can be scaled according: f=D/const.

COMSOL Simulation

In Fig. 3 the vibration pattern at synchronism is shown as simulated for the structure in Fig. 2. The longitudinal BAW displacement is shown in colors representing thickness compression and thickness extension, respectively.

The frequency response, for 100μm x 100μm surface area and thickness dimensions as discussed above. The calculations are made presuming acoustic losses corresponding to a materials quality factors Q of about 2000. In Fig. 5 the scattering S21 coefficient as function of frequency is shown in dB format representing the insertion loss of the device connected to 5 Ohm and 500 Ohm source and load real impedances. The 25 Ohm source is connected to the input contact 9 and the common ground contact 10 (Fig.2) , while 5000 Ohm load is connected to "high voltage” output contact 11 and the common ground contact 10.

The square root of the ratio of the environmental resistors determines (neglecting the losses) the output-to-input voltage ratio, which in this case is sqrt(5000/25)=14.

Conclusions

Using a stack of piezoelectric layers with periodically flipping polarization allows “rectifying” the direction of electric field generated by standing acoustic wave with the wavelength equal to 2D. The difference of potentials is accumulated in this way proportionally to the number of layers in the stock.

The device can be used for "wake-up" devices getting energy from the signal received by antenna.

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REFERENCES