The Piezoelectric Effect of the Surface Acoustic Waves Methods

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ABSTRACT: *The changes in the piezoelectric layers caused by the use of a few chemicals are studied in this paper. The piezoelectric effect of the surface acoustic waves methods is extensively studied. The MEMS microgenerator is addressed which use the dynamic mode. The relation between the piezoelectric voltage and mechanical vibration frequency is also studied.*

Keywords: MEMS, EHD, Piezoelectric Effect, PZT, ZnO, Microgenerator

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1. Introduction

Nowadays, it has been paid serious attention on developing of systems, using the resources, taken from renewable energy sources, such as sun, wind, vibrations, temperature differences etc [1]. Such primary resource can be stress/pressure, vibration or more generally called mechanical stress [2, 3]. By the choice of appropriated material, which has piezoelectric properties, that mechanical stress can be used for generating of electrical energy [4]. It is possible because of the properties of piezoelectric materials in which a piezoelectric effect is observed. In some materials this effect is so called “forward piezoeffect” - generating electric energy by the applied mechanical pressure, or the “reverse piezoeffect” – when applying voltage to them, they are mechanically deformed. These properties of piezoelectric materials are used generally in system as small-output supply sources.

Nowadays, some of the most frequently investigated energy harvesting devices (EHD) are the piezoelectric microgenerators. Values of 244 µW for the output power have been reported [5]. The piezoelectric microgenerators usually work in so called dynamic mode - periodical mechanical load with different frequency and amplitude and they generate AC piezovoltage. Therefore, this is the reason to make investigations of the layers in dynamic mode by taking into account the dependence of output voltage, according to the frequency of mechanical vibrations.

Lead zirconate titanate (PZT) and zinc oxide (ZnO) films are the most frequently used materials for implementation in such types of devices, because of their relatively high piezoelectric coefficients. There are many reports, concerning different approaches for deposition of such layers [6, 7, 8]. It seems that the sputtering technique is the most favorable, regarding crystalline structure, chemical composition and thickness control.

In this paper, two of the most widely used piezoelectric materials, PZT and ZnO, are investigated. At the MEMS piezoelectric microgenerators, these materials have to be in form of thin films, with thickness about several hundreds of nanometers. For the investigation of the films a Surface Acoustic Wave (SAW) structure is used, by using of which, the piezoelectric effects, both in the two materials, can be easily registered.

2. Experimental Section

For the experiment, thin PZT and ZnO layers were deposited, with thickness of around ~ x.100 nm. A sputtering target ($Pb(Zr_{0.52}Ti_{0.48})O_3$), purchased from "Semiconductor Wafer, Inc." and "Goodfellow", with 75 mm in diameter, and thickness of 3 mm was used. The layers deposition was done in vacuum chamber A400 VL at the following parameters:

working vacuum level of 10^{-5} Torr, sputtering inert gas – Ar_2 with partial pressure of 2.10-2 Torr, plasma voltage and current, respectively U_{plsm} = 0.75 kV and Iplsm = 150 mA, plasma power P_{plsm} = 112 W, deposition time of 1 hour.

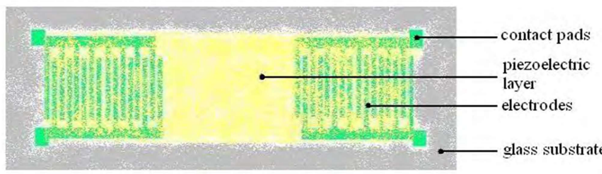

Figure 1. Top view of SAW structure

The structure includes two pairs comb electrodes, which are input and output transducers respectively. They are prepared by chrome layer, deposited on glass substrate and patterned by photolithography. The dimensions are shown in fig 2. The both samples (PZT and ZnO) are with the same construction and dimensions.

For better elasticity, a flexible organic substrate of polyethylenetherephtalate (PET) is used, by which the maximal allowable temperature of the technological processes must not exceed 70^0C, to avoid thermal deformation. In fig. 2, a simplified technological sequence and the cross-section view of the microgenerator is shown. For the top and bottom electrodes Al layers, with thickness of 200 nm, are used, deposited by thermal evaporation in vacuum.

The bottom electrode is deposited on the whole surface of the substrate, and the top electrode is evaporated through shadow mask, by using of lift-off process. In this way, the photolithography process is avoided for the top layer. In fig. 3, the dimensions of the structure are shown. To investigate the influence of the electrodes areas on the output voltage, five top electrodes are deposited at the same conditions, having the same dimensions and at a distance of 3 mm from each other. In this way, the area of the electrodes is increased from 18 mm^2 (1 electrode) to 90 mm^2 (5 electrodes), one by one.

Figure 2. Technological sequence of microgenerator

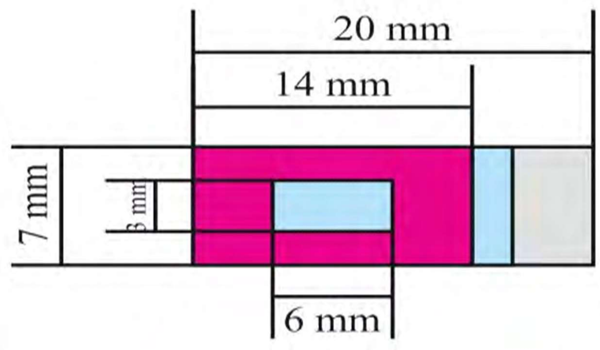

Figure 3. Topology's dimension

In the construction proposed, a piezoelectric material PZT, with a thickness of about ~150 nm and piezoelectric coefficient d_{33}=360 pC/N is used, deposited for 1 hour at the same parameters of the process. By this approach, a bigger amplitude of the output voltage, in dynamic mode, in comparison with the ZnO (d_{33} = 12.4 pC/N), is provided. The electrical connections, between the contact pads and the testing equipment, are wire bonded by using of silver paste.

3. Measurements and Results

For detection of the forward and reverse piezoelectric effect from one structure, the method of SAW is used [9]. The test of the piezomaterials is performed by using of the following experimental disposition, shown in figure 4, which consists of two groups of comb electrodes - for input and output transducers, and layer of piezoelectric material, deposited on them.

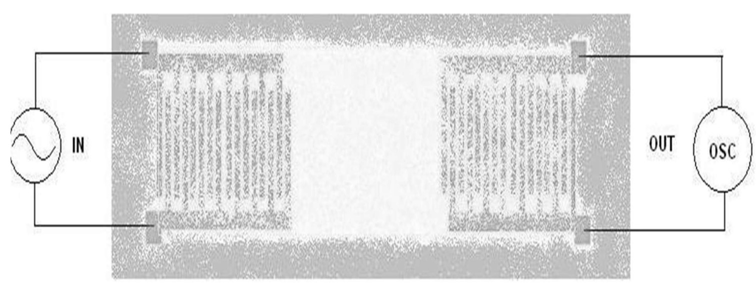

Figure 4. Schematic of the stup for SAW test

The aim is, by making of the input transducer to vibrate, a mechanical wave in the piezomaterial to be generated. The vibration is excited by sinusoidal signal, obtained from functional generator (MPF3060, 60MHz) at certain frequencies. When a mechanical wave is generated, it is spread into the whole piezoelectric layer, deposited on the electrodes and the area between them. The wave induces a voltage between the electrodes, when it reaches the output transducer. In figure 5, the curves of ZnO and PZT reactions are shown.

By dual channel oscilloscope (DQ2041CN, 40MHz), the signals of the structure's input and output are observed simultaneously.

Because of the low elasticity of the glass substrate we cannot estimate the electromechanical coupling coefficients in this way. This is the reason, the mechanical waves, induced by the input transdicer to be restricted in their magnitude. As a consequence, the amplitude of the output voltage is also limited.

For testing of the piezoelectric microgenerator in dynamic mode, the setup, presented in fig. 6, was used. As a mechanical wave source an electromagnetic shaker was used.

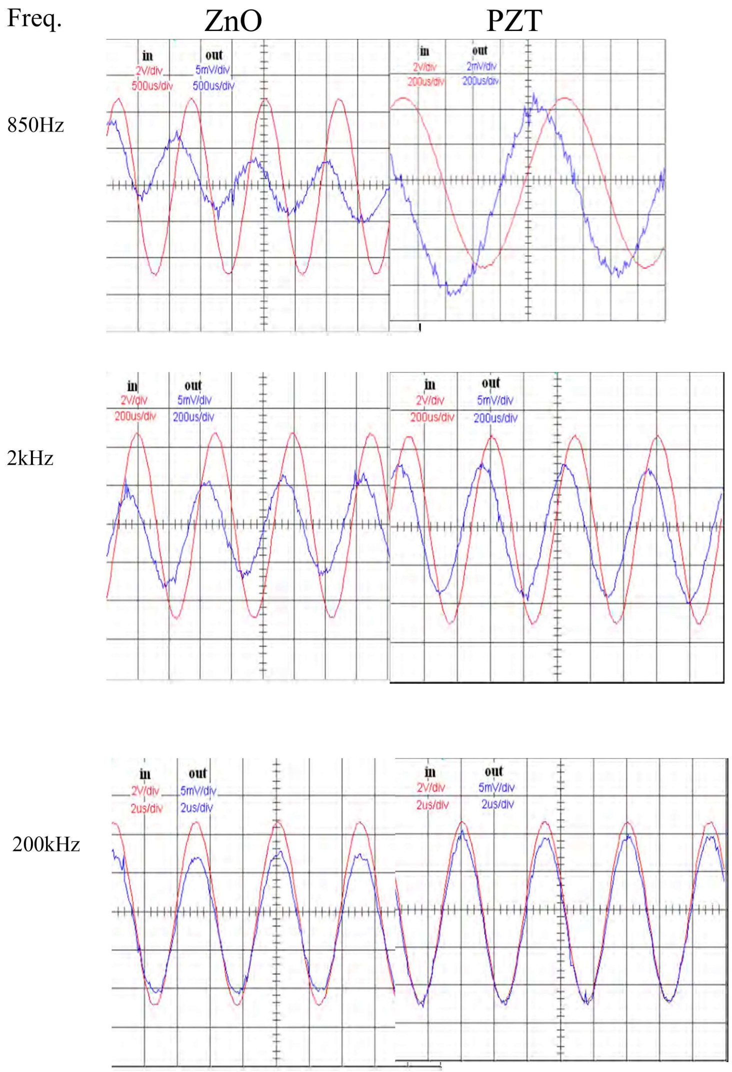

Figure 5. Measured results from the SAW test

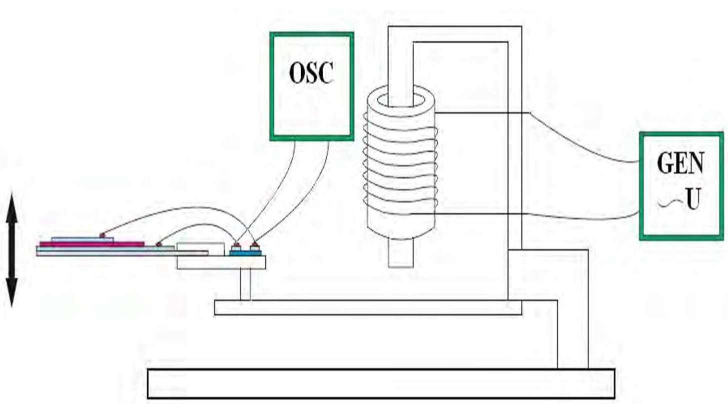

Figure 6. Measurement setup for dynamic mode testing

It contains a coil with anchor, at the end of which the sample is clipped. The coil was supplied by sinusoidal voltage with defined frequency, coming from low frequency signal generator G3-109. This cause a vibration of the anchor with the same frequency. During the mechanical vibration of the structure, a voltage with almost the same sinusoidal shape is generated. The measurement is performed again by using of a digital oscilloscope, connecting its two channels, respectively to the sample and the coil. Figure 7 represents the dependence of the generated volatge (peak-to-peak value) on the electrode's area, respectively for 100Hz and 200Hz.

It is obtained as a result of the mechanical transformations and the time delayes, which happen during vibrations propagation, from anchor to the sample.

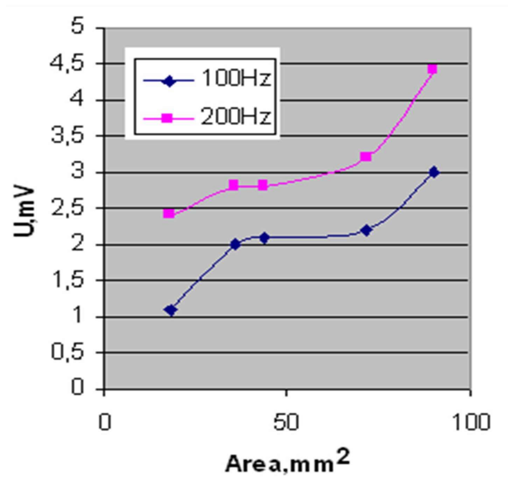

Figure 7. Dependence of the generated voltage (peak-to-peak value) versus the electrode's area

During the measurement, some shift in the phase of generated voltage, in relation to input voltage, feeded to the coil was observed.

The generated voltage has nearly sinusoidal shape. With the enlarging the area of the electrodes, an increasing of its amplitude occurs. This is as a result of transferring of bigger quantity of charges to the electrodes. The measurements show that, in case of increasing the frequency of the vibrations, the output voltage is also increased, keeping the same amplitude of the sinusoidal signal of the generator. This effect could be explained by the fact that, for shorter time more current carriers to the electrodes are generated.

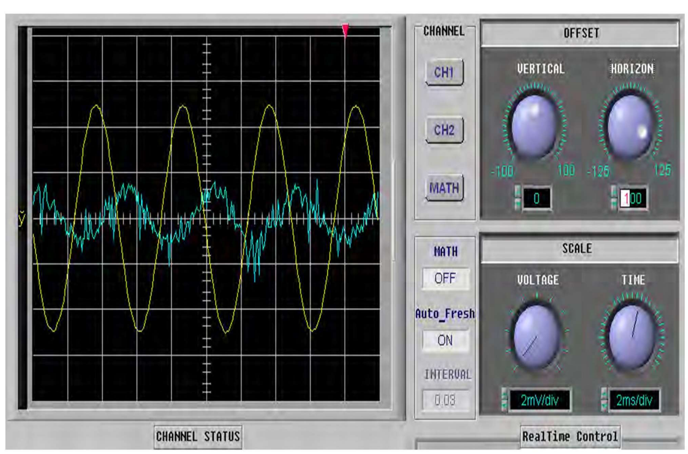

Figure 8. Waveform of the signals

During the design of the microgenerator, it have to bear in mind that the thickness of PZT should be more than 150 nm, because, in the case of thinner layer, several metal microbridges occur, which lead to creation of short connections through the layers.

4. Conclusion

During the design of piezoelectric microgenerators, we have to bear in mind the needed output power and also the frequency range of the vibrations, which would be transformed in voltage.

The voltage, generated in this way, is with alternative current (AC) character. For its rectifying, electron rectifiers are necessary.

The application and using of flexible substrate provides higher elasticity of the whole structure, which fact ensure the corresponding voltage generation, by using of lower mechanical loading.

The increasing of the electrodes area and the vibration frequency, increase the output power of the generator.

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