DESIGN OF PIEZOELECTRIC SCAVENGERS USING FBAR TECHNOLOGY

Gonzalo Murillo[1], **Gabriel Abadal**[1], **Francesc Torres**[1], **Joan Lluis Lopez**[1], **Joan Giner**[1], **Humberto Campanella**[2], **Arantxa Uranga**[1], **Jaume Esteve**[2], **Nuria Barniol**[1]

[1] Dept. Enginyeria Electrònica, Universitat Autònoma de Barcelona, Bellaterra, Spain
[2] Centro Nacional de Microelectrónica CNM-CSIC, Bellaterra, Spain

Abstract: In this work, a process to fabricate piezoelectric energy micro-generators is presented. Energy harvesting concept tries to extract useful energy from environmental vibrations, coupling the typical resonant frequency of the scavenger device with this vibration frequency. In this case, the mechanical energy is converted to electrical energy by means of piezoelectric transduction. The process to develop this piezoelectric devices takes advantage of the basic technology used to deposit AlN in a proved FBAR technology. The main goal of these technology process is that it is possible to share the same AlN material and processes to integrate piezoelectric energy scavenger elements, along with FBAR resonators for wireless RF communications systems. Therefore, the development of wireless autonomous systems could be consider. The fabrication process uses a BESOI wafer, and a KOH based wet etching to pattern both wafer sides. Several energy scavenger, designed to have a resonant frequency about 100Hz, have been simulated using a FEM tool.

Key words: FBAR; Energy harvesting; Energy scavenging; Micropower generation; Piezoelectric transduction;

1. INTRODUCTION

Research on micropower generators is recently becoming very popular thanks to the quick growth of portable and wireless products' market. Photovoltaic and thermoelectric generators have been already established in the scavenging state-of–the-art. However, the exploitation of environmental vibrations can be the better choice to supply energy to the future ultra-low-power communication systems, especially when no light sources or large temperature gradients are available. Three main types of transduction for vibrant energy scavengers have been explored to extract this energy; i.e. electromagnetic, electrostatic and piezoelectric transduction [1]. The last one seems to be the approach that supplies more power [2].

2. FABRICATION PROCESS

The process to fabricate piezoelectric energy micro-generators presented here is based in basic technology used to deposit AlN in a FBAR technology recently developed [3]. Thus, the same AlN material and processes can be shared to integrate piezoelectric energy scavenger elements, along with FBAR resonators for wireless RF communications systems.

In the Fig. 1, we can see the whole manufacture process. The process begins with a 4'' silicon BESOI wafer, n-type, (100) oriented and 450µm thick, from ShinEtsu.

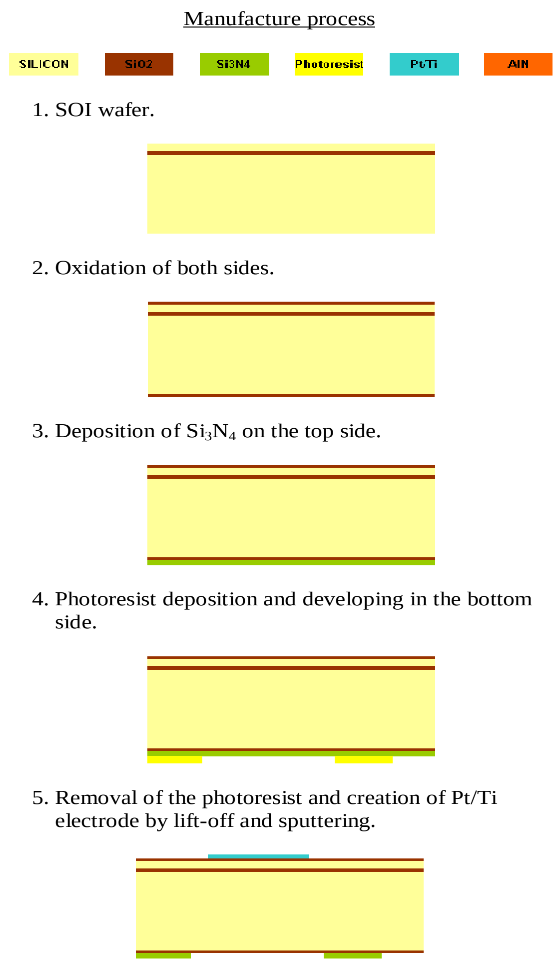

Fig. 1: Fabrication process to make piezoelectric scavenger based on FBAR technology.

The thickness of the top silicon layer is 15 µm, separated by an oxide layer of 2 µm. Then the wafer is oxidized by the both sides. Afterwards, silicon nitride is deposited on the bottom side and it is etched after the back-side mask is defined. When the photoresist is removed, the bottom electrode is created in the top side, over the oxide. Lift-off technique and RF-sputtering is used to do it.

The next step (Fig. 2) is the deposition of the AlN, i.e. the piezoelectric material which is the transduction material to extract the energy and the acoustic layer of FBAR as well. With a standard photo-lithography and a wet etching, the devices are ready for the creation of the Pt/Ti top electrode with similar steps than with the bottom electrode. Then, the layout of the scavenger must be patterned and etched on the top silicon and the back side of the wafer must etching with a KOH wet etching, in order to define the inertial mass. Finally, the structure is released when the sacrificial oxide is removed.

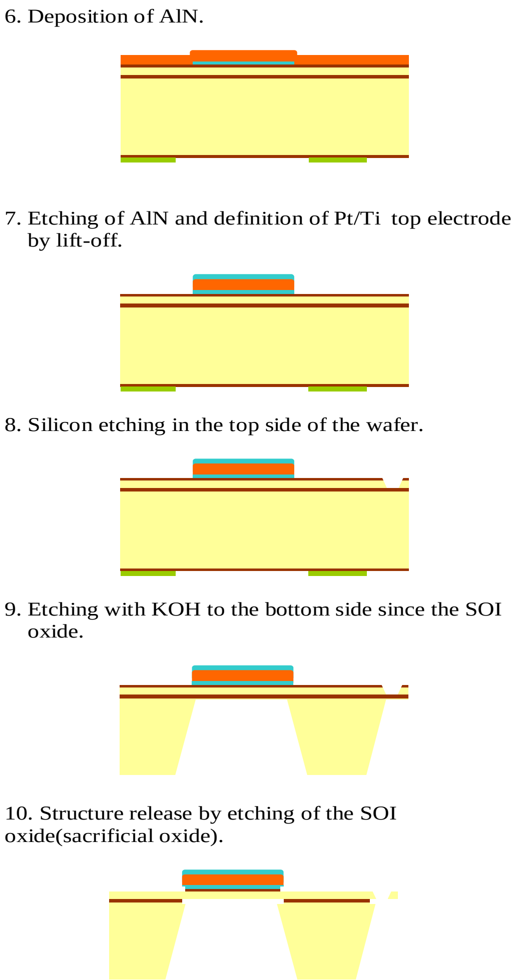

Fig. 2: Last steps of the fabrication process to make piezoelectric scavenger based on FBAR technology.

3. ENERGY SCAVENGERS DESIGN

This energy harvesting concept tries to couple the typical resonant frequency of the scavenger device, composed basically of a inertial mass and a cantilever based spring, with the environmental vibration frequency. The inertial mass movement in resonance generates torsion in the piezoelectric material, AlN, which generates a voltage signal (Fig. 3)

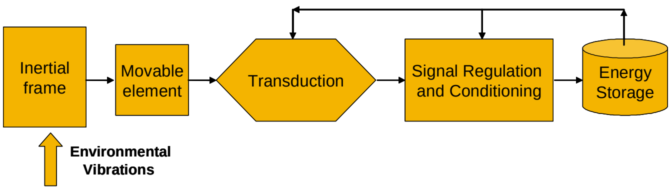

Fig. 3: Block diagram of an Energy Scavenging System with active transduction control

In order to design a resonant element coupled with the environmental vibration, we have the well-kwon expression for the frequency of a mass-spring system:

$$f = \frac{\omega}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{k_{ef}}{m_{ef}}} \cong 100Hz \qquad (1)$$

where the effective mass of the system, m_{eff}, is approximately the inertial mass, and the effective spring constant of the compound support beam, k_{eff}, can be calculated as:

$$k_{ef} = \left(k_{beam\_Si} \parallel k_{beam\_AlN}\right) \approx k_{beam\_Si} + k_{beam\_AlN} \qquad (2)$$

where the expression for each elastic constant, k_{beam_Si} and k_{beam_AlN} , of the compound cantilever is taken by:

$$k = \frac{E}{4} h \left(\frac{w}{l}\right)^3 \qquad (3)$$

where E and h are the Young's Modulus and the thickness for each material, and w and l are the width and length of the cantilever based suspension.

In order to estimate the inertial mass amount, we have to take into account that the etching of (100) oriented silicon using aqueous KOH creates V-shaped grooves with (111) planes at an angle of 54.74º from the (100) surface [4].

Therefore, the mass defined in the substrate silicon will have a pyramid shape, and the volume of this inertial mass can be calculated using:

$$V(A',B',H) = A'B'H + \frac{2H^2}{\tan 57.74^o}(A'+B'+2H) \quad (4)$$

where A',B' and H are the defined dimensions of the mass, as it is shown in the Fig.4 and 5. These backside dimensions are related to the real mass dimensions on the front side, A and B.

$$A' = A - \frac{2H}{\tan 57.74^o} \quad (5)$$

and

$$B' = B - \frac{2H}{\tan 57.74^o} \quad (6)$$

Several designs have been designed, in order to manufacture few devices with different process parameters. Looking for a resonant frequency of about 100Hz, a simple design with a beam of 1500 μm x 320 μm, and a mass of 2000 μm x 2000 μm has been modeled using COVENTOR® FEM tool[5].

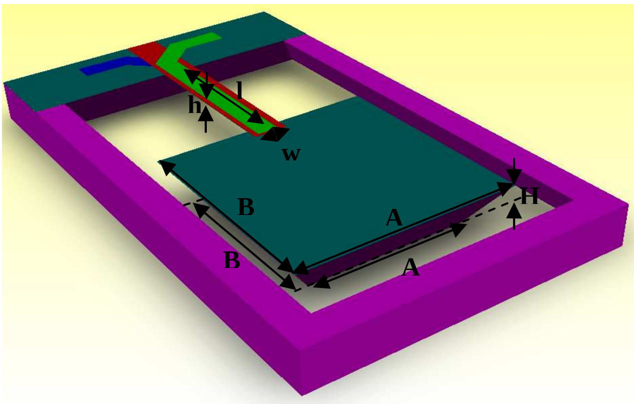

Fig. 4: Energy scavenger with dimensions fabricated with the technology presented in this work.

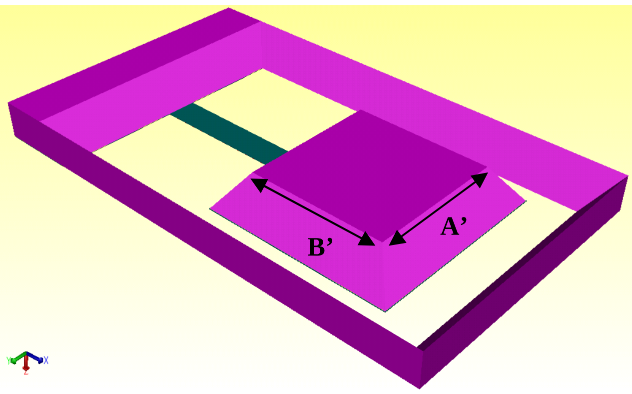

Fig. 5: Backside view of the energy scavenger.

Different views and the main dimensions are shown in the Fig. 4 and Fig. 5 In the last one, we can see the characteristic shape of the silicon wall due to the use of KOH to etch the SOI wafer.

4. ANALYSIS AND SIMULATIONS

4.1 Mechanical Simulations

This design has been proved by means of modal simulations using COVENTOR® software as well. In Fig. 6, we can see the modal simulation for this design.

Moreover, novel designs have been designed and simulated as well, in order to include them in the BESOI wafers which will be fabricated with this process. The designs are pointed to maximize the mass and the power extracted.

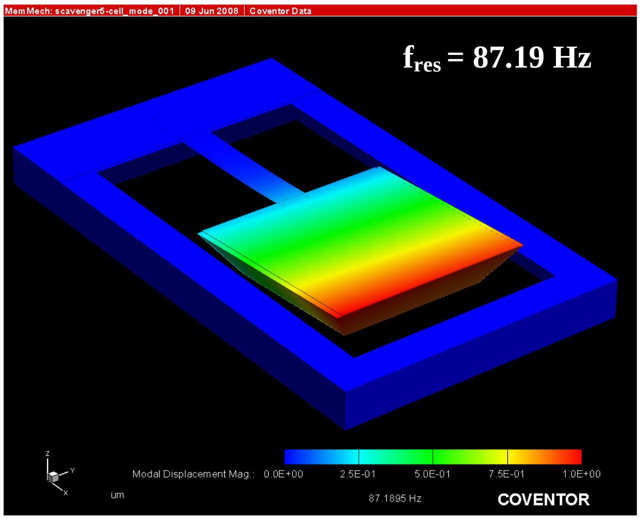

Fig. 6: Modal simulation of modeled scavenger.

4.2 Piezoelectric Theoretical Analysis

The piezoelectric coefficients experimentally measured are reported in [3]. The main expressions for piezoelectricity are [6],

$$\delta = \frac{\sigma}{Y} + dE$$
$$D = \varepsilon E + d\sigma \quad (7)$$

where δ is mechanical strain, σ is mechanical stress, Y is the modulus of elasticity (Young's Modulus), d is the piezoelectric strain coefficient, E is the electric field, D is the electrical displacement (charge density), ε is the dielectric constant of the piezoelectric material.

The piezoelectric constant voltage-to-stress, d, is defined as the electric polarization induced on a material per unit mechanical stress applied to it.

Alternatively, it is the mechanical strain experienced by the material per unit electric field applied to it. For the next values, the first subscript refers to the direction of polarization at zero-electric field (E = 0), or to the applied field strength. The second one refers to the direction of the applied stress, or to the direction of the induced strain, respectively.
Two relevant components of the d-constant are:

- d_{33} [m/V]: is the induced polarization per applied unit stress, both in the Z-axis ("3"). Alternatively it is the induced strain per unit electric field applied in the same direction.
- d_{31} [m/V]: is the induced polarization in direction 3 per unit stress applied in direction 1 (X-axis). Alternatively it is the strain induced in direction 1 per unit electric field applied in direction 3.

The values of d_{33} and d_{31} are 2.85 and 1.12 pm/V, whose magnitudes are roughly equal to a half the value of previously reported epitaxial AlN films. Other important parameters for the AlN in this technology are the following ones: E_{AlN} is from 200 GPa to 350 GPa, ε_{AlN} is about $8.81 \cdot 10^{-11}$ F/m and the AlN density is around 3000 kg/m^3. With these values, we can expect a voltage signal enough to extract the energy, when this signal is regulated and conditioned.

5. CONCLUSION

In conclusion a manufacture process to build piezoelectric energy scavengers has been proposed, using a well-kwon process compatible with FBAR fabrication. Hence, it is possible use the same run to fabricate energy microgenerators and FBAR devices, such as resonators, mass sensor [7] and others.

6. ACKNOWLEDGMENTS

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