Fabrication and characterization of the electrets material for electrostatic energy harvester

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Abstract. Electrostatic energy harvesting devices have been found feasible to convert ambient vibrations into electrical energy. Fabrications of such devices are carried out using standard CMOS technology. This paper explains the fabrications processes of the energy harvesting components and the characterizations of the electret material for the electrostatic energy harvester device. The electrostatic energy harvester components are made up of the trapezoidal electrodes and electrets structures. The aluminum-silicon-copper (AlSiCu) electrodes reside on the Micro Electro-Mechanical System (MEMS) structure of 25 mm^2 and comprises the seismic mass and serpentine beams. On the other hand, the electrets which made up of Silicon Dioxide (SiO_2) and Silicon Nitride (Si_3N_4) material, are fabricated separately. A 0.35 μm CMOS processes technology is utilized to fabricate the electrodes and electrets structures onto 200 mm silicon wafers. The performance of the energy harvester is evaluated through the characterizations of the electrets material. The electrets are charged with the Corona charging method and the surface potential is measured. From the experiment, it is proven that the CVD oxides is chargeable at 4.7 kV Corona voltage, 200 V grid voltage, 10 minutes charging time and 70^{o}C substrate temperature, hence it is a recommended material for electrostatic energy harvester device.

1. Introduction

Energy harvesting system is defined as a process to convert ambient energy sources such as vibrations, solar, thermal, wind, wave and RF energies into electrical energy. Energy harvesting topic has recently gained extensive research interest mainly driven by the needs of alternative power sources for ubiquitous sensor networks and low power application devices. Existing energy harvester devices are used in wireless sensor nodes (WSN) for monitoring structural health, home/building energy management system (HEMS/BEMS), automotive tire pressure monitoring systems (TPMS), and biomedical devices such as pacemakers and hearing aid [1].

Among the available ambient energy sources mentioned, the mechanical vibration energy source is of specific interest due to its availability anytime anywhere. The vibration to electrical energy conversion method known as the transduction mechanisms, are the feasible techniques used currently on the energy harvesting devices and can be categorized into electrostatic, electromagnetic and piezoelectric [2]. In this paper, the electrostatic conversion method is the target subject of study due to ease of integration into monolithic structure and fabrication into micro systems. Hence, the small scale electrostatic energy harvester is designed and called the micro energy harvester [3]. However, the conventional electrostatic conversion method has its own drawbacks, whereby a separate voltage source is required to provide initial charge to the electrodes [4]. Therefore, to overcome such drawback, *Electret* which is a form of dielectric material, is deposited onto the electrode and then charged with a Corona charging method [5].

The Corona charging process provides a surface potential with constant electrostatic field, hence the electret transforms into a quasi-permanent charged material. In this paper, the process to fabricate the components of the electrostatic energy harvester device is explained. The energy harvester electrodes and electrets structures are designed, fabricated and then the electret material is characterized with certain parameters in order to gain insights into its performance.

2. Energy harvester design

The electrostatic energy harvester described in this paper uses the *Trapezoidal* electrode design. As the name implies, the electrode is designed adopting a trapezoidal shape whereas the electrets design remains a rectangular shape as depicted in figure 1. In the electrodes structure, two trapezoidal electrodes are placed adjacent to one another. The electrodes are embedded onto a seismic mass with beams which vibrates in response to input vibrations. The electrets structure however, is made up of silicon dioxide (SiO_2) and placed on a stationary structure. The electrets are patterned and aligned to the trapezoidal electrodes structure as in figure 2.

The electrode and electrets designs are laid out with Cadence Virtuoso® software leveraging MIMOS 0.35 µm process technology. The completed layouts of the electrodes and electrets are depicted in figure 3 and figure 4 respectively. The final layouts are later sent to the mask shop where the photo masks or reticles are developed.

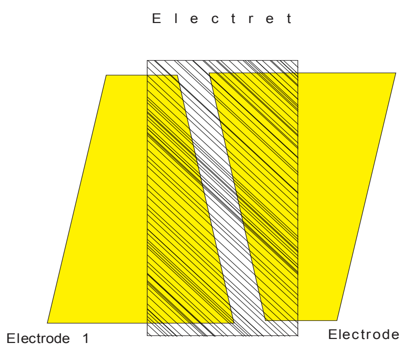


Figure 1. Basic topology of the electrets energy harvester [6].

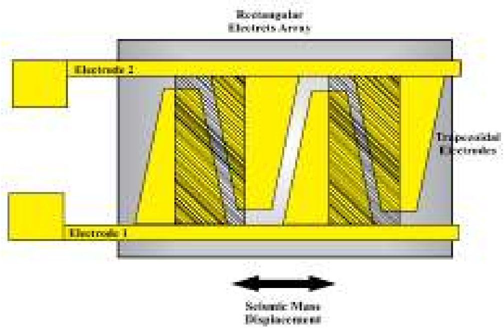


Figure 2. A preliminary design of the electrets energy harvester [6].

3. Device fabrications

Fabrications of the electrostatic energy harvester components, i.e. the trapezoidal electrodes and electrets, into silicon wafers are carried out at *MIMOS Berhad* (Malaysian Institute of Microelectronic Systems) adopting the Double-Poly-Triple-Metal CMOS process technology.

The fabrication process of the electrodes and electrets structures begins with the selection of silicon substrate. In this paper, a 200 mm Single Crystal Silicon (SCS) substrate with P-type <100> crystal orientation is selected for the fabrication. The detail fabrication processes of the energy harvester components are explained next.

3.1 Trapezoidal electrodes fabrication

Fabrication of the trapezoidal electrodes structure requires seven masking steps. Each mask is subjected to deposition, pattern transfer, develop and etch processes. The processes are repeated for each and subsequent masks. Each masking process creates either a layer or trench on the wafer, specifically on the dice leaving behind the intended pattern of the designs where positive photoresist materials are used throughout the process. The masking processes of the trapezoidal electrodes are described in table 1.

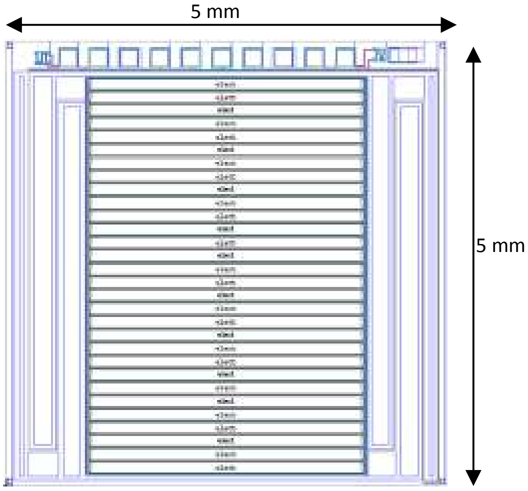


Figure 3. Layouts of the trapezoidal electrodes.

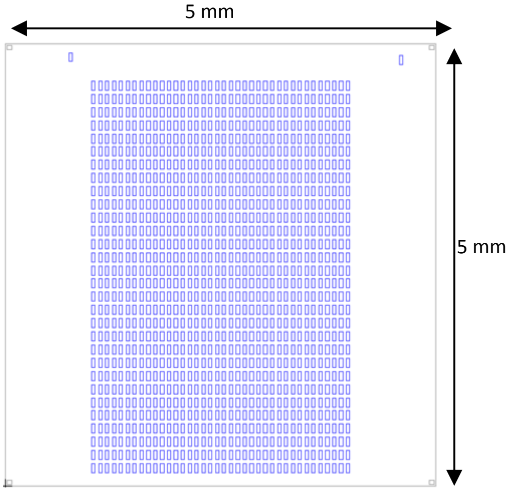


Figure 4. Layouts of the patterned electrets.

Table 1. Trapezoidal electrodes process.

Masks	Process name	Functions
Four corner guide	Developer	Pattern the four corner guide trenches
Metal 1 pattern (Photo-Lithography)	Developer	Transfer M1 interconnect pattern from the mask/reticle onto the wafer.
Via1 pattern	Developer	Pattern via hole for interconnection between M1 and M2
Metal 2 pattern	Developer	Transfer M2 interconnect pattern from the mask/reticle onto the wafer
Via 2 pattern	Developer	Pattern via hole for interconnection between M2 and M3
Metal 3 pattern	Developer	Transfer M3 interconnect pattern from the mask/reticle onto the wafer
Pad pattern	Developer	Define bond pad opening

3.2 Electrets fabrication

Fabrication of the electret structure begins with the Tetra Orthosilicate (TEOS) glass deposition by Chemical Vapor Deposition (CVD) method at 400°C, to achieve overall thickness of 20,000 Å (2 µm). Next, a thin layer of Silicon Nitride (Si_3N_4) of thickness 1500 Å is deposited onto the oxide by a CVD method using Silane (SiH_4) and Ammonia (NH_3) gases at 400°C. Then, a photoresist film of 4 µm thickness is spin coated onto the nitride layer. To pattern the rectangular shape electrets, the photoresist is first exposed with UV light through an electret mask or reticle, which is later developed and UV baked. Later, Reactive Ion Etching (RIE) also called the plasma etch process is utilized to remove the unwanted nitride layer. The RIE process condition is set as follows, 80 sccm of CF_4, 20 sccm of CHF_3, 200 sccm of Ar, 300 mT of pressure and 1100 W of RF power. The remaining photoresist left on the patterned nitride layer is further removed with oxygen plasma and acid resist strip. The patterned electrets goes through a post annealing process at 450°C in N2 atmospheric furnace for 1 hour. The annealing process re-arranges the oxide molecules which are damaged due to the etching process. Last but not least, the Aluminum of 0.5 µm thickness is deposited at the backside of the wafer using the e-beam deposition method. The aluminum layer provides a conductive surface required for the charging process. The detail process steps of the electrets fabrication are described in table 2.

Table 2. Electrets fabrication process.

Process steps	Process name	Functions
Four corner patterning	Developer	Pattern the four corner guide trenches
Four corner etching	DRIE	Create notches / trenches for the electrode / electrets alignment at each corner of the device
TEOS Oxide deposition	PECVD	Deposit thin oxide layer to form the electrets layer
Nitride deposition	PECVD	Deposit thin Silicon Nitride layer to passivate the electrets layer
Photoresist coating and Nitride patterning	Developer	Transfer the rectangular pattern of the electrets from the mask / reticle to the wafer.
Nitride layer etching	RIE	Etch away the unwanted oxide / nitride material and leave behind the electrets pattern.
Oxide Annealing	Post Anneal	To cure the oxide at 450°C in N_2 for 1 hour
Aluminum backside deposition	E-beam	To deposit thin layer of Aluminum

4. Electrets characterization

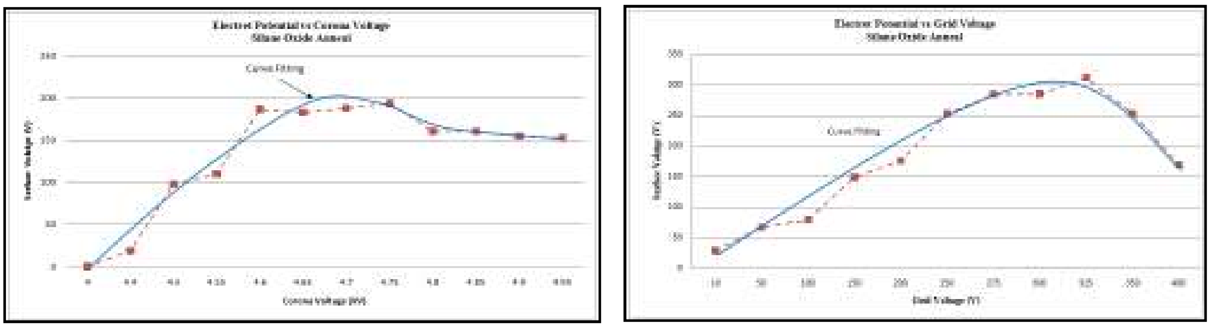
Electrets characterization is a process to charge the fabricated oxide samples by Corona charging method. During the charging process, negatively charged ions ($CO3^-$) are deposited onto the oxides surface which carries the electrostatic potential. To achieve this, several equipments are required e.g. Corona chamber with heater base, high voltage DC power supply (-5 kV), grid voltage DC power supply (-600 V), electrostatic voltmeter (Monroe Electronics Inc. USA, model 344 with probe) and probe holder. The oxide samples are first cut into 10 x 10 mm dimension for ease of handling during the experiment.

There are six parameters identified for the characterizations, i.e. Corona voltage, charging time, grid voltage, substrate temperature, grid height and needle height, as shown in table 3. The Corona voltage also called the needle voltage is first characterized. This highly negative DC voltage potential ionizes the surrounding air molecules which later broken down into positive and negative ions. The negative ions are attracted to the oxide sample due to positively polarize conductive base. The Corona voltages are set to sweep from -4 kV to -4.9 kV (limitations of the power supply), while the rest of the parameters remain constant. Once completed, the Corona voltage is set to the optimum value while characterizing the next parameters. The process continues until all the intended parameters have been characterized.

Each sample is charged for 15 minutes. When the charging time is completed, the sample is measured with the Monroe electrostatic voltmeter at five different locations. Measurements of the same sample are repeated three times and the average values are recorded and plotted into trend charts. The charging process is repeated for three different oxide samples in order to achieve consistency. The characterization results in figure 5, shows that the oxide deposited through CVD process is responded well to the Corona voltages where the optimum surface charge obtained occurs at 4.7 kV.

Table 3. Characterization parameters.

Parameters	Constant	Variables	Units
Corona Voltage	4.7	4 – 4.9	kV
Grid Voltage	200	50 - 450	V
Substrate Temp.	80	25 - 85	^{o}C
Charging Time	15	5 - 40	mins
Needle Height	10	10 - 15	mm
Grid Height	2	1 - 5	mm



(a) (b)

Figure 5. Electrets potential with respect to the parameters. (a) Corona voltage and (b) grid voltage.

5. Conclusion

This paper described the fabrication processes of the vibration-based MEMS electrostatic energy harvester components, i.e. the trapezoidal electrodes and electrets, leveraging MIMOS 0.35 µm CMOS technology. The electrodes and electrets structures are fabricated on separate processes. Once the fabrications are completed, the performance of the electrets component is evaluated using the Corona charging method. Measurement results of the electrostatic potential show that the CVD oxides is easily chargeable and responded well to all parameters. From the experiment, it is concluded that the CVD oxide is a suitable electrets material for use on the electrostatic energy harvester device.

6. References

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