POSSIBLE APPLICATIONS OF FREESTANDING CARBON NANOTUBES IN MEMS TECHNOLOGY

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Abstract

Carbon nanotubes (CNTs) are molecular-scale tubes of graphitic carbon with outstanding properties. They are among the stiffest and strongest fibers known, and have remarkable electronic properties and many other unique characteristics. In our experiment, CNTs were synthesized using plasma enhanced chemical vapor deposition on the silicon wafer with patterned iron catalytic layer. If the catalyst is only located in certain areas (patterned), then nanotubes grow only in those areas. The arrays with freestanding carbon nanotubes were created. It is possible to apply this method of CNTs preparation in many areas, such as sensor-based applications. For example, thanks to the CNTs dimensions is possible to increase the surface in capacitance pressure sensors that are one of the most used in microelectronic devices for pressure sensing. The novel MEMS structure was designed to be utilized as capacitance pressure sensor. The most applicable topology of the MEMS structure was chosen by means of electrostatic models analysis. There were proposed five structures and the best solution was selected the “chessboard” structure, since it provides the suitable capacity for the sensor. The computing model supposes geometric symmetry of created CNTs arrays, thanks to that it was necessary to find only two dimensions (width of CNTs array and gap between those arrays). The very first laboratory results measured on fabricated structures show very accurate values which correspond with simulated results.

Keywords: Micro-Electro-Mechanical System (MEMS), capacitive sensor, carbon nanotubes

1. INTRODUCTION

The pressure sensors are very important microelectronic devices. We are able to recognize several types of them mostly divided due to their function principles. The major problem of capacitive pressure sensor is small electrode surface which has influence on the capacitance value. The CNTs utilization gives us the possibility to increase the electrode surface.

Carbon nanotubes (CNTs) are molecular-scale tubes of graphitic carbon with outstanding properties. They are among the stiffest and strongest fibers known, and have remarkable electronic properties and many other unique characteristics. For these reasons they have attracted huge academic and industrial interest, with thousands of papers on nanotubes being published every year. The diameter of a nanotube is on the order of a few nanometers (approximately 50 000 times smaller than the width of a human hair), while they can be up to several millimeters in length [1] [2].

Several techniques have been developed to produce nanotubes in sizeable quantities, including arc discharge, laser ablation, high pressure carbon monoxide and chemical vapor deposition (CVD). Most of these processes take place in vacuum or with process gases. Large quantities of nanotubes can be synthesized by CVD methods; advances in catalysis and continuous growth processes are making CNTs more commercially viable.
2. THEORY

The capacitive sensor consists of two high-doped silicon electrodes with multi-wall carbon nanotubes (MWCNTs) arrays. Usually, for pressure measurement, one electrode is anisotropically etched to obtain a sensitive membrane and the other one is solid. Between both parts of the body of the sensor there is an insulating spacer made of a double-sided sticky tape for first tests. Its thickness depends on the required distance between electrodes i.e. the main factor for its thickness is the CNT length. For non-detachable connection an anodic bonding technology will be used by a SIMAX® glass disc. The structure of the device is shown in Fig. 1.

![Fig. 1 The structure of capacitive pressure sensor.](image)

3. SIMULATIONS

3.1 Simulation of membrane performance

Membrane area and thickness was optimized by an ANSYS simulation of membrane performance for different shape and dimensions (Fig. 2). The goal of the simulations was to find out sufficient sensor sensitivity for pressure range 0 – 300 kPa.

![Fig. 2 ANSYS simulations of membrane performance.](image)

3.2 Electrostatic models analysis

The most applicable topology of the MEMS structure was chosen by means of electrostatic models analysis [3]. The analyses proceed using of MatLAB software. There were proposed several structures and the best solution was selected as the “chessboard” structure as shown in Fig. 3, since it provides the suitable capacity for the sensor. The other analyses of structures were comb structure, pyramid structure and chimney structure. The last two structures were discarded firstly, because of the possible fabrication problems with substrate preparation or non-ability to control of CNTs growth (pyramid structure).

The proposed “chessboard” structure consists of the top and bottom plates forming together the designed pressure sensor. Since the capacity of the sensor depends on the area of the plates, the CNTs were added to increase the overall capacity. Each patch of the plates serves as substrate for CNTs growth. The plates
with nanotubes change their capacity according to applied pressure. It is due to the columns of nanotubes, which are more or less fitted together depending on applied pressure.

![Fig. 3 The principle of the selected structure “chessboard”.](image)

To find out the optimal dimension of these arrays and the gap between them, we created a model for calculation of the electric field. The model supposes geometric symmetry of created CNT arrays, thanks to which it was possible to find only two dimensions (width of the CNT array and the gap between those arrays). The result of the simulation is shown in Fig. 4.

![Fig. 4 Result of optimization proportions for CNT array.](image)

4. PREPARATION OF SENSING LAYER

The sensing layer consists of nanometers grid. In our experiment, CNTs were synthesized using plasma enhanced chemical vapor deposition on the silicon wafer with patterned iron catalytic layer. If the catalyst is uniformly distributed, nanotubes grow everywhere on the substrate. If the catalyst is only located in certain areas (patterned), then nanotubes grow only in those areas. Iron catalytic layers with defined shapes and dimensions were prepared for carbon nanotubes growth. Various dimensions of these shapes were fabricated to monitor influence of catalytic layers. There were produced shapes from 100 nm to 10 μm dimensions.
The typical deposition conditions were: flow rates of argon, methane and hydrogen \( Q_{\text{Ar}} = 1000 \text{ sccm}, \ Q_{\text{CH}_4} = 50 \text{ sccm} \) and \( Q_{\text{H}_2} = 200 \text{ to } 300 \text{ sccm} \), respectively, microwave (mw) power of 400 W, substrate temperature 900 to 1100 K, deposition time 1 minute. Thin CNTs with a diameter of about 100 nm were standing vertically perpendicular to the substrate due to a crowding effect. A detailed study of the preparation of catalytic layer and the microwave torch for deposition of CNTs and their characterization were published in Ref. [4] [5].

The detail of four different dimensions of testing catalytic layers is shown in Fig. 5.

![Fig. 5 The detail of photolithographically patterned catalytic layer.](image)

5. RESULTS AND DISCUSSION

For first tests there is an insulating spacer made of a double-sided sticky tape between both parts of the body of the sensor. Its thickness depends on the required distance between electrodes, i.e. the main factor for its thickness is the CNT length. For the full function of the sensor, the encapsulation of the body of the sensor should be solved. Suitable solution can be utilization of anodic bonding with a thin SIMAX® glass disk as an insulator layer [6]. Both parts of the sensor are connected with help of a special controlled nanostep holder.

The monitoring and measurement of the capacity value will be observed by AD 7745 circuit, which represents capacity-to-digital converter (CDC). So the capacity is measured directly from the device inputs.

![Fig. 6 SEM and AFM analysis's of the CNTs array and practical realization of the capacitive sensor.](image)
From the production process perspective, we are able to reproduce this process, including influencing the nanotube length. The length can be influenced by the deposition time. We managed to prepare freestanding nanotubes that are perpendicular to the surface base. We are now trying to deal with an essential problem - the instability of individual nanotubes. In principal the nanotubes "twist", which is unwanted effect. Ideally, the nanotubes should form a vertical field to the base area. If we succeed, it is possible to apply this method of CNTs preparation in many areas, such as sensor-based applications [7] [8] [9].

6.  CONCLUSION

The paper describes possible applications of freestanding carbon nanotubes in MEMS technology. The most applicable topology of the MEMS structure was chosen by means of electrostatic models analysis. The analyses proceed using of MatLAB software. There were proposed several structures and the best solution was selected as the “chessboard” structure since it provides the suitable capacity for the sensor. The simulation results helped to define real dimensions of the sensor plates for sensor fabrication. Carbon nanotubes were used as well. The overall capacity increased, because the area of the final sensor construction increased too.

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LITERATURE