ELECTRIC FIELD SENSORS BASED ON MEMS TECHNOLOGY

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Abstract The design and optimization of two types of novel miniature vibrating Electric Field Sensors (EFSs) based on MicroElectroMechanical Systems (MEMS) technology are presented. They have different structures and vibrating modes. The volume is much smaller than other types of charge-induced EFSs such as field-mills. As miniaturizing, the induced signal is reduced enormously and a high sensitive circuit is needed to detect it. Elaborately designed electrodes can increase the amplitude of the output current, making the detecting circuit simplified and improving the signal-to-noise ratio. Computer simulations for different structural parameters of the EFSs and vibrating methods have been carried out by Finite Element Method (FEM). It is proved that the new structures are realizable and the output signals are detectable.

Key words Electric Field Sensor (EFS); MicroElectroMechanical Systems (MEMS); Finite Element Method (FEM)

I. Introduction

Measurement of the electric field intensity has significant importance for many applications. For example, accurate measurements made in different altitude by Electric Field Sensors (EFSs) provide important information in the study of weather phenomena such as thunderstorms. The results are also of significant importance for rocket launching[1]. Semiconductor fabrication and assembly rely on the avoidance of ElectroStatic Discharge (ESD) which may damage the product being manufactured or bring about malfunction in the manufacturing equipments. EFSs can be used to control an air ionization system to keep the manufacturing process in a safe condition, or to provide danger alarm. EFSs can also be used to detect the electric field generated by power line, which has been alleged to cause health effects.

Many EFSs have been developed, such as fiber optic EFSs[2] and charge-induced EFSs. Charge-induced EFSs in existence include twin balls charger, rotating-vane electrical field-mill, and vibrating reed field-mill[3,4].

Comparing with macroscale EFSs, the miniature sensor based on MEMS technology is much smaller and lighter in weight. Therefore, it is suitable for measuring the electric field in outer space or at an altitude in atmosphere. This advantage also offers a possibility to study the detail of spatial distribution of an electric field, that is very useful in science research.

Two kinds of novel miniature EFSs are presented in this paper. They all consist of

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the driving electrodes, the shielding electrodes and the sensing electrodes. The vibrating orientations of the shielding electrodes of the two EFSs are different: One is perpendicular to the wafer, the other is parallel to the wafer. Therefore the sensors are called perpendicular-vibration EFSs and parallel-vibration EFSs respectively.

II. Perpendicular-vibration EFS

1. Working principle

The structure of the perpendicular-vibration EFSs is shown in Fig.1.

The grounded shielding electrodes with an array of holes (see Fig.2) are used to modulate the electric field at the surface of sensing electrodes, in order to change the value of the induced electric charge on the sensing electrodes periodically. An alternating current signal whose peak value varies with the strength of the electric field around the sensor is detected in the circuit connected to the sensing electrode.

The driving electrodes are used to excite the shielding electrodes to vibration in z-direction by electrostatic force. The z-directed electrostatic force added on the shielding electrode can be calculated from the relation

\[ F_z = \frac{\partial W}{\partial d}, \]

where

\[ W = \frac{CV^2}{2} \]

is the capacitive energy stored between the shielding electrode and the driving electrode, \( d \) is the distance between the two sets of electrodes, \( V \) is the voltage added on the driving electrode.

If fringing fields are neglected, the capacitance

\[ C = \frac{\varepsilon A}{d}, \]

where \( A \) is the total area of driving electrodes, and the driving force

\[ F_z = \frac{\varepsilon AV^2}{2d^2}. \]

When the distance between the shielding electrode and the sensing electrode is large enough, the shielding electrode would shield most part of electric field onto the sensing electrode (See Fig.3(a)). Therefore little charge would be inducted on the sensing electrode. When the distance decreases, the shielding effect weakens, and more electric field gets to the sensing electrode (as shown in Fig.3(b)). Hence more inducted electric charge appears on the sensing electrode. If the distance changes periodically, alternative electric current will be induced in the circuit. This current can be used to measure the electric field.

2. Simulation results

As it is much smaller than the macro EFSs, the miniature EFSs have an additional design issue, that the small sensing electrode can only generate a tiny current. In order to increase the variety value of the induced charge, the structure parameters need to optimize, which include thickness of the shielding electrode, size of the holes in the shielding electrode,