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引信 MEMS 静电探测器阵列设计

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摘要:引信可以利用空中目标运动产生的静电场信息对目标进行探测,而 MEMS 的特殊性能非常适合于引信静电探测器的设计。在引信有限的体积内布设 MEMS 静电探测阵列,通过对目标静电场信息进行检测,可以获得目标的位置和速度信息。本文运用表面加工工艺设计了一种 MEMS 薄膜电极的垂直振动式电场传感器阵列。介绍了该电场传感器探测单元及阵列的结构、组成及工作原理,说明了该器件的加工工艺。通过 MEMS 静电探测单元的空间布阵,研究了引信 MEMS 静电探测阵列对目标定位的原理,推导了目标定位的公式,使用 MEMS 静电探测阵列探测了目标的静电场,实现了对目标位置的定位。

关 键 词:微机电系统;静电探测阵列;引信;电场传感器;有限元法
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Design of fuze MEMS electrostatic detection array

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Abstract: The motion of a target in air will produce electrostatic fields which can be detected by a fuze to provide some useful information of the target. Moreover, MEMS devices have shown their characteristics of small sizes, low power consumption and high integration to be suitable for design of MEMS electrostatic detection arrays. When a MEMS electrostatic detection array is placed in the limited space of a fuze,the array can acquire the information of position and velocity of the target by detecting electric field around it. A MEMS electrostatic field detection array with a vibrating film is designed using surface machining processes in this paper. The princile and fabrication of the electric field detection array are systematically presented and the processing techniques of a electrostatic field sensor are explained particularly. The principle and formula of target locating are also studied . The results show that the electrostatic field of the target can be detected by using three MEMS electrostatic detectors,and the positions of the point target along the axis of the projectile and vertical to the axis of the projectile can be obtained. It is concluded that the MEMS electrostatic detection array can locate exactly the target.

Key words: MEMS; electrostatic detection array;fuze; electrostatic field sensor; finite element method

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1 Introduction

The target motion in air will have electric charges and will produce a electrostatic field that could not be erased, and a fuze can get some useful information of the target by detecting the electric field around it. The plate electrostatic detectors with detective plates in common use can not acquire the information of position and velocity of the target, because of the structure of plate electrostatic detectors, detection principle and the limitation of fuze capacity. Moreover, the MEMS is micro-electromechanical technology based on silicon substrates. MEMS minitype electrostatic field sensors have advantages of the small-sizes, low costs, low power consumption and high integration characteristics, which makes it feasible in design of electrostatic detectors. In fact, the MEMS electrostatic detection array placed in limited capacity of a fuze can acquire the information of position and velocity of the target by detecting the electric field around the target.

2 Fabrication of electrostatic field sensor

The fabrication of an electrostatic field sensor is shown in Fig. 1, it consists of a silicon underlay, a Si_3N_4 insulating layer, a metal exciting electrode, an inducing electrode, a poly-Si layer and a shielding electrode accreted on the poly from bottom to top.

The shielding electrode is earthed to induce the connection between electrode and measure circuit when the sensor works, as shown in Fig. 2. When the space between shielding electrode

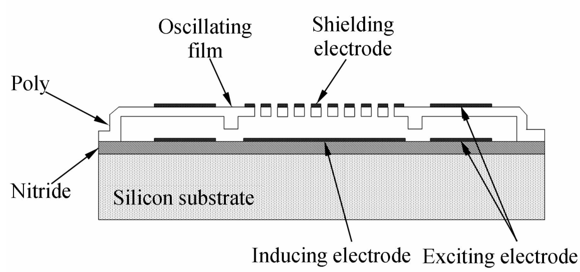


Fig. 1 Schematic of electric field sensor fabrication

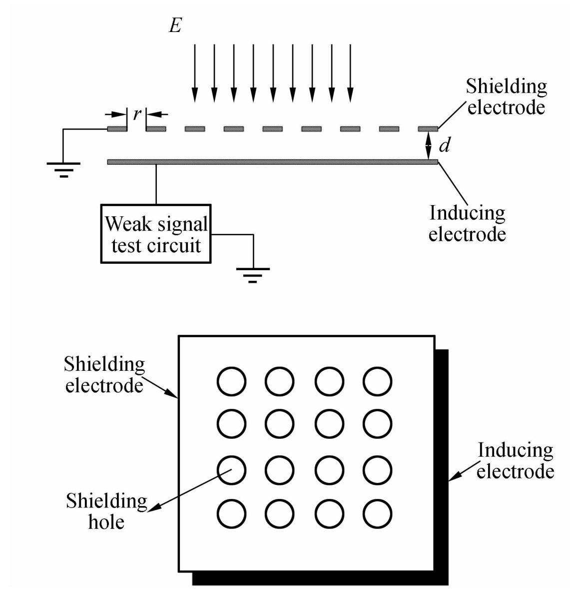
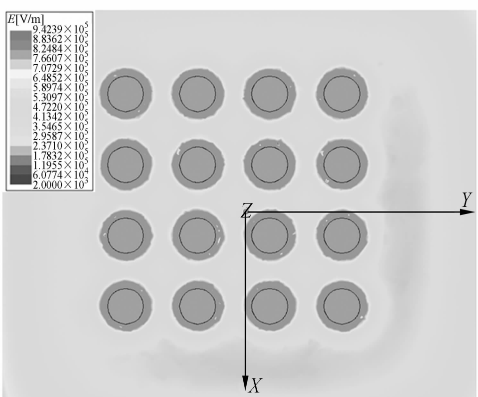


Fig. 2 Principle of electric field sensor

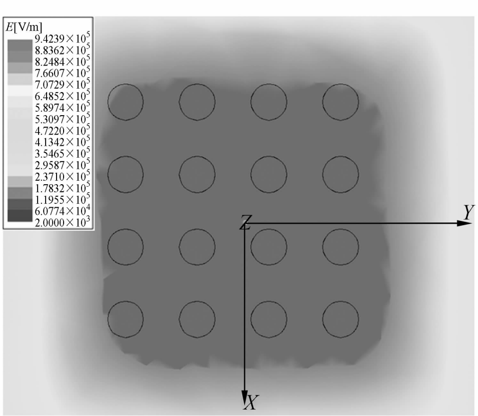
and inducing electrode is relatively large, the electric intensity of inducing electrode surface is much weak and the inducing electrode will have few electric charges because it is impossible for an electric fluxline to go through shielding holes. When the space between shielding electrode and inducing electrode is relatively small, the shielding function of the electrode is reduced. And then the inducing electrode will have more electric charges because the electric fluxline can easily go through shielding holes to the electrode surface . When the shielding electrode vibrates vertically, induced electric charge is generated by electrode change periodically. So induced electric current related to electrostatic field intensity is generated in the measure circuit connected to the inducing electrode. Electric intensity can be detected by a weak current measuring.

3 Simulation and analysis of electrostatic field sensor performance

Induced electric charges generated by the electrode of a detector is relative to the area of shielding holes(dia. of hole is r) and the interval of the inducing electrode and the shielding electrode. System performance is analyzed by finite element analysis software MAXWELL. 11 in order to get optimal parameters of the system. The electrostatic field intensity distribution of inducing electrode is shown in Fig. 3. When the space between shielding electrode and inducing electrode is relatively small, the electric intensity of inducing electrode surface is very intensive, and the inducing electrode will have more electric charges, as shown in Fig. 3(a). When the space between shielding electrode and inducing electrode is relatively large, the electric intensity of inducing electrode surface is very weak and the inducing electrode will have few electric charges because of the shielding function of shielding electrode. Fig. 4 shows the induced electric charges generated by the inducing electrode when the interval of inducing electrode and shielding electrode changes. The maximum of induced electric charge of inducing electrode could be 10^{-13} C, in the case that the area of shielding hole is adjusted properly, and the electric intensity E is 1 000 V/m. Induced electric current could be on the level of 10^{-11} A which can be measured by a weak signal test system, when shielding electrode vibrates vertically at frequency $k=1$ kHz.



(a) Electrostatic field of inducing electrode at close distance



(b) Electrostatic field of inducing electrode at far distance

Fig. 3 Distribution of electrostatic field intensity of inducing electrode

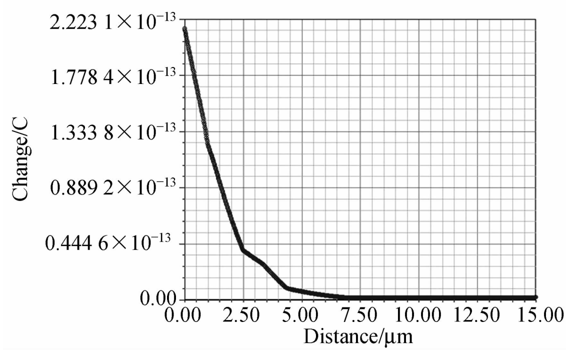


Fig. 4 Curve of induced charge of inducing electrode

4 Machining technics of electrostatic field sensor

The basement of sensor is silicon, and a Si_3N_4 insulating layer is grown on the basement. The inducing electrode and exciting electrode are produced on the insulating layer. After the sacrificial layer and poly layer are grown, and the shielding electrode and exciting electrode are grown on the ploy layer. Finally, the mechanism is released after removing the sacrificial layer.

The silicon substrate and Si_3N_4 insulating layer form the operable substrate, which is the foundation to produce other mechanisms. The inducing electrode and exciting electrode are metal layers produced on the Si_3N_4 insulating layer using positive photoresist lithography technique. The a polysilicon film is produced by a surface micromachining process. The polysilicon film forms some downward supporting structures by controlling the shape of the sacrificial layer. The functions of the downward supporting structures determine the closest distance between the polysilicon film and the inducing electrode, and make sure the sensor vibration by preventing the polysilicon membrane and the inducing electrode staying together. The shielding electrode is a metal layer sputtered on the membrane. Pinhole array is produced on the metal layer by corrosion and then a method of deep etching is used to breakthrough the poly layer. The pinholes can decrease damping when the membrane vibrates, then the mechanism can be released by removing the sacrificial layer.

5 Target location based on MEMS electrostatic field sensor array

Because single detection unit can not locate the motion target, a detection array formed by MEMS electrostatic dectors is used to position the target. Here we benefit the small voulme of the MEMS electro static detectors, and establish the relation between the mount of detectors and the position of target.

Assuming the target is a point charge, the projectile and the target are on the same plane. 3 MEMS electrostatic detectors are placed in the fuze along the axis of the projectile as shown in Fig. 5. The distance between two detectors is l. The approach velocity between the projectile and the target is T. In a certain time, the distances between the 5 electrostatic detectors and the targe are R_1, R_2, R_3, R_4 and R_5 respectively. The angle between the line connecting detector 2 and the target and the velocity of projectile is θ, and the supplementary angle is α.

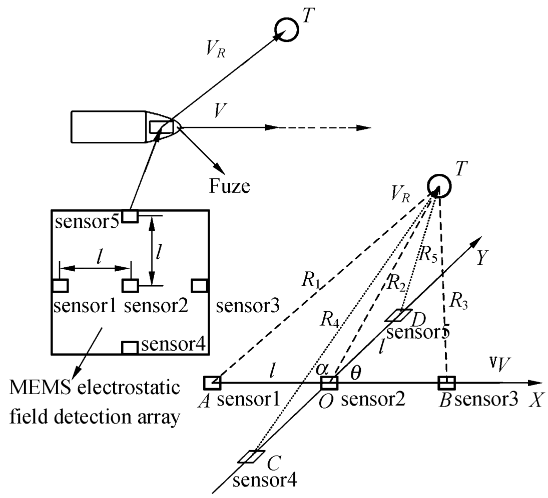


Fig. 5 Principle for target locating

It is a good approximation if we ignore the influence among the sensors and assume the sensors work independently. The electric intensities of the target in the positions of the 3 sensors are E_1, E_2 and E_3 respetively. According to the formula of electrostatic field intensity of point charge, we have

$$E_1=\frac{q}{4\pi\varepsilon R_1^2},E_2=\frac{q}{4\pi\varepsilon R_2^2},E_3=\frac{q}{4\pi\varepsilon R_3^2}\ . \quad (1)$$

From Eq. (1), we can get:

$$\frac{R_2}{R_1}=\sqrt{\frac{E_1}{E_2}}=K_1,\frac{R_3}{R_2}=\sqrt{\frac{E_2}{E_3}}=K_2. \quad (2)$$

According to cosine theorem, we can get:

$$\cos\theta=\frac{l^2+R_2^2-R_3^2}{2l\cdot R_2}\ , \quad (3)$$

and

$$\cos\alpha=\frac{l^2+R_2^2-R_1^2}{2l\cdot R_2}\ , \quad (4)$$

where $\theta+\alpha=\pi$, so we can get

$$R_1^2+R_3^2-2R_2^2=2l^2\ , \quad (5)$$

$$\begin{cases}R_1=l\sqrt{\dfrac{2}{1+K_1^2K_2^2-2K_1^2}}\\ R_2=K_1\cdot l\sqrt{\dfrac{2}{1+K_1^2K_2^2-2K_1^2}}\\ R_3=K_1\cdot K_2\cdot l\sqrt{\dfrac{2}{1+K_1^2K_2^2-2K_1^2}}\end{cases}, \quad (6)$$

We can get θ and α from Eq. (6). The electrostatic field of the target can be detected using 3 MEMS electrostatic detectors, and then the positions of point target along the axis of the projectile can be obtained. Simultaneously, the positions of point target vertical to the axis of the projectile can be gotten also.

6 Conclusions

According to the analysis of working principle of sensors, computer modeling and simulation, MEMS electrostatic detectors are designed based on the surface micromaching process. The MEMS electrostatic detector has the advantages of small sizes, low costs, low power consumption and high integration. Electrostatic detection array composed by electrostatic detector units is proposed to detect the electrostatic field of a target and locate the target position which is the basis of initiation ammunition for the fuze.

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