The Ignition Performance of Metal Film Bridge

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Abstract. The ignition voltage of micro-satellite and MEMS fuse become more and more lower, the conventional electro-explosive devices are hardly meet the requirement. In this paper, Ni-Cr metal film bridge of different size/substrate were designed by MEMS processing technology. By using Neyer D-optimal sensitivity test method, it got the result that the threshold of ignition voltage would decrease with the decrease of designing size, and the threshold of ignition voltage with the glass substrate would be less than the silicon substrate.

Keywords: Metal film bridge, capacitor discharge, ignition, substrate.

1. Introduction
The conventional Electro-Explosive Devices in hotwire type are difficult to meet the high security and high reliability requirements from new micro-satellites and Micro-Electro-Mechanical System fuse. With the development of micro-electromechanical system technology, metal film bridge became a good plan. In order to achieve a good safety and reliability of ignition, its shape structure needs to be designed. The metal film bridge is made up with the substrate, the effective metal film and the conductive pads. If the acreage of the metal film is big enough, its ignition mechanism is heat conduction [1] as the traditional bridge wire initiators, otherwise, its ignition mechanism comes to be the Micro-convection principle as plasma ignition.

The main research institutes for the metal film bridge, such as Vishay Company in America, CNRS [2], Mechanical and Electrical Engineering, National University of Singapore [3], and Korea Institute of Technology [4]. America contributed most of the researches to reduce the fire energy of the metal film bridge. While others contribute carried out researches about the safety. The metal film bridge were applied to airbag at first, then to the ignitor in explosive train. Four improvements were made by designing the relationship between the structure and primary explosive charge [5]. The fourth generation has the lowest ignition voltage which is 1.23~1.54V, it is suitable for MEMS devices. The bridge’s Parameters are shown in Table 1.

In 2008, American Vishay Company produced a metal film resistor chip [6]. The five parameters are as the following Table 2 and the structure is right on the Fig.1. The resistance is between 2Ω and 10Ω, with the fire voltage can be decreased to 50μJ and the fire time be decreased to 50μs. This kind of metal film bridge has been used in some MEMS fuse [7].
Figure 1. The structure of metal film resistor chip.

Table 1. Fourth generation initiating element in America.

| Shape | Resistance/Ω | Firing voltage/V | Standard deviation/V |
|-------|--------------|------------------|-----------------------|
|       | 1.1          | 1.43             | 0.068                 |
|       | 2.3          | 1.54             | 0.056                 |
|       | 1.8          | 1.23             | 0.051                 |
|       | 1.5          | 1.45             | 0.213                 |

In 2010, American MAT Company announced its heating device [8] in electronic detonators which ignition voltage can be 1.6V. There is a trend that the ignition voltage becomes smaller and smaller, with the ignition accuracy increased.

In 2009, Guanghai Wang [9, 10] designed a “double-V” metal film bridge by means of masking, which structure is shown in Fig.2. He studied the comparison experiment of the safety, the fire performance and the antistatic ability between MFB and bridge wire. And got the result that the “double-V” metal film bridge had better fire performance and antistatic ability with the minimum fire voltage to be 22.6V. Ruizhen Xie [11] studied the impact factor in the fire voltage, like different shapes and sizes, found that which had the lowest fire voltage was 4.09V with the thickness of 0.9μm.

Figure 2. Structure and infrared thermal imaging of MFB.

2. Structure Design and Preparation of MFB
Metal film bridge is made up of four parts. The first layer is the substrate, which material can be glass or silicon, etc. The second is Ni-Cr alloy, with thickness of 0.3μm, which can transform the electricity into heat to give power to ignite the fire powder, which is sputtered on the substrate. The third is Titanium which strengthens the degree of cohesion between Ni-Cr alloy and golden pads, to prevent the golden pads from shedding off from the pad. The fourth is gold pads, which are used in connection with the bonding wire, conduction and radiating. The production flow chart is presented in Fig.3. Sliced with a slicing machine, and selected chips are adhered with HY914 epoxy adhesive on the PCB, and electrode connection of wiring plate and the bridge on the PCB is made with aluminum or gold wire by ultrasonic welding technology, which is shown in Fig. 4.
3. Ignition performance of MFB/LTNR

A capacitor discharge firing circuit (10μF) supply current to MFB with an electrical trigger pulse to test the critical ignition voltage and fire time. Firing circuit is shown in Fig. 5. A fast photo diode is used to record emission of light. Both voltage signals loading on the MFB and the output of the photodiode, are recorded in multiple channel digital oscilloscope (DPO7104, 1GHz, 2.5Gs/s) during the whole ignition process.

The energetic material LTNR is ignited with electric characteristics curves of the MFB/LTNR are shown in Fig.6, where the letters V and I represent the voltage and current in the metal film bridge, and the letter R represents the resistance, which is calculated from the measured voltage and current. Resistance of MFB first increases and then decreases, finally rises to a certain value. If the heat enough, LTNR will be ignited, with the optical signal appeared shown in Fig. 6(a). If the heat too high, MFB will be exploded, the signal showed in Fig. 6(b).
Figure 6. Characteristic curve of MFB under the capacitor discharge.

Around the exploding critical voltage, the MFB starts to melt and vaporize, no plasma is formed, and LTNR is ignited by the Ni-Cr vapor, which transfers heat from the MFB to the energetic material is via convection rather than conduction. Ignition time became 60µs from 130µs.

Figure 7. Relation between aspect ratio and the critical firing voltage.

Table 2. Ignition voltage and Standard deviation of MFB on the different substrates.

| Substrate material | The sample No. | Quantities | 50% of the firing voltage/V | Standard deviation/V | 99.9% of the firing voltage/V |
|--------------------|----------------|------------|----------------------------|---------------------|-----------------------------|
| Glass              | A              | 20         | 10.26                      | 0.07                | 10.48                       |
|                    | B              | 20         | 9.22                       | 0.29                | 10.12                       |
|                    | C              | 20         | 8.27                       | 0.26                | 9.08                        |
|                    | D              | 20         | 7.46                       | 0.17                | 7.98                        |
|                    | E              | 16         | 5.46                       | 0.12                | 5.84                        |
| Silicon            | A              | 15         | 21.34                      | 0.23                | 22.05                       |
|                    | B              | 20         | 19.45                      | 0.50                | 20.99                       |
|                    | C              | 20         | 17.77                      | 0.26                | 18.56                       |
|                    | D              | 20         | 15.99                      | 0.24                | 16.72                       |
|                    | E              | 15         | 12.33                      | 0.24                | 13.07                       |
Comparing with two metal film bridges prepared on glass and silicon substrate from the Table 2 and Figure 8, which have the same bridge size, the ignition voltage of the glass substrate is half of the silicon substrate. The result suggests that thermal conductivity of the substrate material have a greater influence on ignition performance of the MFB/LTNR experiment.

4. Conclusions
This paper presents Ni-Cr (80/20) metal film bridge in simple construction with bridge area in various sizes, and are made on the two substrates of glass and silicon with MEMS processing technology. The following conclusions have been drawn:

(1) Reducing MFB area has a significant contribution to reduce ignition voltage.
(2) Increasing the width has a more significant contribution to reducing ignition voltage than decreasing length (the slope with fixed length higher than the slope with fixed width).
(3) The thermal conductivity of the substrate material has a great influence on ignition performance of the MFB/LTNR.

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