Study on the Design of bridge microstructure for Energy Conversion Components

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Abstract: Microstructure energy conversion components, as the key components of MEMS initiating explosive device, has a significant impact on the output performance and energy utilization of the initiating explosive device, especially the design of its bridge microstructure. In order to perfect the design theory of microstructure energy conversion components of MEMS (Micro Electro-Mechanical Systems) initiating explosive device, 8 different bridge microstructure are designed for energy conversion components in this paper, and using simulation research and infrared test to carry out the research on the planar microstructure effect and the better bridge type choice of a series of bridge type. Obtained two optimization bridge structure of microstructure energy conversion components and the influence law between different microstructure and output performance of energy conversion components, and the average ignition voltage of V-50 bridge microstructure energy conversion components up to 100μF/3.5 V, and the energy utilization rate is 46.6%.

Key Words: microstructure energy conversion component; bridge structure; temperature rise rate; bridge fusing current

1 Introduction
Initiating explosive device (IED) is the disposable components with detonation, ignition and powered, which has the characteristic of function first, sensitive, widely used and etc. With the research and development of Micro-Electro-Mechanical-Systems (MEMS), MEMS initiating explosive device became a research hotspot in the field of IED in recent years. MEMS initiating explosive device which base on the MEMS technology or compatible with MEMS process, it has some size characteristics: the structure of energy conversion components and the scale of energy materials in...
micro, the scale of core device in the sub-millimeter level, and the scale of system in millimeter level. This kind of initiating explosive device is integrated with information control, safe and actuator and detonating unit, bring it has the characteristics of information, small and multi-function, and it’s a key basic technology of informatization and smart ammunition\(^\text{[2-4]}\).

Microstructure Energy Conversion Components is the core devices of IED to realize energy conversion, and it generally is a plane resistance that made of metal film or semi-conducting material in substrate, and to realize the energy transfer and implementation with energetic materials through resistance heating and so on. The focus in the study of MEMS IED is the study on microstructure energy conversion components, and research has been widely spread in several research institutes at home and abroad, which focus on substrate materials\(^\text{[5,6]}\), the structure of bridge\(^\text{[7-9]}\) and the matching with sequence energy, etc. Research indicates that lower ignition energy and the high energy conversion efficiency are the main characteristics of ideal energy conversion components of MEMS IED\(^\text{[10]}\).

At present, the research of microstructure energy conversion components are relatively more, but have not formed a series of study. For example, the influence of bridge structure on performance of energy conversion components, which most study is aimed at a single bridge structure, and did not comprehensive comparison of the performance for different bridge structure energy conversion components. Based on this, eight different bridge structures energy conversion components were designed in this paper, and to develop research of performance for them, and obtained a better bridge structure and the influence law of different bridge structures for energy conversion components performance.

2 Design research for bridge of microstructure energy conversion components

2.1 Bridge design of microstructure energy conversion components

At present, bridge design of microstructure energy conversion components mainly includes the square, inverted “V” shape, serpentine, etc, and considering resistivity scale effect of metal film at the same time, and eight different bridge structures energy conversion components were designed, that are shown in Figure 1. Bridge material of energy conversion components is Ni-Cr alloy, and the substrate is Pyrex7740 glass.
Figure 1. Design structure of bridge for energy conversion components (units: mm)

The above design bridge structure is based on a square bridge (150μm*150μm, F-150) to transform. The inverted “V” structure, which bridge width on both sides to keep 150 micron, and the center of the bridge area is reduced to 50 micron and 100 micron respectively, and to obtain two different inverted “V” bridge structure, and named V-50 and V-100. The trapezoidal structure, which bridge center width keep 150 micron, and the bridge width on both sides is reduced to 50 micron and 100 micron respectively, and to obtain two different trapezoidal bridge structure, and named T-50 and T-100. The curve structure, which bridge width on both sides to keep 150 micron, and the center of the bridge area is reduced to 100 micron, and to obtain a hyperbolic bridge structure, and named S-100; And the bridge center width to keep 150 micron, and the bridge width on both sides is reduced to 100 micron, and to obtain an ellipse bridge structure. The diamond structure, which bridge center width keep 150 micron, and the diamond sides are 150 micron, and the diamond on each side extension of 15 microns to make two electrode distance increased to 290 micron, and named L-1.

2.2 Simulation research for microstructure energy conversion components

Initial bridge area of MEMS energy conversion components is solid, and the temperature in the bridge area increases gradually with the increase of the energy conversion time. When the temperature in the bridge area is over bridge material melting point, and the bridge area gradually change from solid to liquid, which flows, namely bridge fusing. Thus, for the different bridge structure energy conversion components, the simulation analysis of electro-thermal and fluid-solid heat transfer is mainly carried out, and to obtain the temperature rise curves under different input conditions, highest temperature in bridge area and the distribution of fluid-solid heat transfer region. Then, the optimal bridge structure can be obtained by comparative analysis.

Figure 2. 1/4 geometric models of microstructure energy conversion components

In the process of simulation research, substrate and outside air domain such as the influence of the interface must be considered, except for the energy conversion components model. Therefore, the exchange of heat with the outside domain after heating, melting and solidification of material, and the air natural convection are main consideration in the simulation calculation. Due to the energy conversion components have symmetry plane structure, and the study was carried out mainly based on as shown in Figure 2 1/4 simulation of geometric model, and to obtain the temperature rise rate and the temperature distribution in different bridge structure under the condition of constant current, and comparison of fluid-solid heat exchange area.
Simulation calculation using two kinds of incentives, including constant current and capacitor discharge. Constant current excitation is from 100 mA to 600 mA, and gradient 100 mA, and capacitance incentive is 100μF/3V. Material of energy conversion layer is Ni-Cr alloy, and substrate is Pyrex7740 glass, and their thermo-dynamic parameters are shown in Table 1.

Table 1. Thermodynamic parameters of two kinds of materials

| materials   | density (kg/m³) | melting point (K) | specific heat (J/kg K) | thermal conductivity (W/m·K) |
|-------------|-----------------|------------------|------------------------|-----------------------------|
| Pyrex7740   | 2500            | 1525             | 753                    | 1.4                         |
| Ni-Cr       | 8400            | 1673             | 460                    | 15                          |

The curve of temperature rise rate that simulation calculation in different bridge structure of energy conversion components under the condition of constant current excitation (200mA) is shown in Figure 3.

![Figure 3](image)

**Figure 3.** Temperature rise rate under constant current excitation of energy conversion components with different bridge structure (200mA)

The figure shows that temperature rise rate of energy conversion components with different bridge structure have obvious difference in 200 mA constant current excitation, and the temperature rise rate of V-50 and L-1 is significantly higher than other bridge, and the output temperature is relatively high.

Then, comparative analysis fluid solid heat transfer area of energy conversion components with different bridge structure, without considering obvious defects that the manufacture craft process on the microstructure of bridge caused, which can effectively predict the broken bridge position after ignition for energy conversion components with different bridge structure, and to guide the design of bridge microstructure. Fluid solid heat transfer area distribution of eight kinds of energy conversion components shown in Figure 4.
The figure shows that other bridge structures give priority to fluid-solid heat exchange at the corner except for the F-150, S-150 and L-1 bridge structure, and where the heat is concentrated that is the location of the most vulnerable bridge. Among them, the V-50 bridge as an example, the center of the bridge is the narrowest, and the current density is the maximum during the energizing process, and heat generated much and relatively concentrated, therefore, it is the easiest to break the bridge. Fluid-solid heat transfer of F-150 bridge occurred preferentially at the center of the bridge, that because the bridge structure is simple without local structure, and the heat is evenly distributed throughout the bridge, and the superposition of heat lead to the highest temperature in the center of the bridge area. Fluid-solid heat transfer of L-1 bridge occurred at the center of the bridge, rather than on both sides, and the analysis shows that the line width is related to the 15 microns length of both sides of the original design. Fluid-solid heat transfer of S-150 bridge occurred neither on either side of the bridge nor in the bridge center, which is caused by the characteristics of the bridge microstructure. The heat concentrated generated on up and down the center of the S-150 bridge, and heat accumulation leads to the highest temperature in the center of the bridge area with the increase of current time energy conversion components.

In conclusion, through the simulation and analysis research for eight kinds of energy conversion components, not only can effectively predict the broken bridge position after ignition, more important is can according to the ignition performance requirements, and further improving the design structure of MEMS energy conversion components.

2.3 **Infrared test for microstructure energy conversion components**

In order to get in response characteristics of energy conversion components under the constant current, and validate the simulation results, infrared test was performed for eight kinds of energy conversion components under the constant current excitation. And the temperature rise curve, critical fuse current in bridge area and the broken bridge location were obtained by infrared test, and further clear the influence law of bridge microstructure for response output of energy conversion components under constant current. Temperature rise curve of infrared test for energy conversion components with different design structure under constant current excitation (200mA) is shown in Figure 5.
Figure 5. Temperature rise under constant current excitation of energy conversion components with different bridge structure (200mA)

The figure shows that the simulation calculation results and the infrared test results are basically identical, the temperature rise rate of V-50 bridge and L-1 bridge is significantly higher than other bridge, and the output temperature is relatively high. The analysis shows that there is an obvious inflection point in the bridge area, and the current density in the inflection point is bigger, therefore, the temperature rise of these type energy conversion components is higher than others.

Critical fuse current in bridge area and the corresponding output temperature of energy conversion components with different microstructure are shows in Tab.2.

Table 2. Bridge fusing current of microstructure energy conversion components with different bridge structure

| Bridge | V-50 | V-100 | F-150 | T-50 | T-100 | S-100 | S-150 | L-1 |
|--------|------|-------|-------|------|-------|-------|-------|-----|
| bridge fusing current/mA | 250  | 300   | 325   | 225  | 250   | 225   | 300   | 225 |
| output temperature/K      | 595  | 547   | 616   | 569  | 594   | 616   | 631   | 645 |

3 Ignition performance test for microstructure energy conversion components

Capacitive ignition performance experiment was carried out for eight kinds of energy conversion components, and the ignition circuit as shown in Figure 6, and the capacitance is 100 uF. And test at same time using oscilloscope gathering the curve of current, voltage change over time, and experiment was carried out in isolation room.

Test samples are shown in Figure 7, the chip of energy conversion components were paste to the PCB board, and using ultrasonic welding to realize the conduction between the chip of energy conversion components and PCB board, and it is convenient to apply electric excitation to carry out the ignition performance test. And the energetic materials are lead styphnate.
Through simple processing by the curve of the voltage over time, the $P(t)\cdot t$ was obtained and shown in Figure 8. Then, to integral curve to obtained the bridge input energy ($Q$), and to calculate the power input energy ($E$) according to equation (2), finally, to calculate the energy utilization rate ($\eta$) of energy conversion components according to equation (3).

\[ Q = P(t) \cdot t = I^2(t) \cdot R_0 \cdot t \quad (1) \]

\[ E = \frac{1}{2}CU^2 \quad (2) \]

\[ \eta = \frac{Q}{E} \quad (3) \]
Ignition performance parameters that obtained by ignition test for energy conversion components with different bridge are shown in Tab.3.

Table 3. the firing performance parameters of microstructure energy conversion components with different bridge (capacitance 100μF)

| bridge  | V-50 | V-100 | F-150 | T-50 | T-100 | S-100 | S-150 | L-1 |
|---------|------|-------|-------|------|-------|-------|-------|-----|
| test resistance/Ω | 6.57 | 5.57 | 5.23 | 8.65 | 6.58 | 9.17 | 8.14 | 8.66 |
| firing voltage/V | 3.5  | 4.5  | 5.5  | 5    | 5    | 5    | 6    | 4.5 |
| ignition time/μs | 138  | 160  | 143  | 150  | 139  | 198  | 176  | 181 |
| E/mJ   | 0.61 | 1.01 | 1.51 | 1.25 | 1.25 | 1.25 | 1.8  | 1.01 |
| Q/mJ   | 0.286 | 0.367 | 0.601 | 0.555 | 0.353 | 0.548 | 0.779 | 0.334 |
| η*100 | 46.6 | 36.3 | 39.7 | 44.4 | 28.2 | 43.9 | 43.3 | 33  |

The ignition performance test results shows that:

(1) Among the eight kinds of microstructure energy conversion components, the energy utilization of V-50 bridge structure is the highest, reached 46.6%, and the ignition voltage, ignition energy and ignition time are less than other bridges.

(2) When the resistance is less than a certain critical value (10Ω), the influence of the resistance for ignition voltage is irregular. The analysis shows that the small resistance (≮10Ω), the ignition performance of microstructure energy conversion components were mainly impacted by design microstructure, the quality and the heat dissipation area of bridge.

(3) Ignition test results of energy conversion components with different bridge microstructure and simulation research, and the infrared test results are consistent, and that is the ignition performance of V-50 bridge structure is the best.
4 Conclusion and perspectives

Microstructure energy conversion components is the key components of MEMS initiating explosive device to realize energy conversion, and the bridge structure of which has a significant impact on the output performance and energy utilization of the initiating explosive device. Through the simulation research, and the infrared test and ignition test for eight kinds of microstructure energy conversion components, the optimization bridge structure has been obtained and the influence law that bridge microstructure for ignition performance.

(1) Different design microstructure of energy conversion components have a significant impact on the output performance, and the “neck” structure is helpful to improve the ignition performance, that reflected in the V-50 bridge structure energy conversion components has the highest output temperature, and the fastest temperature rise rate; In addition, fluid-solid heat exchange priority occurred at the corner of bridge area, and the bridge area where centralized heat is the most easily broken bridge location.

(2) When the resistance is less than a certain critical value (10Ω), the influence of the resistance for ignition voltage is irregular. The analysis shows that the small resistance (≥ 10Ω), the ignition performance of microstructure energy conversion components were mainly impacted by design microstructure, the quality and the heat dissipation area of bridge.

Subsequently, to further study on low-energy for microstructure energy conversion components, and to study on the information integration technology, so as to promote and expand the application research for microstructure energy conversion components.

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