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Micro Fuse Fabrication and Testing

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Abstract

This paper presents a micro copper fuse developed on a glass epoxy plate using wet etching technology. The fuse structure has a length of 600 μm and a width of 80 μm. The thickness of the copper layer is 30 μm. Numerical simulation was studied with ANSYS software to predict the temperature distribution of the micro fuse with variable input current. Different micro fuse cross sectional areas were obtained by controlling the etching time. The fuse characteristics were evaluated experimentally using input power to the blowing current at 0.1 A increment.

Measured temperature showed good agreement with the simulation data. Under safety standard test requirement, the normal rated current of the design micro fuses are 1.15 A, 1.60 A and 2.10 A at an input voltage of 3.6 V.

Key Words: Micro Copper Fuse, Wet Etching, Glass Epoxy Plate, Temperature Distribution, Blowing Current, Safety Standard

1. Introduction

A high capacity electric fuse [1] is an important component in modern energy systems. Despite the extensive study of fuse characteristics, manufacturers are still looking for models and tests that can represent fuse behavior. The fuse has played an extremely important role in the field of micro electronic product safety. The development of micro fuses [2,3] for different demands and applications is necessary.

M. A. Saqib and A. D. Stokes [4] presented the radiation spectrum of arc plasma in a simple high voltage experimental mode, high breaking capacity (HBC) fuse. A 62.5 μm diameter multi-mode silica fiber was used as a light-pipe to carry the plasma radiation from within the arc space of the experimental fuse to the spectrograph. D. Maier-Schneider et al. [5] developed a low-power polysilicon fuse with high reliability made from LPCVD-poly-silicon. The length of the fuse notch was approximately 3 μm. The width and thickness were approximately 1 μm and 0.5 μm, respectively. The initial resistance was about 200 Ω. This fuse could be blown with high yield using voltage pulses at an amplitude of approximately 4V and a blowing current of 20–40 mA.

In 2002, Psomopoulos et al. [6] modeled the function of medium and low voltage fuses to estimate the increase in temperature across the fuse elements during nominal current operation for different types, diameters lengths and currents. The analytical expression for the temperature of the fuse elements, under nominal current operation, was the main advantage of their theoretical model. Many micro shaping techniques have been realized for various microstructures [7,8]. A high aspect ratio of the micro-structure manufacturing process is implemented for micro devices, such as micro motors, micro valves, micro nozzles and micro-channels. In this paper, a micro copper fuse was developed on a glass epoxy plate using wet etching technology. The fuse structure has a length of 600 μm and a width of 80 μm. The thickness of the copper layer is 30 μm.

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2. Micro Fuse Fabrication

With the progress of the Interconnect Technology, the wire pitch has been reduced, making the electrical capacity among the wires greater. This has produced RC time to postpone (RC Time Delay) [9]. Replacing aluminum as the conducting wire with copper and metal occurs more now. Because the electron signal transmits determines the resistance (R) and product capacitance (C). The smaller the RC value, the faster the speed [10]. Copper was therefore used to make the fuse to reduce the RC Time Delay in this study.

The micro fuse processing sequence is depicted in Figure 1, glass epoxy plates were selected using wet etching for the micro copper fuses. The process is described below:

a. Glass epoxy plate cleaning: DI water was used to remove particles from the surface of the glass epoxy plates.
b. Expose and developing: The well-controlled ultraviolet exposure was operated to cross-link and strengthen the dry film photoresist. Then blended potassium carbonate developer and DI water for developing and dissolved and washed off the uncross-linked photo-resist.
c. Etching: Iron chloride ($FeCl_3$) solution is used to etching copper. Different micro fuse cross sectional areas were obtained by controlling the etching time.
d. Remove photoresist: The glass epoxy plate samples were dipped in alcohol to remove the photoresist.

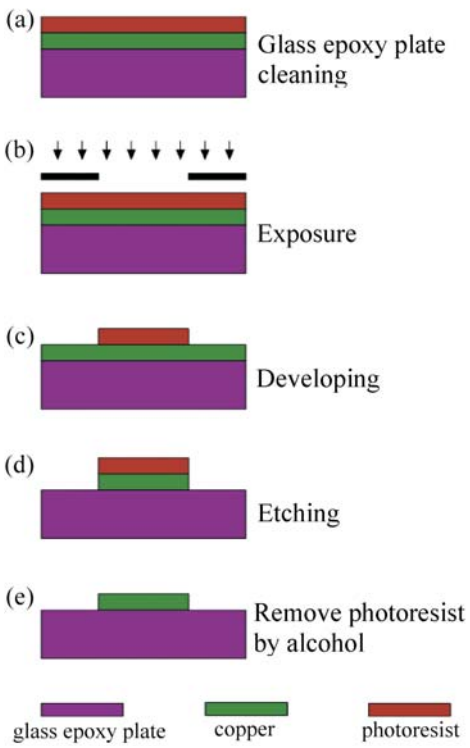

Figure 1. The illustration of process for fabricating the micro fuses.

Micro copper fuses were formed as shown in Figure 2. The micro copper fuse illustration is shown in Figure 3.

3. Micro Fuse Test and Analysis

According to the security norm of the fuse [11] that must to obtain the UL248 or IEC127 safety certification is defined as below:

a. Electrified with the normal rated current and does not blow in an hour.
b. The temperature increase below 75 °C the when the normal rated current is electrified.
c. Electrified with two times of normal rated current, blowing within one minute.
d. While adding the normal capacity of broken circuit will not produce and fly arcly or guide and fire in succession.

Experiments and the finite element method were used to measure micro copper fuses in the simulations. Voltage, current, temperature and blowing time tests were performed for micro fuses in these experiments.

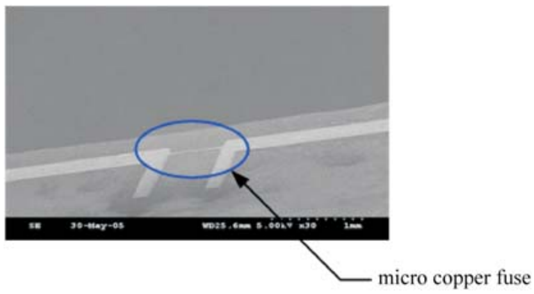

Figure 2. The SEM photograph of micro copper fuse.

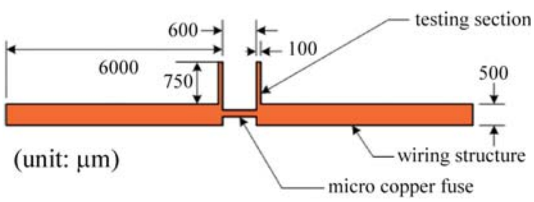

Figure 3. The illustration of the micro copper fuse.

(1)Voltage, current and temperature measure:

The experimental apparatus is shown in Figure 4. A power supply was employed to control the voltage and current for the micro fuse. The fixed input voltage was 3.6V and gradually increased input current from 0.1A to blowing current have been used. The voltages V_1 and V_2 were acquired from voltmeter at wiring structure section and micro copper fuse section and would be used to simulate using ANSYS.

ANSYS element 69 and 90 were used respectively to simulate micro copper fuse and glass epoxy plate. The input parameters thermal conductivity coefficient and resistance coefficient varied as temperature changes. The boundary conditions included air convection heat transfer coefficient, environment temperature and voltage V_1 and V_2. The temperature distribution of micro fuse is shown in Figure 5.

Three different normal rated current of micro copper fuse that were 1.15A, 1.6A and 2.1A would be tested. As the input current increases, the measured voltage V_1 of the micro fuses increases, nearly in agreement with the linear relations. Figure 6 is one of the test results.

Figure 7 is one of the tests of the relation of temperature and input current for micro copper fuses. Temperature raises as the input current increases and the experimental data and the ANSYS simulate are in a good agreement. The data are presented in Table 1.

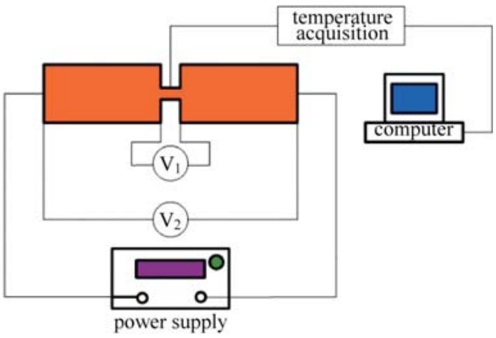

Figure 4. The illustration of the experimental apparatus.

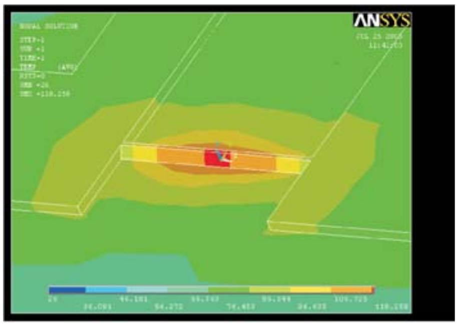

Figure 5. The temperature distribution of micro fuse.

(2)Blowing time measure:

Table 2 shows the average blow out time for three size micro fuses at 41.8, 48.4 and 24.6 sec. at twice the normal rated current input 2.3A, 3.2A, and 4.2A, respectively. Under these circumstances the normal rated current is input, exceeding an hour, the three kinds of fuses do not all blow, see Figure 8(a). This is in accord with the fuse security norm. Figure 8(b) shows that the micro fuse blew under over current input.

Figure 9 shows the blow out time for micro fuses to reduce as input power to its blowing current with an increment of 0.1A. Under twice the normal rated current input 2.3A, 3.2A, and 4.2A for three size micro fuses, the blow out times are 41.8, 48.4 and 24.6 sec., respectively.

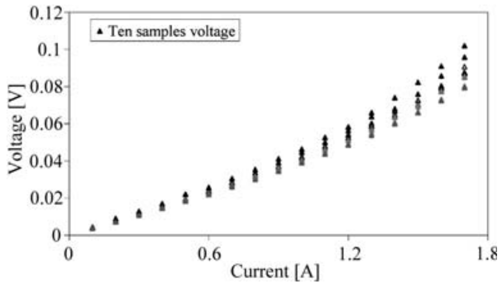

Figure 6. The relation of voltage and input current for 1.15A normal rated current of micro copper fuse.

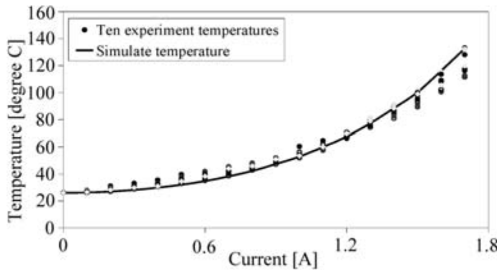

Figure 7. The relation of temperature and input current for 1.15A normal rated current micro fuses.

Table 1. The temperature of experiment and simulation at normal rated current input

Areas (μm^2)	Current (A)	T (°C) (Experimental)	T (°C) (Increase)	T (°C) (Simulate)	T (°C) (Increase)
750	1.15	67.7	41.7	66.8	40.8
900	1.60	72.8	46.8	71.5	45.5
1200	2.10	75.8	49.8	74.7	48.7

Table 2. The blow out time for micro fuse at twice the normal rated current input

Areas (μm^2)	Current (A)	Input current (A)	Blowing time (sec)
750	1.15	2.2A	347
		2.3A	41.8
900	1.60	3.1A	91.7
		3.2A	48.4
1200	2.10	4.1A	77.9
		4.2A	24.6

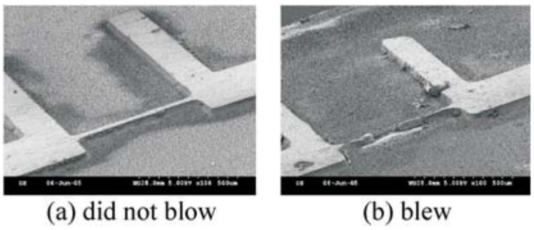

Figure 8. The SEM photograph of micro copper fuse that did not and did blow.

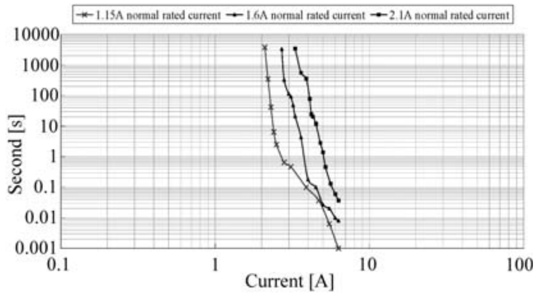

Figure 9. The relation of the blowing time of micro fuses and input current.

4. Conclusion

A simple, economical and effective technology for fabricating micro copper fuses using wet etching on glass epoxy plates is proposed. Three different cross sectional micro copper fuse areas; 750 μm^2, 900 μm^2 and 1200 μm^2 were obtained by controlling the etching time. The normal rated fuse currents were 1.15A, 1.6A and 2.1A respectively.

Numerical simulation was studied with ANSYS software to predict the temperature distribution of the micro fuse with variable input current. The highest temperature was found at the middle segment of the micro fuse. The temperature increased as the input current increased and the experimental data and ANSYS simulation were in a good agreement.

Under normal rated current input, micro fuses do not blow in an hour and the maximum increase temperature was 49.8 °C for three size micro fuses. The times for blow out for three micro fuse sizes were 41.8, 48.4 and 24.6 sec. This data fits with the fuse security norm.

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