Investigation of Inrush Current in Nickel Microfuses

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Abstract. This paper presents investigation of inrush current in nickel microfuses using microelectromechanical systems technology with high-aspect-ratio micromachining technology by x-ray lithography technique. The nickel microfuses were designed by the tether and saw-tooth pattern and studied the melting time, maximum melting current, maximum voltage and maximum energy consumption of the nickel microfuses in a blowing circuit. A microcontroller is used as a device to measure and collect the values of current, voltage, and energy consumption. The experimental results showed that tether fuses used melting time faster than saw-tooth fuses. But saw-tooth fuses can withstand melting current greater than tether fuses. By increasing the length of the two type fuses are ability to withstand current, power, energy consumption, and voltage are similar for the two type fuses. The $I^2t$ of inrush current is increased by the length of nickel microfuses. The length of tether 500 µm has the $I^2t$ value of inrush current a minimum at 0.0014 A²-s and the length of saw-tooth 2000 µm has the $I^2t$ value of inrush current a maximum at 0.0164 A²-s.

1. Introduction
The power consumption of electronic appliances and electric system of automotive is increasing because of the short circuit in this equipment. Therefore, the fuses in such equipment are becoming large. As current increases, the voltage fluctuations become large when a fuse is blown due to a shorting accident or an overcurrent. Components in the equipment or in other equipment connected to the DC distribution might be damaged by the voltage fluctuations [1,2]. The fuse should be used to prevent fire and overheating. It should be chosen to limit the current in the circuit below the point where components could dangerously overheat and initiate ignition. Fuses won’t even protect circuits against all faults. They typically will only help prevent overheating from a significant change in current. Fuses may protect against additional types of faults, but the fuse will not typically be the primary method of protection for those faults [3,4]. In this paper, We have studied $I^2t$ of inrush current, melting time, melting current, blowing voltage, blowing power, energy consumption of nickel microfuses prototype. The design of structural fuses are two types of tether and a saw-tooth as shown in figure 1. The fuses are fabricated of the electrodes size 1000×1000 µm² and a line width of 100 µm fuses all the same. The difference structure is the length of the fuse, such as 500, 1000, 1500 and 2000 µm respectively.

Figure 1. Fuse pattern (a) Tether design (b) Saw-tooth design
2. Principle and Theory
Inrush current refers to the maximum, instantaneous input current drawn by an electrical device when first turned on. When electrical equipment is first turned on, a large current flows that exceeds the steady-state current value. Figure 2 shows the current waveform when the power is turned on. When the power is turned on, current begins to flow, and the initial current flow reaches the peak current value that is larger than the steady-state current value. Following this, the current value gradually decreases until it stabilizes at the steady-state current. The part during which a large current flows before reaching the steady-state current is the inrush current. If the size of the inrush current exceeds that allowed by the part in use, depending on the magnitude of the inrush current (difference between the peak current value and the steady-state current value) and length of its duration (the length of time until the peak current value converges with the steady-state current value, hereafter called the pulse width), the part used in the circuit may overheat, potentially causing the electrical device to malfunction or break down [5].

![Figure 2. Current waveform when the device is powered up [5].](image)

3. Experiments
DC power supply in the experiment were used for testing the melting current of nickel microfuses. A microcontroller is used as a device to measure and collect the values of current, voltage, and power consumption. If nickel microfuses get current and voltage over the coordinates of electricity, electric stress and heat. As a result, the melting fuse and disconnect the circuit in figure 3.

![Figure 3. Testing fuse circuit block diagram [6].](image)

Figure 3 shows voltage sensor, which uses to create a simple test circuit for the principle of voltage divider. Then forwarded to the microcontroller, which allows the resistors to divide the voltage does not exceed 5 Vdc so that the microcontroller can read an analogue input. Then processed for export to store data. The detector current using Ohm's law, since the microcontroller can be measured only in an analog voltage that does not exceed 5 Vdc only needed this principle. By measuring the voltage drop across the resistor relative to ground, then divided by the resistance to the current flowing through the fuse. Because the resistor used to measure voltage connected in series with the fuse. The current flowing through the resistor equals the current flowing through the fuse. The experiment consisted of nickel microfuses with circuit shown in figure 2. Microcontroller is used as a tool to measure the voltage drop across the fuse and the current flowing through the test. Then use the function of microcontroller to calculate the voltage and current to the power according equation 1.
where \( P \) is the electric power (W), \( I \) is current (A), and \( V \) is voltage (V). Then, the measured data is exported to the hyper terminal program and then plot a graph of the response of the fuse. Which can be calculated from the inrush current waveforms of the experiment. Then the waveform of the current surge in the experiment is shown in figure 4.

\[
P = IV
\]  

(1)

Figure 4. (a) Inrush current waveform (b) Inrush current waveforms. Grey Line is a waveform derived from the measurement. Black line is the waveform of the estimation [7].

Calculating the \( I^2t \) (Joule Integral) inrush currents estimated from the waveform. This formula is based on an estimated waveforms. For example, Figure 4 is waveforms with a width of 1 ms and a maximum current of 6 A, when an estimated waveforms is a triangle. The formula used to calculate the equation 2.

\[
I^2t \text{ of inrush current} = \frac{1}{3} I^2_{m} t
\]  

(2)

Where \( I^2_{m} \) is the peak current (A), \( t \) is the pulse applying time (s), and \( I^2t \) of inrush current is the peak current squared times time (A²-s). Equation 2 calculates the \( I^2t \) of inrush current. Results of the \( I^2t \) of inrush current is \((1/3) \times 6^2 \times 0.001 = 0.012 \text{ A}^2\text{-s}.\) This method will be used to determine the \( I^2t \) of inrush current the following range of nickel microfuse sizes.

4. Results

In the experiments, the nickel microfuses are measured such as length of tether 500, 1000, 1500, and 2000 µm and length of saw-tooth 500, 1000, 1500, 2000 µm, respectively. We used a blowing circuit in figure 3, which can measure the voltage and the current flowing through the fuse and storage data of current and voltage. These data were calculated the power consumption that occurs, then the experiments and analyzed the results below. Table 1 shows the characteristic of nickel microfuses rated testing and important parameters, such as melting time, peak current, peak voltage, peak power and peak energy consumption, etc. The initial resistance was measured by a digital LCR Meter (Digicon Model DM-845) measured at a frequency of 1 kHz.

Table 1. Concluded other important parameters of the nickel microfuses.

| Parameters                  | Tether length (µm) | Saw-tooth length (µm) | Units |
|-----------------------------|--------------------|-----------------------|-------|
| \( I^2t \) of inrush current| 0.0023             | 0.0045                | A²-s  |
| Peak voltage                | 13.23              | 13.19                 | V     |
| Average voltage             | 13.17              | 13.17                 | V     |
| Peak current                | 0.37               | 0.50                  | A     |
| Average current             | 0.24               | 0.22                  | A     |
| Melting time                | 0.05               | 0.09                  | s     |
| Peak power                  | 4.88               | 6.60                  | W     |
| Average power               | 2.70               | 2.83                  | W     |
| Peak energy consumption     | 0.24               | 0.59                  | J     |
| Average energy consumption  | 0.14               | 0.25                  | J     |
| Initial resistance          | 0.250              | 0.319                 | Ω     |
| Final resistance            | -                  | -                     | Ω     |
5. Conclusions
The experiments showed that the duration of current, while the melting time of the nickel microfuses tether types with a length of 500, 1000, 1500, 2000 µm and a saw-tooth types with a length of 500, 1000, 1500, 2000 µm and thickness all microfuses of 90 µm, which showed that the microfuses can withstand peak current following the in Table 1. The tether types take a melting time faster than saw-tooth types but saw-tooth types can withstand current and melting time over tether types. However, if the microfuses is increased the length, which increases the ability to withstand current, power, energy consumption is increased as well and the microfuses voltage are the same for all. The $I^2t$ of inrush current is increased by the length of nickel microfuses. The length of tether 500 µm has the $I^2t$ value of inrush current a minimum at 0.0014 A²-s and the length of saw-tooth 2000 µm has the $I^2t$ value of inrush current a maximum at 0.0164 A²-s.

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