EUROPEAN QUALIFYING EXAMINATION 2018

Paper B

This paper comprises:

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Description of the Application

[001] The invention relates to fuses for protecting electronic circuits.

[002] Fuses are used to protect the components of an electronic circuit from damage caused by excessively high electrical currents (hereinafter: overload currents). The components of an electronic circuit can be categorised with respect to overload currents as being either low-sensitivity electronic components or high-sensitivity electronic components.

[003] A prior art fuse is shown (not to scale) in Fig. 1A in perspective view, in Fig. 1B in plan view, and in Fig. 1C in cross-sectional view. The fuse 1 comprises an electrically insulating substrate 2, a fuse track 3, and two electrodes 4. The fuse track 3 and the electrodes 4 are provided on the substrate 2. The fuse track 3 is formed of metal alloy such as nichrome, which is a nickel-chromium alloy. The fuse track 3 is connected at its ends to the respective electrodes 4. In use, the fuse 1 is connected via the electrodes 4 to the electronic circuit to be protected. During normal operation of the electronic circuit, the fuse 1 is electrically conducting, that is, an electrical current flows from one electrode 4 to the other electrode 4 via the fuse track 3, whereby the fuse remains intact. However, in the event of an overload current, the fuse track 3 will heat up, melt, and rupture, leaving the two ends of the fuse track separated by a gap 3', as shown in Fig. 1D. The fuse 1 is then described as being “blown”. The gap 3' prevents the overload current from flowing through the components of the electronic circuit and damaging them. The value of the overload current at which the fuse 1 blows is predetermined.
For effective protection of electronic components, it is desired that the blowing of the fuse be irreversible, and occur at the predetermined current. However, the above-mentioned prior art fuse with a fuse track made of nichrome suffers from metal reflow under unfavourable conditions such as high humidity. Metal reflow is the phenomenon whereby the metal of the fuse track of a blown fuse flows back into the gap between the electrodes such that the fuse track re-forms and the fuse becomes conducting again. As a result, the blowing of the prior art fuse is not irreversible, thereby endangering the electronic circuit.

An aim of the invention is therefore to provide a fuse for protecting an electronic circuit which overcomes the above problem. According to claim 1, the fuse track is formed of aluminium-copper (AlCu) alloy.

A fuse 11 according to an embodiment of the invention is shown in Fig. 2 in plan view. The fuse 11 has a structure similar to the prior art fuse described above, and comprises an electrically insulating substrate 12, a fuse track 13 and two electrodes 14. The fuse track 13 is connected at its ends to the respective electrodes 14. The fuse track 13 is made of AlCu alloy. The preferred amount of Cu in the AlCu alloy is 5-25% by weight, more preferably 10-20% by weight, most preferably 15% by weight. The fuse 11 functions in the same fashion as the prior art fuse 1 described above, but with the benefit of reduced metal reflow of the fuse track.

The fuse track 13 can have a neck portion 13a between its two ends. The fuse track 13 is narrower at the neck portion 13a. When an overload current passes through the fuse track 13, the metal heats more rapidly at the neck portion 13a due to its reduced cross-section. The fuse track 13 will thus rupture at the neck portion 13a when the fuse 11 blows. The value of overload current at which the fuse 11 blows is proportional to the width of the neck portion 13a. Thus, the value of the overload current which in operation blows the fuse 11 is predetermined by the width of the neck portion 13a.
A fuse 21 according to a second embodiment of the invention is shown in Fig. 3A in plan view and in Fig. 3B in cross-sectional view. The fuse 21 comprises an electrically insulating substrate 22, a fuse track 23 and two electrodes 24. The fuse track 23 is connected at its ends to the respective electrodes 24. The fuse 21 differs structurally from the fuse 11 of Fig. 2 in that a cover layer 25 made of epoxy resin is provided to cover the fuse track 23. When an overload current passes through the fuse 21, the AlCu fuse track 23 heats up, melts, and ruptures, thereby forming a gap. Some of the heat is transferred to the cover layer 25 which then softens and flows into the gap. With the material of the cover layer 25 present in the gap, the metal of the fuse track 23 cannot flow back into the gap. Metal reflow of the fuse track 23 is thereby reduced. The amount of Cu in the AlCu alloy is 10-20% by weight. The fuse track 23 comprises an optional neck portion 23a.

In each of the following Examples 1-10 and Comparative Examples 1 and 2, batches of 100 identical fuses were provided. In Examples 1-10, different compositions of AlCu alloy were employed as the metal of the fuse track. In Examples 1-5 (Table 1), no cover layer was provided. In Examples 6-10 (Table 2), a cover layer made of epoxy resin was provided. In Comparative Examples 1 and 2, nichrome having nickel 80% by weight and chromium 20% by weight was used as the metal of the fuse track, without a cover layer (Table 1) and with a cover layer made of epoxy resin (Table 2), respectively. The fuses were subjected to an overload current sufficient to blow them. Testing was conducted in an atmosphere with relative humidity of 95%. We present the results of the tests to determine metal reflow as follows:

(i) A quality score (Q) was determined according to our in-house protocol, namely by counting the number of “good” fuses. We define a “good” fuse as one where metal reflow was minimal. Thus a high quality score (Q) indicates a low degree of metal reflow.

(ii) For each batch of fuses the standard reflow index (SRI) was determined. The SRI is well-known to the person skilled in the field of electronic circuits. A low value on the index indicates a low degree of metal reflow.
The results are shown in the following Tables.

### Table 1

<table>
<thead>
<tr>
<th>No.</th>
<th>Metal of fuse track</th>
<th>Amount of Cu (wt%)</th>
<th>Quality score (Q)</th>
<th>Standard reflow index (SRI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example 1</td>
<td>AlCu</td>
<td>5</td>
<td>32</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
<td>AlCu</td>
<td>10</td>
<td>33</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>AlCu</td>
<td>15</td>
<td>35</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>AlCu</td>
<td>20</td>
<td>34</td>
<td>11</td>
</tr>
<tr>
<td>5</td>
<td>AlCu</td>
<td>25</td>
<td>32</td>
<td>14</td>
</tr>
<tr>
<td>Comparative Example 1</td>
<td>NiCr</td>
<td>-</td>
<td>28</td>
<td>16</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>No.</th>
<th>Metal of fuse track</th>
<th>Amount of Cu (wt%)</th>
<th>Cover layer</th>
<th>Quality score (Q)</th>
<th>Standard reflow index (SRI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example 6</td>
<td>AlCu</td>
<td>5</td>
<td>Epoxy resin</td>
<td>45</td>
<td>7</td>
</tr>
<tr>
<td>7</td>
<td>AlCu</td>
<td>10</td>
<td>Epoxy resin</td>
<td>66</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>AlCu</td>
<td>15</td>
<td>Epoxy resin</td>
<td>85</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>AlCu</td>
<td>20</td>
<td>Epoxy resin</td>
<td>62</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>AlCu</td>
<td>25</td>
<td>Epoxy resin</td>
<td>40</td>
<td>8</td>
</tr>
<tr>
<td>Comparative Example 2</td>
<td>NiCr</td>
<td>-</td>
<td>Epoxy resin</td>
<td>29</td>
<td>15</td>
</tr>
</tbody>
</table>
[011] It can be seen that a quality score greater than 30 is obtained if the metal of the fuse track is AlCu alloy having a content of Cu in the range 5-25% by weight. A fuse with a quality score (Q) greater than 30 provides protection for low-sensitivity electronic components against dangerous overload currents. Furthermore, it can be seen that a quality score (Q) greater than 60 is obtained if the metal of the fuse track is AlCu alloy having a content of Cu in the range 10-20% by weight and a cover layer made of epoxy resin is provided. A fuse with a quality score (Q) greater than 60 provides protection for high-sensitivity electronic components against dangerous overload currents.

[012] A fuse track of a fuse according to the present invention may be very thin. If the surface of the substrate on which the fuse track is provided is rough and the fuse track is very thin, this may lead to significant variations in the thickness of the fuse track along its length. This may lead to the undesirable situation that the fuse blows at a value of overload current deviating significantly from the predetermined current. The surface of the substrate should therefore be quite smooth. An average surface roughness Ra equal to 5 µm or less is thus preferred. To reduce roughness, the surface of the substrate may be subjected to a polishing step prior to forming the fuse track thereon.
Claims

1. A fuse (11, 21) comprising:
   - an electrically insulating substrate (12, 22);
   - first and second electrodes (14, 24) provided on said substrate (12, 22);
   - a fuse track (13, 23) made of AlCu alloy and connected at its ends to the respective first and second electrodes (14, 24);
   - whereby the fuse track (13, 23) is configured to melt when an electrical current of a predetermined value passes through it.

2. Fuse according to claim 1, wherein the fuse track (13, 23) is made of AlCu alloy having 15% by weight Cu.

3. Fuse according to claim 2, further comprising a cover layer (25) covering the fuse track (23) and wherein the fuse track (23) has a neck portion (23a).

4. Fuse according to claim 2, wherein the upper layer is made of epoxy resin.

5. Fuse according to claim 1, wherein the substrate (12, 22) has a smooth surface.
Communication

1. The examination is based on the application as originally filed. Documents D1, D2, and D3 are prior art according to Art. 54(2) EPC.

2. The subject matter of claim 1 is not novel within the meaning of Art. 54(1) and (2) EPC, because it is known from D1 or D3:

2.1 D1 discloses (see paragraphs [001], [002] Figs. 1A and 1B) a fuse (101) comprising:
- an electrically insulating substrate (102);
- first and second electrodes (104) provided on said substrate (102);
- a fuse track (103) made of AlCu alloy and connected at its ends to the respective first and second electrodes (104);
- whereby the fuse track (103) is configured to melt when an electrical current of a predetermined value passes through it.

2.2 D3 discloses (see paragraphs [002], [004], Figs. 1A and 1B) a fuse (301) comprising:
- an electrically insulating substrate (302);
- first and second electrodes (304) provided on said substrate (302);
- a fuse track (303) made of AlCu alloy and connected at its ends to the respective first and second electrodes (304);
- whereby the fuse track (303) is configured to melt when an electrical current of a predetermined value passes through it.

3. The subject matter of dependent claim 2 is also known from D1:
- D1 additionally discloses AlCu alloy having 15% by weight Cu (see D1, paragraph [002]).

4. The subject matter of dependent claim 3 does not involve an inventive step (Art. 56 EPC) in view of D1 and D2:
- D2 discloses in paragraphs [001], [002] a fuse (201) having a cover layer (205) covering the fuse track (203). The skilled person, seeking to improve the fuse of D1, would consider employing the cover layer of D2 in the fuse of D1. Furthermore, D1 clearly discloses in Figs. 1A and 2 a fuse track (103) having a neck portion.
5. **Dependent claim 4** lacks clarity because there is no precedence in the claims to which claim 4 refers for “the upper layer” (Art. 84 EPC).

Insofar as it is understood, the subject matter of dependent claim 4 is known from D1, or does not involve an inventive step in view of D2 or D3:

D1 discloses in paragraph [003] a fuse (101) comprising an upper layer (protective layer 105) made of epoxy resin (Art. 54(1) and (2) EPC).

D2 discloses in paragraph [003] a fuse (201) comprising an upper layer (wall 206) made of epoxy resin (Art. 56 EPC).

D3 discloses in paragraph [003] a fuse (301) comprising an upper layer (308) made of epoxy resin (Art. 56 EPC).

6. The relative term “smooth” renders **dependent claim 5** unclear (Art. 84 EPC).

Notwithstanding this, D1 discloses in paragraph [001] the additional feature that the substrate (102) has a smooth surface (Art. 54(1) and (2) EPC).

7. If the applicant wishes to maintain the application, new claims should be filed which take the above objections into account. Care should be taken to ensure that the new claims comply with the requirements of the EPC in respect of clarity, novelty, and inventive step (Art. 84, 54 and 56 EPC). Any amendments should not introduce subject matter which extends beyond the content of the application as originally filed (Art. 123(2) EPC).

8. In the letter of reply, the problem-solution approach should be followed. In particular, the difference between the new claims and the prior art disclosed in D1, D2 and D3, the objective technical problem underlying the invention in view of the closest prior art, and the solution thereto should be indicated. The basis in the application documents for the amendments should be indicated (Art. 123(2) EPC and Rule 137(4) EPC).
The invention generally concerns fuses for protecting electronic circuits. Figs. 1A and 1B show a fuse 101 according to the invention comprising an electrically insulating substrate 102 having a smooth surface. The fuse 101 further comprises a fuse track 103 and two electrodes 104. The fuse track 103 is connected at its ends to the respective electrodes 104. In the event of an overload current, the fuse track 103 will heat up, melt, and rupture, i.e. the fuse 101 is blown.

A suitable metal for the fuse track 103 has been found to be aluminium-copper alloy having a Cu content of 15% by weight. Fuses made using this alloy are found to be less likely to become conducting again after blowing, a problem which occurs with some low quality alloys. When the quality of the fuses of the invention was assessed using the well-known standard reflow index (SRI) in an atmosphere with relative humidity equal to 95%, the fuses were found to have improved values vis-à-vis those using low quality alloys.

The fuse 101 can comprise a protective layer 105 to protect the electrodes 104 of the fuse from corrosion due to harsh environments (Fig. 2). The preferred material for the protective layer 105 is epoxy resin or ceramic. The material used for the substrate 102 may be a resin, e.g. glass fibre reinforced epoxy resin, or glass. The surface of the substrate 102 preferably has an average surface roughness \( R_a \) equal to 5 \( \mu \)m or less. The average surface roughness \( R_a \) is a well-known parameter defined in accordance with the International Standards Organization (ISO).
Figs. 1A and 1B show a fuse 201 which is designed to protect an electronic circuit. The fuse 201 comprises a fuse track 203 and two electrodes 204 provided on an electrically insulating substrate 202, which typically has a polished surface. The fuse track 203 is formed of a metal alloy, preferably palladium-gold. However, another metal alloy may be used provided it has a suitable melting point. The fuse track 203 is connected at its ends to the respective electrodes 204.

The fuse 201 further comprises a cover layer 205 provided on the fuse track 203. The cover layer 205 is formed of glass. In the event of an overload current, the fuse track 203 will heat up, melt, and rupture, leaving the two ends of the fuse track separated by a gap, i.e. the fuse 201 is blown. The cover layer 205 of glass confines the energy in the fuse track 203 causing a micro-explosion which ruptures the cover layer 205. This rupture allows the vaporized metal of the fuse track 203 to escape and promotes a significant break in the fuse track, leaving the two ends of the fuse track separated by a gap 203', i.e. the fuse 201 is blown irreversibly (Fig. 2).

When the fuse 201 is mounted on a printed circuit board having electronic circuit components, there exists the danger that metal spraying from the fuse onto the components of the electronic circuit could damage them or cause a short-circuit. To prevent this, the fuse 201 comprises one or more walls 206 provided on the substrate 202, one wall being shown in Fig. 3. The walls 206 block any metal which is sprayed from the fuse 201 when it blows, thereby protecting the electronic circuit. The walls 206 may be formed from a layer of plastic or epoxy resin.
[001] Fuses have been incorporated into electronic circuits for protection purposes. However, under certain conditions the metal alloy can close the narrow gap formed in the fuse track after blowing of the fuse, a phenomenon known as metal reflow. We propose measures to reduce the latter.

[002] The fuse 301 shown in Figs. 1A and 1B comprises a substrate 302, an expansion layer 305 provided on the substrate, a fuse track 303 formed on the expansion layer, and two electrodes 304. The fuse track 303 is connected at its ends to the respective electrodes 304. The fuse track 303 is formed of a metal alloy. The expansion layer 305 is formed of a material which greatly expands when subjected to heating. In the event of a current overload, the fuse track 303 will rapidly heat up, melt, and rupture thereby forming a gap 303’. Some of the heat is transferred to the expansion layer 305 which then expands. As the expansion layer 305 expands under the fuse track 303, the gap 303’ between the two ends of the fuse track increases (Fig. 1C). Thus, even if the metal alloy of the fuse track is susceptible to metal reflow, the probability that the fuse track re-forms is significantly reduced.
Instead of being a single layer as described above, the expansion layer can be a stack of two layers. For instance, a suitable expansion layer stack 306 comprises a moisture-containing gel as a lower layer 307 and an upper layer 308 made of a resin (e.g. epoxy resin), the upper layer being provided directly on the lower layer (Fig. 2A). The upper layer 308 prevents the moisture from leaking out of the lower layer 307 during the normal operation of the electronic circuit. In the event of a current overload, heat from the fuse track 303 is transferred to the lower layer 307, causing the moisture in the latter to vaporise. Because the vapour cannot escape, it causes the lower layer 307 to blister, forcing the upper layer 308 upwards, thereby causing the expansion layer stack 306 to expand. As the expansion layer stack 306 expands under the fuse track 303, the gap 303' between the two ends of the fuse track increases (Fig. 2B).

Suitable metal alloys for the fuse track 303 are nichrome (Ni 80% by weight – Cr 20% by weight), aluminium-copper, and palladium-gold, which although being an expensive material is less susceptible to reflow.
Dear Mr Nick Rome,

Attached is a draft set of claims (marked-up and clean versions) we propose for filing with your reply to the official communication.

In further experiments we found that if the fuse track is made of AlCu alloy having a content of 5% Cu by weight, the AlCu alloy is of poor quality and the current at which the fuse blows becomes unpredictable. If, however, the content of copper in the AlCu alloy is 25% by weight, copper can diffuse into the substrate, which may lead to the undesirable situation that the fuse blows at a value of overload current which is higher than the predetermined value. We do not have any results for a content of copper in the AlCu alloy of greater than 25% by weight.

Our invention has the advantage that the quality score (Q) of the fuse is much improved. We consider that the subject matter of amended claim 1 is new and involves an inventive step in view of the prior art documents D1 – D3. We have amended the dependent claims to overcome the clarity objections.

Please make any amendments to the proposed set of claims you consider to be necessary for the claims to fulfill the requirements of the EPC, whilst giving us the broadest possible scope of protection for our invention. We do not expect you to add further independent or dependent claims.

Regards

Kurt Z. Schluss
Draft set of claims

1. A fuse (11, 21) comprising:
   - an electrically insulating substrate (12, 22);
   - first and second electrodes (14, 24) provided on said substrate (12, 22);
   - a fuse track (13, 23) made of AlCu alloy and connected at its ends to the respective first and second electrodes (14, 24);
   - whereby the fuse track (13, 23) is configured to melt when an electrical current of a predetermined value passes through it;
   - characterised by a cover layer (25) covering the fuse track (23), wherein the quality score of the fuse (21) is at least 60.

2. Fuse according to claim 1, wherein the fuse track (13, 23) is made of AlCu alloy having 15% by weight Cu.

3. Fuse according to claim 2, further comprising a cover layer (25) covering the fuse track (23) and wherein the fuse track (23) has a neck portion (23a).

4. Fuse according to claim 2, wherein the upper cover layer (25) is made of epoxy resin.

5. Fuse according to claim 1, wherein the substrate (12, 22) has a smooth surface is subjected to a polishing step before providing the fuse track (23) thereon.
Draft set of claims (clean copy)

1. A fuse (21) comprising:
   an electrically insulating substrate (22);
   first and second electrodes (24) provided on said substrate (22);
   a fuse track (23) made of AlCu alloy and connected at its ends to the respective first
   and second electrodes (24);
   whereby the fuse track (23) is configured to melt when an electrical current of a
   predetermined value passes through it;
   characterised by a cover layer (25) covering the fuse track (23), wherein the quality
   score of the fuse (21) is at least 60.

2. Fuse according to claim 1, wherein the fuse track (23) is made of AlCu alloy having
   15% by weight Cu.

3. Fuse according to claim 2, wherein the fuse track (23) has a neck portion (23a).

4. Fuse according to claim 2, wherein the cover layer (25) is made of epoxy resin.

5. Fuse according to claim 1, wherein the substrate (22) is subjected to a polishing
   step before providing the fuse track (23) thereon.