SOME DESIGN AND APPLICATION ASPECTS OF VERY SMALL FUSES

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Abstract

For the protection of electronic circuitry normally fuses with small dimensions are used. For so-called on-board protection on PC-boards and especially for surface mount technology there is a trend to very small sized fuses. This offers special problems for design and application of such fuses which do not occur in that extend with "normal" miniature fuses. On hand of some theoretical calculations and experimental results the influences as mentioned will be shown and principle solutions for these problems are indicated.

1. Introduction

In modern electronic equipment it is common practice to use components with smaller and smaller dimensions and with a high package density. This is especially true for the so-called surface mount technology. Also for fuses used for the protection of such circuitry there is a requirement for smaller dimensions. In figure 1 typical dimensions for a fuse as used for surface mount applications.

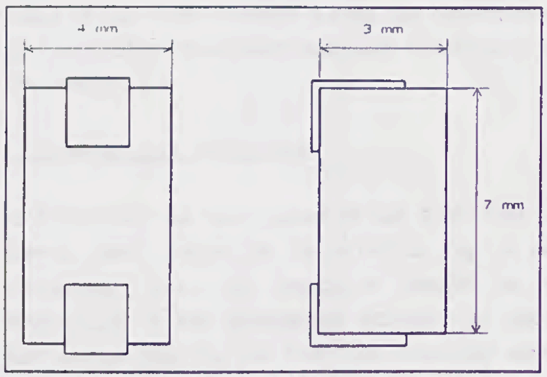

Figure 1: typical dimensioning of a fuse for surface mount technology.

These relatively small dimensions offer special problems for design and application which do not occur in that extend with 'normal' miniature fuses. It is obvious that the length of the fuse element in fuses of such dimensions is very small. Sometimes an 'active' fuse element length of less then 2 mm is formed in such fuses. Apart from the technological aspect of manufacturing such fuses in large quantities, there is the question of breaking capacity. But the very short length of the fuse element in such fuses may also create problems in getting a reproducible time-current characteristic. In the following sections these problems will be treated in more detail.

2. The minimum fusing current for very short fuse wires

Solving the energy balance equation for current carrying conductors under steady state conditions gives a temperature distribution along such conductors, as shown qualitatively in figure 2 [1].

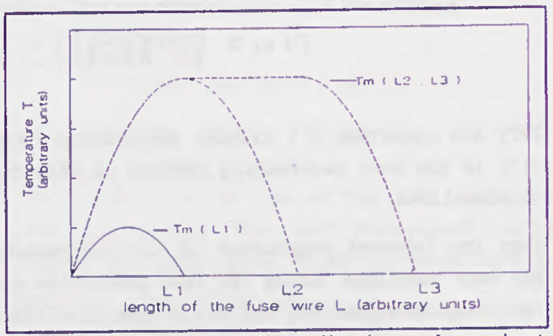

Figure 2: temperature distributions along short and long wires carrying the same current I.

In deriving such temperature distributions it is assumed that the wire is connected to two end blocks 1 and 2 which are kept at environmental temperature T_0 (see figure 3). If the wire is long that means $L \geq L_2$ (see figure 2) the highest temperature Tm is not influenced by the end effects. For short wires, that means wires with $L < L_2$, the highest value Tm may be influenced considerably by the length of the fuse wire. For these situations the heat transfer to the ends play the major role, radial heat transfer can be neglected. This means, however, that for short wires the value of the minimum fusing current I_t depends on the length of the fuse wire. In case of short fuse wires, where only the heat transfer to the ends of the fuse wire is to be taken into account, the minimum fusing current can be calculated from the energy balance equation for steady state conditions:

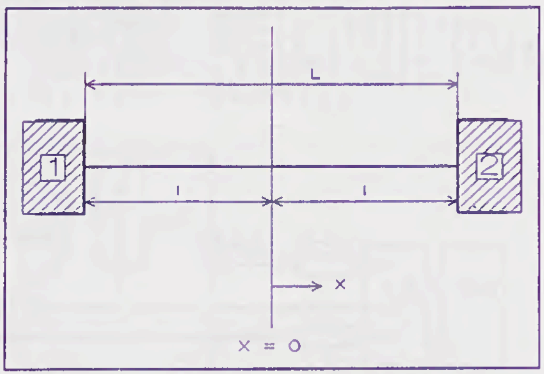

Figure 3: a wire connected to two end-blocks 1 and 2.

$$(1)\quad \lambda \frac{d^2T}{dx^2} + J^2 . \varrho_0 . (1+\beta . T) = 0$$

where:

λ : heat conductivity of the conductor material
T : temperature of the conductor at x
J : current density
ϱ_0: specific resistance at room temperature
ß : temperature coefficient of resistance

The coordinate x is demonstrated in figure 3

At x=0 is valid dT/dx=0. Introducing $T=T_0$ at $x=\pm l$ and I=AJ, where A is the cross section of the wire, the following expression for I_s can be derived from (1), taking into account that the value of I_s is determined by the melting temperature T_s.

$$(2)\quad I_s^2 = A^2 \left[\frac{\lambda}{l^2 \beta \varrho_0} \left\{ \arccos \frac{1}{1 + \beta(T_s - T_0)} \right\}^2 \right]$$

Assuming cylindrical wires for which is valid $A = (\pi d^2)/4$ (d is wire diameter) then the graphs shown in figure 4 can be calculated from equation 2. These graphs show the relationship between Is and d for different wire lengths L= 21 of the fuse wire and with the assumption that T_0=0.

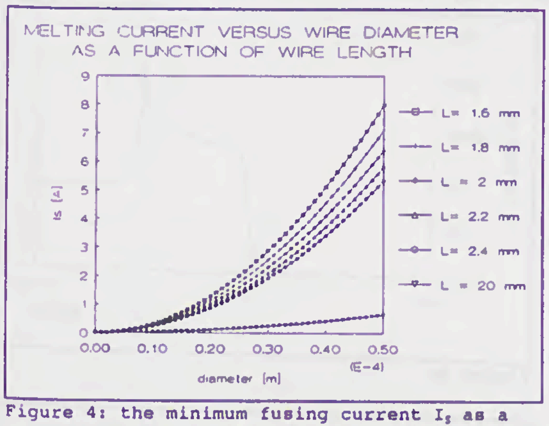

Figure 4: the minimum fusing current I_s as a function of the wire diameter of Cu-wires. The length L of the wire is parameter.

(For comparison also the value of a long fuse wire is plotted in this figure) The last assumption is more or less valid if the end blocks 1 and 2 in figure 3 have a relatively high heat capacity and a very good heat transfer to its surroundings. In many cases in practice such an assumption is not justified; the end blocks are heated up by the energy supplied by the fuse wire, that means that under steady state conditions the end blocks have a temperature $T_0 = T_e$, the value of which depends on the mounting conditions on e.g. a p.c.board. Such conditions are e.g. determined by differences in pad-sizes and amounts of solder as will be found with different soldering methods(see figure 5). Also differences in cross sections of tracks on the p.c.board have an influence on the value of T_e.

To get an impression how the value of Is is influenced by the value of T_0, one can calculate I_s as a function of T_0 from equation 2. Some results are shown in figure 6 for some different length of fuse-wire and calculated for Cu-wires. Such curves just give an impression of the influance of T_e, for a quantitative evaluation more factors are to be taken into account.

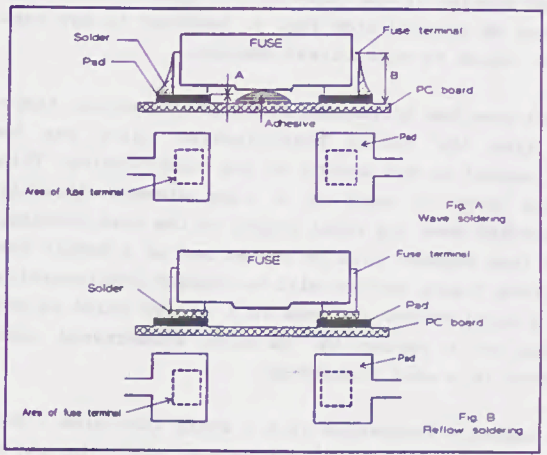

Figure 5: mounting by wave soldering (A) and reflow soldering (B).

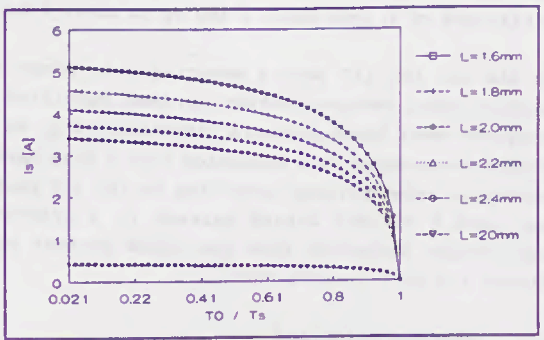

Figure 6: Minimum fusing current I_s in relation to the temperature T_0 of the end-blocks, calculated for a Cu-wire of 40 μm diameter.

In figure 6 the area close to the point T_0/T_s=1 has only a theoretical meaning, the value of T_0 can never be equal to T_s by heating the wire connections by the fusewire only.

What do we learn from the above?

Let us take an example.
From figure 4 it can be seen that the I_s value of a copper-wire with d=40 μm and l=2 mm is 4 A, assuming that T_0=0. A change of the length of the wire from 1.8 to 2.2 mm, that means 2 mm ± 0.2 mm, changes its I_s value from approximately 4.6 A to 3.6 A. It is difficult if not impossible to get an accuracy in wire length of ± 0.2 mm or less by using soldering

technologies for the connection of the fuse-wire. It is common practice to solder the fuse wire in miniature fuses. From the above example it is obvious that connecting methods for very small fuses have to be changed to get a rather well defined value of the minimum fusing current I_f.

Another aspect is how to make such a small fuse for low current ratings? As an example, a 100 mA fuse with a copper fuse wire of 2 mm length requires a cross section of the fuse-wire of approximately 7 μm as may be derived from fig. 4. Needless to say that this leads to unpractical designs.

Apart from the influences as mentioned before, there is also the radial heat-transfer which can be influenced by the design of the fuse-housing. This means that in case of a fuse element directly connected over its total length to the fuse housing, the fuse element will be cooled and as a result the minimum fusing current will be changed considerably. As a total effect a change in I_f can be found in the order of a factor 10, we have encountered this factor in a real fusedesign.

We tested a fusedesign with a short fuse wire (less then 2 mm) for which was quoted that the rated current was 500 mA. We created a situation in which this fuse didn't blow at 11 Amp! Mounted on a p.c.board with different conditions of soldering, pad-sizes and track cross sections, we found variations of I_f from about 1 Amp up to about 5 Amp.

In the new IEC 127 part 4 covering a.o. fuses for surface mount designs nothing has been specified or required about these possible variations of I_f. So in future there might be a situation that a fuse having a certain rated current according to IEC 127 part 4 may have a minimum fusing current in a practical application differing from the rated current by a factor 1.5 to 5 or even more.

3. Possible solutions

From the above it is clear that the longer the wire, the less vulnerable the fuse will be for mounting conditions and inaccuracies of fuse assembly methods.

If the wire is long ($L > L_2$ in figure 2) then the radial heat transfer plays also a role which, in a properly designed fuse, has a compensating effect on influences from the outside.

Not only the length of a fuse-wire, but also the physical parameters of the fuse-wire material, determine if a fuse-wire has to be considered as long or not.

In fig. 7 a fuse design is shown which allows for a relatively long but well controlled length of the fuse wire. Such a design makes it also possible to get some degree of balancing between the heat transfer to the ends of the wire and the heat transfer via the fuse body. If moreover the proper fuse-wire material is selected then, under all practical circumstances as found on a p.c.-board, a change of I_f-value of less then 5% can be achieved. This requires of course also a rather high accuracy regarding the assembly of the fuse, which means that an assembly technology has to be developed which allows for this required high accuracy.

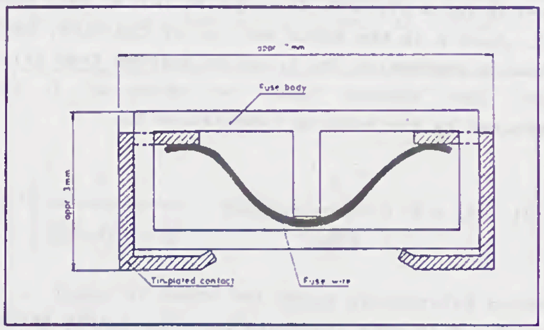

Figure 7

This "two-chamber" design not only makes it possible to design a fuse with a rather well defined It-curve, it realises also a better control of the arc voltage and a relatively high breaking capacity, without the use of any filler material in the cavities.

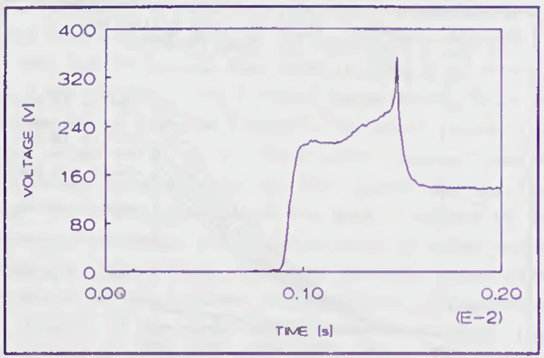

Figure 8a

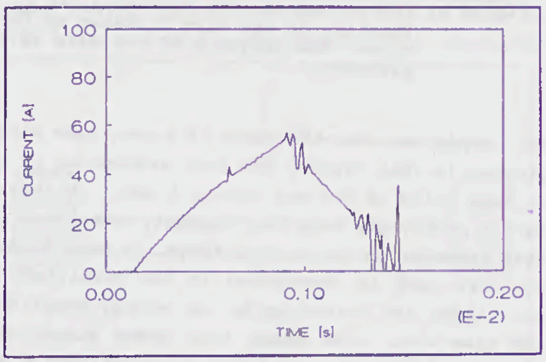

Figure 8b

Fig. 8 shows, as an example, the oscillogram taken at the interruption of a 150A effective current at 125V AC. From this oscillogram it can be seen that the max. value of the arc-voltage does not exceed 350 volts. As a remark for the basic design as shown in fig. 7 a European patent application nr. 89202921.6 has been filed.

Literature:

[1]: Fischer, J., Die stationare Temperatur stromdurchflossener, mässig langer Drahte. Arch.f.Elektrot. XL.band H3 (1951) 11, 171.