LOW VOLTAGE LITHOGRAPHIC FUSES: PRELIMINARY RESULTS OF BREAKING CAPACITY AND CYCLIC LOAD TESTS

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Abstract: High breaking capacity fuse of low rated current is one of the most difficult fuses to design and build. The fuse element is of such small dimensions that its mechanical fragility is too high. Besides the fuse filler, usually quartz sand could deteriorate the element after the assembling, mainly during the filling process. In order to solve this difficulty the fuse-on-substrate technique has been in use from the 1980 decade. Initially rigid substrate materials were used, such as alumina, silica, glass-polytetrafluoroethylene (PTFE), solidified quartz sand, etc. Also extra cooling was provided through a metallic plate applied to the other substrate face. Lately, lithographic techniques in use for printed circuit construction were extended for fuse manufacturing on flexible substrates. The offset printing technique on flexible substrate added to the use of new conductive inks, allows the manufacturing of good accuracy dimension fuses. The lithographic fuses could find an excellent application field on the protection of small size semiconductors. Several fuse samples on three dissimilar flexible substrate materials were manufactured, having rated current from 0.1 to 1 A. Rated current and temperature rise tests do not represent a problem due to the low current values. However the main manufacturers´ concerns are related with cyclic long duration overload behavior and high current breaking performance. The paper presents the results of a limited number of cyclic loading, and high current breaking tests. The high current tests correspond to duties I_1 and I_2 specified by IEC 60127, carried out in a circuit with 230 V ac and currents of about 1,500 A. It is preliminarily concluded that fuses using one of the tested substrates present a reasonably good performance, no far away from the conventional HBC fuse. Further research is necessary especially on the fuse material dimensions accuracy and on substrate material behavior under arcing conditions.

Keywords: Fuse on substrate, lithographic circuits, cyclic load, breaking capacity.

1. Introduction

Introduction of fuse in substrate using lithographic technology

The lithographic fuse was born as a derivation of the concept of lithographic printed circuits. The traditional printed circuits (Printed circuit board, PCB), is conformed by thin layers of conductive material deposited on a base of laminate resin, by means of photographic procedure and of engraving (etching). During more than fifteen years, many research groups have been working on the substitution of such a methodology for the lithographic printing, on flexible substrate similar to normal paper, using inks with metallic load. This new methodology, denominated Conductive Lithographic Film (CLF) has been applied in circuits for telephones, temperature detectors, impact detectors, etc. [1].

The printing procedure is very fast (6,000 to 10,000 prints per hour), simple and very well-known, for what their low cost makes it very attractive. Another negative aspect of the traditional printed circuit boards is the ecological one, since the production effluents and the circuit de-activation require of the elimination of toxic materials. Also, 90% of the copper that is on the resin base is transformed into waste.

Among the printing processes, the most appropriate is the offset that is based on the indirect deposition of ink on the substrate. The first cylinder possesses the print plate, where the ink is deposited that is subsequently transferred to an intermediate cylinder (blanket). The cylinder (blanket) transfers the image to the substrate that is wound on the printing cylinder [2].

Once the printing process is selected, the ink characteristics should be defined. The ink must be conductive and lithographically printable, and besides, the substrate should be compatible with the adopted ink (appropriate ruggedness and having affinity with the ink).

In this printing process, the thickness of the deposited ink is of the order of the 3 µm, which should be compared with the 50 µm of the thick conductors obtained by serigraphy and the 100 µm of the traditional printed circuits. The thickness of the deposited ink can be increased by re-impression, with excellent discrimination, of the order of 25 µm and attainable white space of 35 to 75 µm. The appropriate conductance is reached by means of the use of inks with metallic particles, fundamentally silver suspended in an organic non conductive resin. The silver

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particles, in form of flakes with an average size smaller than 1 µm, represent 80% of the weight of the compound. The layer resistivity is in the order of the 0.025 $\Omega mm^2/m$ that decreases between 40 and 50% for being heated by some minutes to 80 °C, which after being in rest for 72 hours reaches its final value of 0.015 $\Omega mm^2/m$. This resistivity is of the order of the one reached with the PCB technology. The circuit once printed must remain invariable in its characteristics in front of the environmental conditions that in the event of not being possible, it requires impregnation, covering or imprint of intermediate layers.

With this methodology resolution limits between 1 and 10 µm are reached, according to the state of the printer. The several electric components, such as resistances, capacitors and inductances can be created easily with this technology. For instance, resistances can be achieved by printing long meandrous conductive paths, reaching values from 1 to 100 kΩ; capacitors are achieved by inter-fingered forks or with metallic and dielectric successive layers getting capacities of some hundreds of pico-farads. This concept can easily be extended to simple T or π filters, to humidity detectors (the capacity is influenced by the substrate absorption), thermometers (variation of electric conductivity with the temperature), deformation meters, etc. [2].

This type of construction can be extend to the creation of conductive paths that behave like to low voltage fuses, with thickness of the order of 5 µm, resistivity of the order of 12 times that of the copper, that is to say 0.22 $\Omega mm^2/m$ and six times that of the PCB. This idea have been exploited for some years, in the self-regenerated capacitors whose structure is composed of several small plates interconnected by means of conductive bridges that act as fuses. Preliminary experiences of low voltage and low current fuse operations have been published, carried out by the group of the Brunel University (England), using ink with copper in the following substrates: high density expanded polyethylene paper, art enamelled paper and polyethylene, being detected certain negative presence of carbon and of its derivate compounds [3].

2. Experimental results

The application of fusible in substrate has been in use for several years. Here are presented preliminary results of the study related to the possibility of applying this methodology to "lithographic fuses". For the experimental determinations, two types of samples were used, both supplied by the Brunel University group:

- Samples *type A*: With copper fuse element on polyart, expanded polyethylene of high density, and on teslin polyethylene substrate, both obtained by offset methodology whose general form and dimensions are shown in Fig. 1a.
- Samples *type B*: With silver fuse element on glossy paper, obtained by the offset methodology whose general form and dimensions are shown in Fig. 1b.

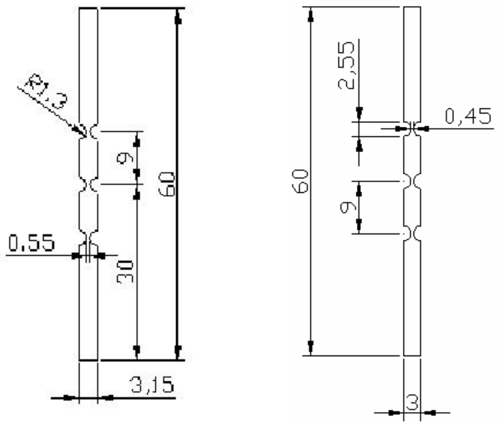

Figure 1a Type A, thickness: 0.13mm   Figure 1b Type B, thickness: 15µm

Form and dimensions of lithographic fuse on flexible substrate

For constructive simplicity, the fuse elements were mounted in NH fuse, size 1 structures normalized by DIN 43620 standard, immersed in quartz sand. The assembly was carried out following the very well-known "rules of art".

2.1. Determination of rated current

Samples type A:

To determine the rated current value an iterative procedure was carried out. The heating test was carried out according to [4] with an assumed initial current value according to the dimensions of the conductive layer. Once the thermal balance is reached, dissipated power and temperatures on the body and fuse-base terminals were measured. By comparing the value of dissipated power with the maximum reference values given by the mentioned Standard, it is determined if the rated current is higher or lower of the test value. The value is adjusted and the test is repeated, until obtaining a value of dissipated power corresponding to certain rated current. Similarly, several samples were operated in order to draw the time current characteristic. With this methodology a rated current of 40 A was determined, based on IEC 60269 standard.

Simples type B:

The same procedure was carried out, but since the rated current is of a very inferior value, approaches shown in [5] were applied. A wider dispersion of the obtained results was observed, resulting an average rated current value of 100 mA. It should be clarified that the ruggedness of the paper used as substrate, makes that the ink spreads in the paper giving a very

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variable thickness of deposited material with values between 5 and 14 µm that generate a high dispersion of the rated current values.

2.2. Behaviour interrupting short circuit currents

In order to determine their behaviour as an interrupting device, several samples underwent breaking tests, with short circuit currents.

Samples type A:

For this determination the test current was chosen in order to produce the maximum arc energy. This current is established in [4], as the test duty 2 and its value are determined in the following way:

It is the current value that produces an instantaneous value at the arc beginning, between 0.85 and 1.06 times the rms value of the prospective current.

To carry out the described tests, a circuit was mounted according to that indicated in [4], with the possibility of adjusting different values of prospective current. The test voltage was adopted as 230 V, considered as rated value due mainly to the fuse element possesses only three notches or cross-section reductions. The current was adjusted for maximum arc energy. For this calibration several preliminary tests were carried out, determining a prospective current of 960 A with pf of 0.23. The obtained values, all with switching angle of 0° are shown in Table I. Figure 2, shows the typical form of the voltage and current oscillograms.

Table I, Measured values corresponding to breaking capacity duty 2.

Sample N°	I_{max} [A]	V_{max} [V]	I^2t_{prearc} [A^2s]	I^2t_{arc} [A^2s]	Insulation resistance [kΩ]
1	927	481	817	1984	10
2	1002	461	897	2651	10
3	1032	502	1146	2624	10

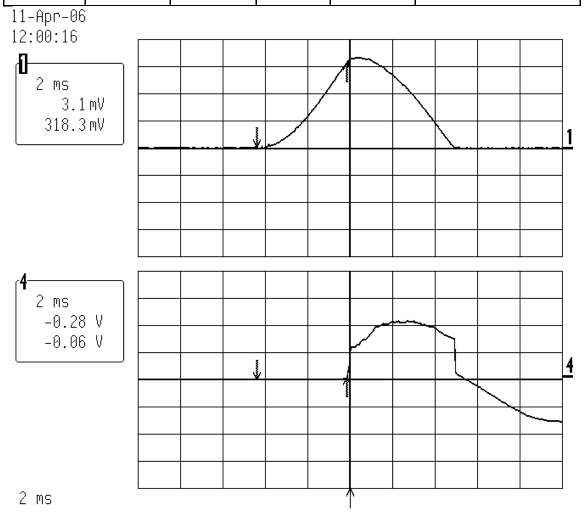

Figure 2, Typical oscillograms of current (above) and voltage (below), 2ms/div. for tests shows in Table I. I_P=960A, V=230V

Although the results are satisfactory, it is noticeable the low value of the insulation resistance after the fuse operation. According to [4], this value should be measured between 6 and 10 minutes after the fuse operation and must be higher than 50 kΩ. Evidently, the carbonaceous residuals of the substrate material are responsible for the low insulation resistance values.

Samples type B:

In this case the test prospective current values are lower than the previous ones, carrying out tests with currents of 1.7A pf of 0.7 and 2.6A pf of 0.2. The tests were carried out on samples assembled without extinguisher filling (quartz sand). The obtained values, all with switching angle of 0°, are shown in Table II. Figure 3, shows the typical form of voltage and current oscillograms.

Table II, Breaking capacity test measured values.

Sample N°	$I_{prospective}$ [A]	p.f.	I_{max} [A]	V_{max} [V]	I^2t_{prearc} x1000 [A^2s]	I^2t_{arc} x1000 [A^2s]	Insulation resistance [kΩ]
1	1.7	0.7	1.47	1090	3.6	2.1	>100
2	1.7	0.7	1.83	493	3.7	3.2	>100
3	1.7	0.7	1.7	820	3.0	2.6	>100
4	2.6	0.2	2.03	451	3.0	13.7	>100
5	2.6	0.2	1.87	919.5	4.3	2.6	>100
6	2.6	0.2	2.09	552	3.6	7.4	>100

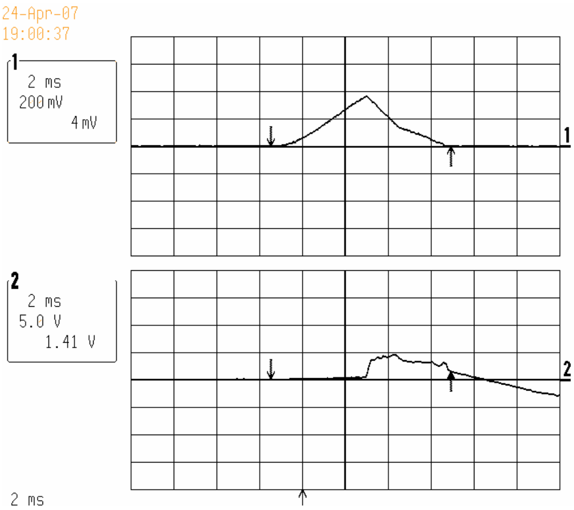

Figure 3, Typical oscillograms of current (above) and voltage (below), 2ms/div. for tests shows in Table II.

From the results, comes off that the current limitation with these fuses is obtained with very low values of prospective current and without high overvoltage surges. What indicates the advantage of being able to have an appropriate fuse element design for rated currents as low as 100 mA.

With the utilization of the paper as substrate, the problem of the low insulation resistance after the fuse

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operation is eliminated, always obtaining values above the 100 kΩ.
The dispersion in the values of prearcing specific energy (I^2t_{pa}) is due to the already mentioned effect, of ink diffusion in the paper.

2.3. Behaviour with cyclic load

Sample type B:
These tests were carried out to asses the behavior of the lithographic technology in the face of the fuse element fatigue with cyclic loads. At the present time, only are available results of tests carried out on type B samples.
The tests were carried out with the rated current, 100 mA, circulating during 15 minutes, followed by a 45 minute period without load. Using for these tests a low voltage circuit (2.5V).
Two samples were tested, the first one operated after 320 cycles and the second one overcame 1500 cycles without deterioration neither appreciable change in the voltage drop.
In Fig. 4 is shown the voltage drop evolution of the operated sample and in Fig. 5 a picture of the operated sample is shown, where can be observed that the cause of the operation is a fissure (marked with a circle on the notch) probably due to a defect in the ink deposition in this area.

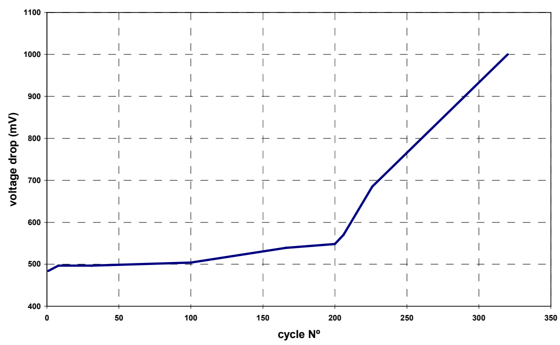

Figure 4, Voltage drop during the cyclic load test.

3. Conclusions

The preliminary experimental studies allow to conclude that the offset technology for fuses on flexible substrate, for the analyzed methods, is extremely promissory.
Keeping in mind the low rated currents that are achieved with this technology, fuses having characteristics of high breaking capacity can be obtained for applications on very low power.

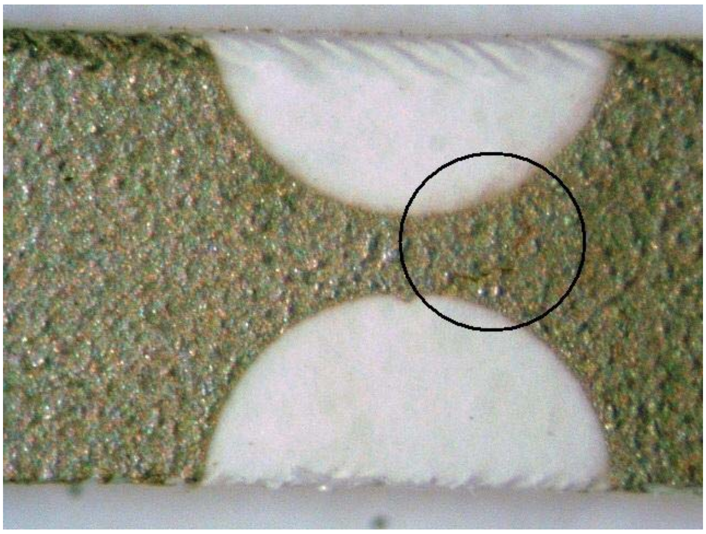

Figure 5, Picture of the fuse element notch that failed during the cyclic load test.

For the development of this technology it is necessary to deepen the studies in the following points, where higher difficulties have been detected:

- To determine the best material to be used as flexible substrate. Of the material used for the experimental determinations, it was found that the polyethylene film produces a low isolation resistance after the short circuit operation, while the glossy paper is very porous and the ink diffusion that takes place generate fuse thickness non-uniformities.
- To deepen the study with cyclic loads to determine the cause of the inopportune and unwanted operations.
- To develop a fuse element assembling structure that allows to obtain an appropriate contact among the fuse element (conductive layer) and the fuse terminals.

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