MINIATURE LAYER FUSES OF HIGH BREAKING CAPACITY

Sulikowski J., Ćwidak K., Ossowicki J.
Electrotechnical Institute, Gdańsk Branch
Gdańsk - Poland

Abstract: Miniature layer fuses possess thin fuse-element (e.g. silver) placed between two insulating plates (e.g. glass-crystal). They are destined, before all, to protect semiconductor systems and devices. To overcome the problem of critical overload currents is a key factor in widening of the application of such fuses.

The authors, by application of the glaze layer doped by metal oxides or carbonates obtained a considerable improvement of the breaking capacity, particularly of the critical overload currents. During interrupting of the overload currents lower than 12 times of the fuse rated current the arcing time became distinctly shorter and the arc quenching very effective.

I. INTRODUCTION

Modern semiconductor elements and systems need the fuses with increasing technical requirements. The fuses, before all, shall indicate a distinctly lower operating I^2t, high speed t-I characteristic and a small susceptibility on the mechanical and thermomechanical ageing. Such features shall be achieved by manufacturing cheap and of small dimensions fuses [1]. In the case of semiconductor elements and systems of low rated power the only fuses which can fulfil above requirements are the miniature layer fuses (MLF) [2, 3, 4, 5].

MLF possess a thin fuse-element (often Ag) usually placed between two insulating plates made, e.g. from alumina, quartz or pyroceram. The Ag-element commonly is deposited on an insulating substrate not direct but using one or two intermediate metallic thin layers. These additional layers provide an appropriate fuse-element adhesion to the substrate despite a considerable temperature fluctuations of the fuse in service.

Experiments [4, 5, 6] show that the known MLFs demonstrate a considerable difficulty during the overload current interruption, specifically in DC circuits. Above difficult critical current range is 3 to 12 times of the fuse rated current. Similar behaviour shows also MLF, despite the arc is quenched in the narrow slots between the insulating plates.

Gdańsk Branch of Electrotechnical Institute for several years has been carried out investigations of the MLFs within arc quenching in a pyroceram slot. In spite of achieved a considerable short-circuit breaking capacity, the problem was with the interruption of already mentioned critical overload currents. Only introducing the essential processing and designing modifications, described in the paper, gave fully positive solution to the problem.

II. REASONS FOR EXISTING OF THE CRITICAL OVERLOAD CURRENTS RANGE

MLFs can correct interrupt a current if the energy delivered to the arc from the circuit will be lower than one absorbed by that arc surrounding.

At large short-circuit currents the interrupting process is a very quick one (Fig. 1) due to high-speed fuse-element explosion. The speed is so high that the fuse-element volume remains practically constant during this explosion. A supercritical state of the matter has been achieved, what means metal-insulator sudden transformation [7].

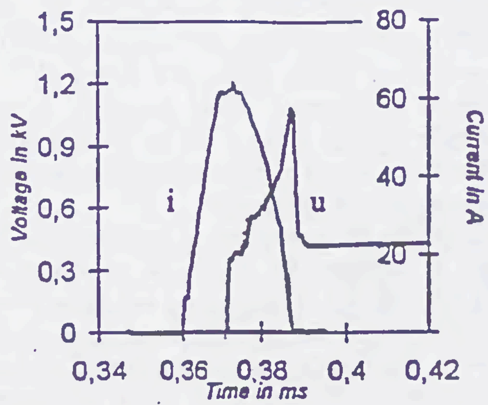

Fig. 1 Records of interrupting of the prospective current ab. 48 kA, 440 V DC, R = 9.2 mΩ, L = 37.5 μH by a MLF of rated current 1.6 A, within fuse-element of length 4 mm, thickness 1 μm. Supply source a capacitor bank 16.5 mF.

On the contrary, during interrupting of an overload current the speed of fuse-element disintegration is much smaller. The slot walls at the arc beginning are now pre-heated due to relatively long pre-arcing time. As a result the arc-voltage is relatively small causing the arc-time elongation and even noninterrupting of the circuit (Fig.2).

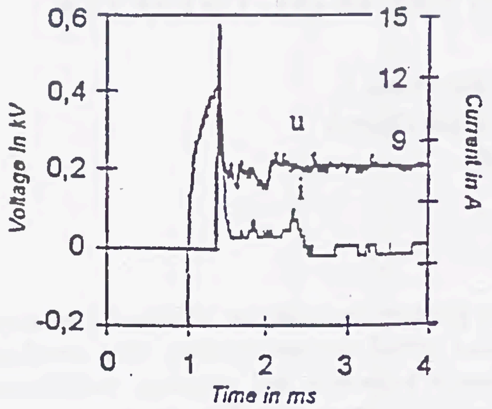

Fig.2 Records of noninterrupting of the prospective current 16 A, 300 V DC, R = 18.7 Ω, L = 1.2 mH by MLF of rated current 1,6 A.

So any improvement of the arc cooling in the critical current region is desirable.

III. NEW MLFs

Well known are the composite contact materials in which the oxides of some metals (CdO, ZnO, SnO_2) are used as one of the components [8]. In the electric arc a thermal dissociation process of these oxides has taken place. Liberated metal in arc immediately sublimates. Since all these transformations are endothermic, they are extremely advantageous for arc quenching.

Bearing in mind above observations, the authors decided to proof a hypothesis that implementation of the afore-mentioned oxides, particularly during the critical overcurrent interruption, should drastically lower the arc temperature and enhance the arc column pressure. Both processes should extremely positively improve the critical overcurrents interruption.

To confirm the correctness of the hypothesis it was decided to evaluate, for $CaCO_3$ as an example, the energy liberated due to dissociation and phase transition of this substance, in the case of a direct action of the arc heat on it. The $CaCO_3$ was selected first of all because the reactions of decomposition of the substance are particularly very endothermic ones. The results of calculations are given in Table 1.

Table 1. Energy of thermal decomposition of $CaCO_3$ [9]

Energy		kJ/mol	J	Total in J
1		2	3	4
Dissociation $CaCO_3 \rightarrow CaO + CO_2$		200	0,008	0,021
Dissociation $CaO \rightarrow Ca + ½ O_2$		600	0,010	
Phase transition Ca	A	8,7	0,000	
	B	172	0,003	

A - melting, B - evaporation

To calculate in Joule's the dissociation and phase transition energy in a defined fuse (see heading 3 in Table 1), has been assumed that doped glaze layer is of 1 μm thick and contains 15 % in weight of $CaCO_3$ and that the full reaction embraces ab. 0.001 mm^3 of this layer. These data evaluated by a microscopic observations.

From earlier authors' measurements it is seen that in the case of overload critical currents the total arc energy usually is from 0.06 up to 0.5 J. From a comparison these values with the given in Table 1 one can conclude that the endothermic reactions during the dissociation of $CaCO_3$ in the temperature close to the arc temperature may have a significant influence on the arc temperature diminishing causing the improved arc quenching.

Fig. 3 shows a simplified drawing of the MLF according to the new suggestion. The substrate 1 and plate 2 are made from glaze crystal material. The surface of the plane facing to the fuse-element is covered by a glaze layer of 1 to 20 μm thick, doped uniformly by $CaCO_3$ or ZnO. The chemical and phase components properties of the basic component of layer are agreed with corresponding properties of the substrate whereas the chemical and phase components properties of the doping material are selected to create an endothermic physical-chemical reaction in the arc, i.e. to generate the dissociation and phase transition.

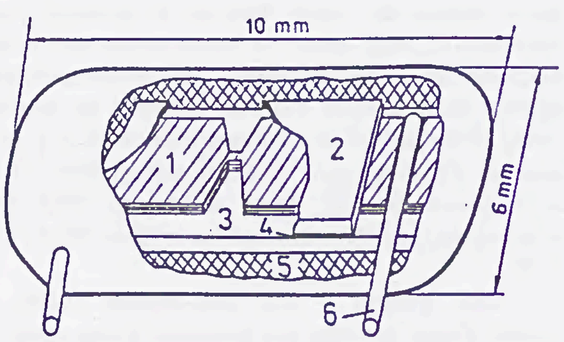

Fig. 3 New MLF of limited critical overload current interrupting ability
1 - fuse-element (Ag + Cu + V), 2 - cover plate; 3 - insulating substrate; 4 - doped glaze layer; 5 - hermetic envelope from epoxy resin; 6 - termination

IV. RESULTS OF TESTS ON MLFs MODEL

Tests of the new MLFs with and without above described doped glaze layer exactly in the same test circuit were carried out. At the beginning the tests were limited to the critical overcurrents which were unsatisfactory interrupted by the fuses without mentioned layer. Two samples of the new MLFs were used for any test current value. The total number of shots was several tenths pieces. In every case all the new MLFs with glaze layer doped by ZnO or $CaCO_3$ passed satisfactory the tests.

Fig. 4 illustrates typical test records for new MLF (Fig. A) and MLF without mentioned layer (Fig. B).

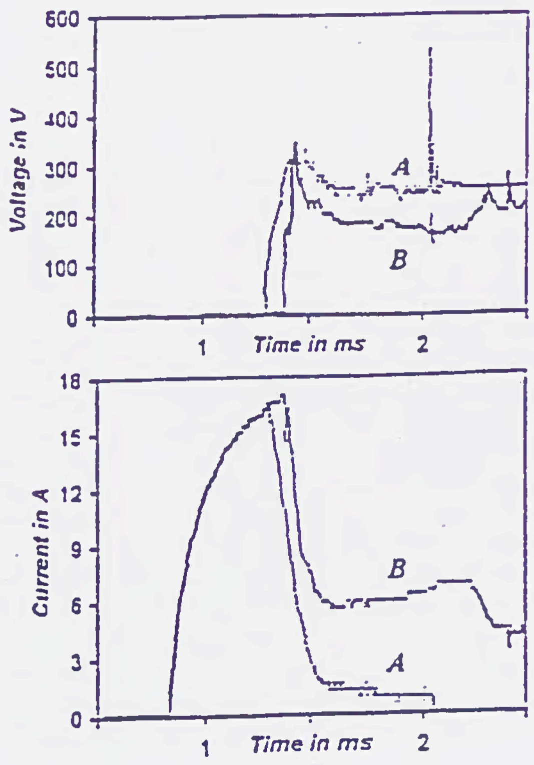

Fig. 4 Records taken from the interrupting tests by MLFs of two kinds. Prospective current 20 A, 250 V DC, R = 12.5 Ω, L = 1.7 mH
A - MLF with doped glaze layer, B - MLF without doped glaze layer.

V. CONCLUSIONS

The investigations carried out on several tenths MLF with a glaze layer doped by the metal oxides (ZnO) and carbonates ($CaCO_3$) made a considerable improvement of the breaking capacity, particularly of the critical overload currents.

The physical-chemical processes taking part in that doped glaze layer make possible to get MLFs: of low-power losses, of small dimensions, of desirable quick acting t-I characteristic, demonstrating very good interrupting ability of the critical overload currents. Moreover they possess a large impulse ageing withstand and a very good current-limiting ability.

By interrupting of the currents greater than 12 times of the MLF rated current up to 50 kA, the arc voltage trace over the whole arcing period is higher than the source voltage. However, the arc voltage is not higher than 2.5 times of the source test voltage. Due to doped glaze layer by interrupting of the overload currents lower than 12 times of the rated currents the arcing time became distinctly shorter and the arc quenching is a very effective one.

Carried out for the time being investigations are aimed to the experimental justification of the layer thickness and the proportion between its basic and dopic components.

ACKNOLEDGEMENTS

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