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Pastors et al.

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[54] **ELECTRIC CIRCUIT BREAKING FUSE**

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[51] **Int. Cl.** **H01h 85/38**

[58] **Field of Search** 337/166, 204, 273, 276, 337/277, 278, 280

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Assistant Examiner—Fred E. Bell
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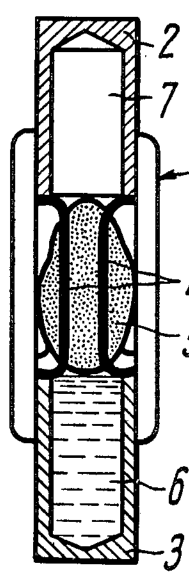
[57] **ABSTRACT**

An electrical circuit breaking fuse intended primarily as a means of protection of semiconductor rectifiers, comprising a sealed casing with a liquid filler and leads, wherebetween a fusible element is included within the fuse casing, the fusible element being embedded in a body of a capillary-porous material immersed in the liquid filler, and part of the communicating pores of the body are in direct contact with the fusible element.

8 Claims, 8 Drawing Figures



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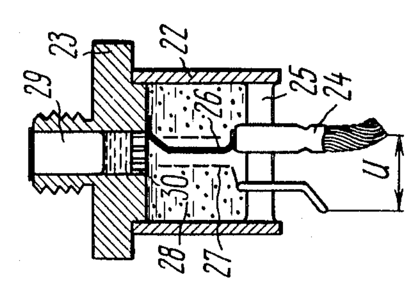

FIG.6

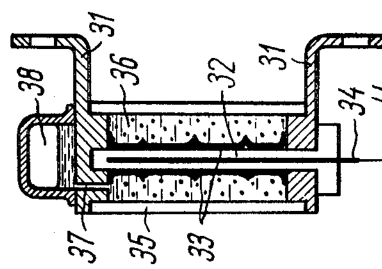

FIG. 7

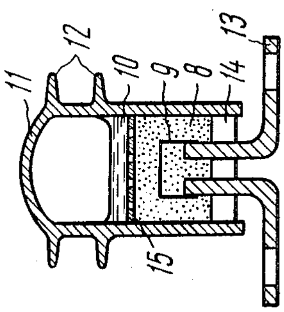

FIG. 2

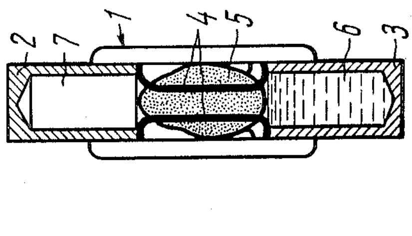

FIG.1

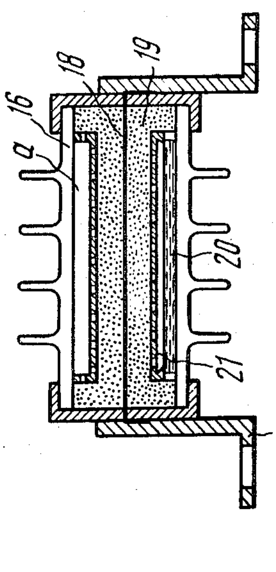

FIG.3

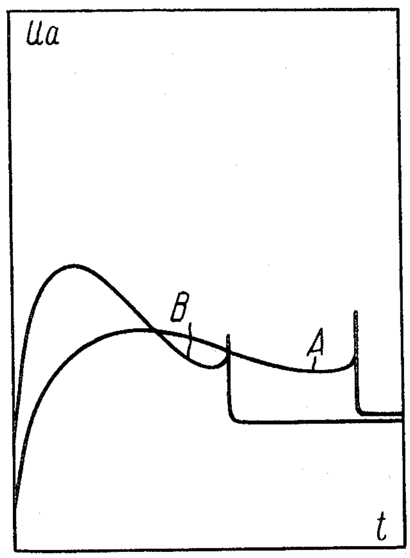

FIG. 4

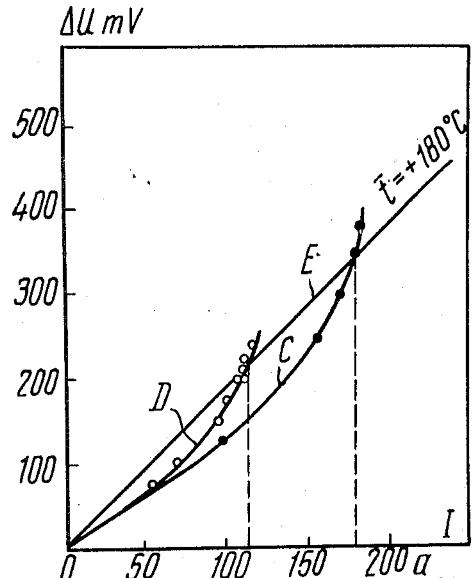

FIG. 5

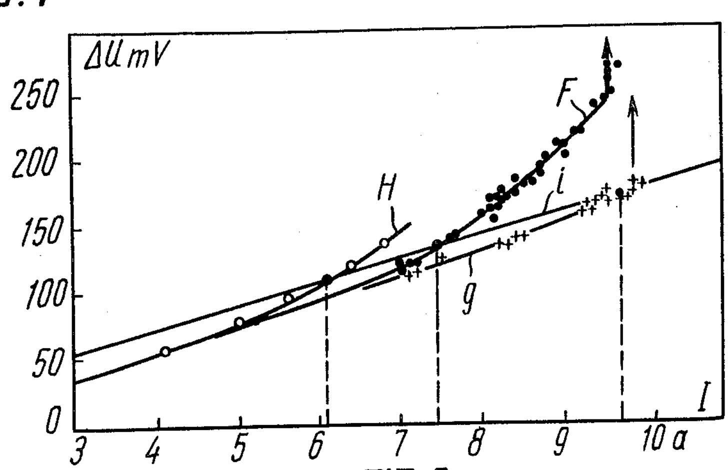

FIG. 8

ELECTRIC CIRCUIT BREAKING FUSE

The present invention relates to electrical circuit breaking fuses, and more particularly to quick-acting fuses used for protecting the electric circuits of, for example, semiconductor rectifiers.

Most known types of quick-acting fuses employ as the arc-extinguishing means quartz sand or an equivalent fine-grained substance. Fuses of this kind offer an essential advantage of providing a relatively high mean arc voltage gradient when cutting out over-currents, resulting in an efficient current-limiting feature. Furthermore, extinguishing of the arc in a fine-grained filler is accompanied by rather small over-voltage peaks.

However, as the rated current density rises to a level requisite for the protection of semicondcutor rectifiers, owing to the inadequate thermal conductivity of fine-grained fillers the temperature of the fusible element of the fuse considerably rises, its resistance increases and the energy losses due to the Joule effect grow.

Recentrly attempts have been made to employ liquid fillers in quick-acting fuses. In liquid-filler fuses, the current rating is so chosen that the temperature of the fusible element of the fuse corresponds to that at which the liquid starts to bubble as it boils up. The liquid evaporates, carrying heat to the condensation area. Thereby the heat removal from the fusible element is increased considerably, enabling the rated current density to be raised. In simple liquid-filler fuses provided with no special arc stretching means, the mean arc voltage gradient is rather low. Besides, arc striking and extinction in these fuses may entail over-voltage peaks. As the fuse casing contains a large amount of liquid, the condensation area is too limited (the liquid usually occupied from two-thirds to three-quarters of the casing volume) and, consequently, when the fuse operates, the pressure is relatively low. Another serious disadvantage of this kind of design consists in that, at large current values the hydrodynamic shock resulting from the explosion of the fuse propagates through the liquid as far as the walls of the fuse casing and is liable to cause its destruction.

Also known are fuses comprising an auxiliary electrode which is used to control the fusion conditions by producing an additional arc melting off the fusible element. Besides, there exist similar fuses where the auxiliary electrode is used to shunt the circuit of the element being protected at the instant the arc is extinguished.

An object of the present invention is to provide a fuse having improved arc extinguishing characteristics and a higher rated current density in the fusible element.

Another object of the invention is to provide a fuse combining the advantages of fuses with powdered and liquid fillers.

A further object of the invention is to make use of an auxiliary electrode with a view to further raising the rated current density in the fusible element through a more efficient cooling thereof.

Accordingly, there is provided a fuse, comprising a sealed casing partially filled with a liquid filler and having current leads, wherebetween a fusible element is included within the casing, in which, in accordance with the invention, the fusible element is embedded in a body of a capillary-porous material with communicating pores, which body is immersed in the liquid filler, and part of the communicating pores of the body are in direct contact with the fusible element and serve to supply the liquid filler to the fusible element area under nominal operating conditions of the fuse, while, under overcurrents, said body helps extinguish the arc produced in the fuse.

The body of a capillary-porous material, wherein the fusible element is embedded, may be immersed in the liquid filler to the extent of only part of its volume, with the quantity of the liquid filler employed being minimum but sufficient to fill the pores throughout the entire volume of the body and to wet the inner surface of the fuse casing, thereby ensuring a continuous evaporation-condensation cycle of the filler under nominal conditions of operation of the fuse.

It is expedient that the buffer volume formed within the fuse casing as it is filled with the liquid filler contain primarily the vapours of the liquid filler, with the foreign gases which fail to condense at the rated temperature of the fuse being kept practically at zero level.

It is preferable that in the space between the body of a capillary-porous material and the side walls of the fuse casing, a liquid-free gap be provided as a means for checking the propagation of hydrodynamic shock as far as the walls of the casing. The capillary-porous body may be formed as a briquet of quartz sand.

The fuse should be preferably provided with at least one auxiliary electrode electrically connected to a source of voltage, which electrode should set up, immediately adjacent the fusible element, an additional electric field which acts upon the boiling liquid in the pores of said body of a capillary-porous material adjoining the fusible element, thereby intensively cooling the latter.

The auxiliary electrode my be insulated from the filler, or else it may be adapted to be conductively coupled to the fusible element through the filler.

The fuse of the present invention functions as a liquid-filler fuse under rated current, and as a powdered fine-grained filler fuse under overcurrents. AS has been shown experimentally, the presence of certain dielectric liquids, such as ditolylmethane, in the pores of the capillary-porous body having the fusible element embedded therein is liable to cause some deterioration of the arc extinguishing characteristic (in some caeses the arc voltage gradient drops by 20 percent), but raises the rated current density almost twofold as compared with a fusible element embedded in a dry fine-grained filler.

Higher rated current volues at a constant cross-sectional area of the intermediate portion of the fusible element improve the quick action of the fuse, for a fuse with a higher rated current density will break the circuit faster (at a lower I^2t) at the same over-current to rated current multiplcity factor.

As distinct from the known liquid-filler fuses, in the proposed fuse the quqntity of the liquid filler is preferably kept at a minimum, as has been noted hereinabove. As a result, when the fuse operates, the pressure within its casing is minimized and the danger of hydrodynamic shock is obviated. The quantity of the liquid filler can be minimized owing to the fact that the capillary-porous body serves as a wick raising the liquid to the fusible element, with the general level of the liquid filler remaining very low.

The present invention will be better understood from the following detailed description taken in conjunction with the accompanying drawings, wherein:

FIG. 1 shows a fuse in accordance with the invention, wherein the capillary-porous body is partially immersed in the liquid filler;

FIG. 2 shows a fuse in accordance with the invention, wherein the capillary-porous body is completely immersed in the liquid filler;

FIG. 3 shows a fuse in accordance with the invention, wherein the capillary-porous body is housed in the fuse casing with a gap in relation to the side walls of the casing;

FIG. 4 is a cathode oscillogram of the arc voltage in quartz sand with an addition of a dielectric liquid compared with an arc voltage oscillogram for pure quartz sand under the same conditions;

FIG. 5 is a curve of voltage losses as a function of current intensity for a fuse filled with a mixture of quartz sand and ethylene glycol, compared with a similar curve for pure quartz sand;

FIG. 6 shows a fuse in accordance with the invention, wherein the auxiliary electrode is conductively coupled to the fusible element through the filler;

FIG. 7 shows a fuse in accordance with the invention, wherein the auxiliary electrode is insulated from the filler;

FIG. 8 is a graph showing the relationship between the voltage losses in the fusible element and the current intensity in the fuse which, in accordance with the invention, is provided with an auxiliary electrode.

Referring now to FIG. 1, the fuse comprises a sealed casing 1, containing leads 2 and 3 passed therethrough, and fusible elements 4 included intermediate of said leads 2 and 3, the fusible elements 4 being embedded in a body 5 of a capillary-porous material partially immersed in a liquid filler 6. The liquid filler 6 fills the fuse only partially, thereby providing a buffer space 7 therein. Hence, the quantity of the liquid filler is chosen to be minimum but sufficient to fill the pores of the entire body 5 and wet the inner surface of the casing 1 and the hollow leads 2 and 3. It is desirable that prior to being filled with the liquid filler 6 the fuse should be throughly outgassed, for example, by vacuum annealing, to prevent the formation of a vapour lock obstructing condensation. Under rated current, the fusible element 4 gets heated, causing the liquid filler in the pores of the layer of the body 5 adjoining the fusible element 4 to boil, the vapour bubbles penetrate through the pores of the body 5 and condense on the inner walls of the casing 1 and the buffer space 7, giving off their heat to the upper lead 2. The condensate flow down the walls of the casing 1 into its lower portion, wherefrom, under the effect of capillary forces, it again rises and gets into the area of the fusible element 4. Thus is ensured a continuous evaporation-condensation cycle of the filler 6 under nominal operating conditions. Under overcurrents, the part of the body 5 adjoining the fusible element 4 dries up, the temperature of the fusible element rises and the fusible element melts off. The resulting arc gets into the pores of the body 5 and is extinguished therein in the same manner as in fuses with a conventional dry fine-grained filler.

In another embodiment of the proposed fuse, shown in FIG. 2, a body 8 of a capillary-porous material, having a fusible element 9 embedded therein is completely

immersed in a liquid filler 10. In this case, the fuse casing 11 is made from an impact-resistant material, such as metal, for the design of this fuse does not rule out the possibility of hydrodynamic shock. To improve heat exchange with the surrounding medium, the casing 11 is provided with ribs 12. The fusible element 9 is coupled to leads 13 fixed in an insulator 14. In this embodiment of the proposed fuse, the body 8 is made of quartz sand tamped and fixed by a grid 15.

The fuse of this kind operates in a manner similar to that of the above-described one, except that capillary imbibition is facilitated by the complete immersion of the body 8 in the liquid filler 10, thereby preventing premature drying of the pores of the body 8 adjoining the fusible element 9.

An alternative element shown in FIG. 3 also comprises a sealed casing 16 and leads 17 including therebetween a fusible element 18 which is embedded in a body 19 of a capillary-porous material partially immersed in a liquid filler 20.

The body 19 is likewise made of quartz sand and is maintained at a gap "*a*" from the walls of the casing 16 by a cylindrical grid 21, which prevents the shock wave from reaching the walls of the casing. Therefore, the casing may be made from a material which need not be impact-resistant.

The foregoing fuse functions like the one shown in FIG. 1, in the following manner.

The liquid filler 20 penetrates through the grid 21 and makes it way into the body 19, wherefrom it is raised by capillary forces to the fusible element 18 and evaporates in the latter's area. The liquid vapours thus produced penetrate through the quartz sand and the grid 21 and condense on the inner wall of the casing 16, giving off their heat to the ribs of the casing 16.

The arc-extinguishing efficiency of the fuses shown in FIGS. 1 – 3, is demonstrated vividly in FIG. 4 which is a typical cathode oscillogram of arc voltage V_a (curve A) versus time for fuses employing fixed quartz sand as the body of a capillary-porous material and ethylene glycol as the liquid filler. It will be seen that the overvoltage peaks are quite low.

For the sake of comparison the same FIG. 4 gives an arc voltage oscillogram for the case of pure quartz sand (curve B). It will be appreciated that the curve A and B are similar which goes to prove that the mixture of quartz sand and ethylene glycol is practically equivalent by its arc-extinguishing properties to quartz sand free from any admixtures, and the latter is known as an excellent arc-extinguishing medium.

FIG. 5 illustrates voltage losses ΔV as a function of current intensity I for the same type of fuse. The curve C represents the case of the filler being a mixture of quartz sand with ethylene glycol, while the curve D corresponds to the case of a pure quartz filler. The straight line E represents the dependence of ΔV on I at a constant mean temperature of the fusible element $t = +180°$ C.

Comparing the results for the given mean temperature of the fusible element by the points of intersection of the curves C and D with the straight line E, it will be seen that the rated current intensity of the fusible element in the mixture of quartz sand and ethylene glycol is 1.5 times higher than that in pure quartz sand. The improved cooling conditions of the fusible elements permit of reducing their thickness.

In the above-described example, the thickness of the fusible element is 0.028 mm, and the minimum width of the intermediate portion of the fusible element is 0.54 mm. The density of the rated current through the minimum cross-section of the fusible element is equal to 1,500 A/mm^2, that is to say far higher than that of the quick-acting fuses of the other known types, whose current density if of the order of 400 to 600 A/mm^2.

FIG. 6 and 7 represent alternative embodiments of the proposed fuse incorporating an auxiliary electrode. The fuse of FIG. 6 comprises a sealed metal casing **22**, an upper lead **23** being an extension thereof. A lower lead **24** is hermetically secured in an insulator **25**. A fusible element **26** is included intermediate of the leads **23** and **24**. Around the fusible element **26** and at a small distance therefrom there is provided an auxiliary electrode **27** made as a thin metal spiral, said auxiliary electrode being conductively coupled to the fusible element **26** through a low-conducting filler. The inner space **28** of the casing **22** is filled with a filler composed of a capillary-porous medium such as quartz sand and a dielectric liquid. Intermediate of a buffer space **29** and the main space **28** there is secured a strong grid **30** serving to fix the capillary-porous material.

Under the nominal operating conditions of the fuse, the voltage V impressed between the lower lead **24** and the auxiliary electrode **27** sets up an electric field in the layer of the porous filler adjoining the fusible element **26**. If the field intensity is high enough, the field will affect the boiling of the liquid phase of the filler, with the result that the rated current density in the fusible element may be chosen to be higher than in similar fuses containing no auxiliary electrode.

The fuse of FIG. 7 comprses leads **31** having disposed therebetween a capillary **32** made of heat-resistant (300° – 400° C.) insulating material, such as quartz glass or Teflon. The capillary **32** is enveloped by fusible elements **33** bent as half-cylinders and welded to the leads **31**. The capillary **32** houses an auxiliary metal electrode **34**. The casing **35** of the fuse is made of a strong insulating material. The main inner space **36** of the fuse is filled with the aforementioned filler (quartz sand plus dielectric liquid). In thermal expansion, part of the liquid from the space **36** penetrates into the buffer space **38** through a narrow slit **37**.

Under rated conditions, a high voltage V from an external source is impressed between one of the leads **31** and the auxiliary electrode **34**, the voltage being variable since the auxiliary electrode is insulated from the rest of the fuse.

In the foregoing types of fuses according to FIGS. **6** and **7**, the cooling of the fusible element is achieved through the use of a physical phenomenon: the effect of an electric field on the boiling of a dielectric liquid.

The effect of the electrode field results in a substantial intensification of the rate of evaporative cooling of the fusible element.

A voltage is applied to the auxiliary electrode at all times, both under nominal conditions and under overload accompanied by the melting of the fusible element and extinguishing of the arc, but it is of practical significance only at the rated current intensity, for the voltage is supplied through a high-resistance resistor or a low-capacitance capacitor (not shown in FIG. **7**) limiting the current through the high-voltage circuit to a value of the order of **1** mA too low to cause an arc discharge. Besides, a transverse electric field of this intensity has practically no effect on the process of arc extinction.

The value of the electrode voltage by and large depents on the kind of liquid, the dielectrical properties of the capillary-porous body and the capillary, as well as on the chosen distance separating the electrode and the fusible element; generally this value ranges from several hundred volts to several kilovolts.

The present invention may be used to minimize the Joule effect, for the electric field acts to reduce the temperature of the fusible element, consequently reducing its resistance.

FIG. **8** illustrates the results of testing of one branch of the fusible element of a fuse, shown as the dependence of the drop of voltage Δ V in the fusible element on the current intensity I. The fuse tested was a mock-up with an auxiliary insulated electrode (FIG. **7**). The curve F represents the result for a filler composed of quartz sand and carbon tetrachloride, the voltage of the auxiliary electrode being equal to zero, that is to say in the absence of an electric field. The curve G represents the results of experiments with the same filler and a 50-Hz 10 kV voltage across the auxiliry electrode. For comparison, a case is given with dry quartz sand used instead of said filler and the voltage V being equal to zero (curve H). The relation of the drop of voltage to the current intensity I at a mean temperature of the fusible element equal to +180° C. is given in FIG. **8** by the straight line *i*. The points of intersection of the straight line *i* with the curves F, G and H represent the current values at which the fusible element has a temperature at +180° C. It will be seen from FIG. **8** that for dry quartz sand said current value is equal to 6.1 A., for the quartz sand-carbon tetrachloride filler 7.4 A., and with the electric field affecting the filler it is equal to 9.7 A.

The fuse incorporating an auxiliary electrode is of the controlled operation type, since its melting characteristics are determined by the voltage V on the auxiliary electrode. Thus, for instance, if the rated current value is close to the critical one, then cutting off the control voltage will cause the fusible element to melt off and the fuse to break the circuit.

What is claimed is:

1. An electrical circuit breaking fuse, comprising a casing; leads passed through said sealed casing; a fusible element disposed intermediate of said leads; a liquid filler partly filling said casing; said liquid filler having a boiling point below that of said fusible element; a body of a capillary-porous material with communicating pores immersed in said liquid filler and having said fusible element embedded therein, part of the communicating pores of said body which are in direct contact with the fusible element serve to supply said liquid filler to the area of said fusible element under nominal operating conditions of the fuse, while, under overcurrent said body helps extinguish the arc producd in the fuse.

2. An electrical circuit breaking fuse as of claim **1**, wherein said capillary-porous body is made of quartz sand.

3. An electrical circuit breaking fuse as of claim **2**, wherein said body of a capillary-porous material is only partially immersed in said liquid fill, the quantity of said liquid filler being minimum but sufficient to fill the pores of the entire said capillary-porous material and to wet the inner surface of said casing, thereby ensuring a continuous evaporation-condensation cycle of the filler under rated functioning conditions of the fuse.

4. An electrical circuit breaking fuse as of claim **3,** wherein between said body of a capillary-porous material and the side walls of said casing of the fuse there is formed a liquid-free gap which prevents hydraulic shock from propagating as far as the side walls of the casing.

5. An electrical circuit breaking fuse as of claim **4,** wherein the buffer space formed within the fuse casing as the latter is filled with said liquid filler contains primarily the vapours of the liquid filler, the proportion of foreign gases which fail to condense at the rated temperature of the fuse being practically equal to zero.

6. An electrical circuit breaking fuse as of claim **5,** which comprises at least one auxiliary electrode electrically connected to a source of voltage and setting up an additional electric field in the immediate vicinity of said fusible element, said additional electric field affecting the boiling of the liquid in the pores of said body of a capillary-porous material, thereby causing an intensive cooling of said fusible element.

7. An electrical circuit breaking fuse as of claim **6,** wherein said auxiliary electrode is conductively coupled to said fusible element through the filler.

8. An electrical circuit breaking fuse as of claim **6,** wherein said auxiliary electrode is insulated from the filler.

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