Sept. 6, 1966 R. C. RAGAN 3,271,544

PRECISION ELECTRICAL FUSE

Filed April 14, 1964 2 Sheets-Sheet 1

FIG. 1

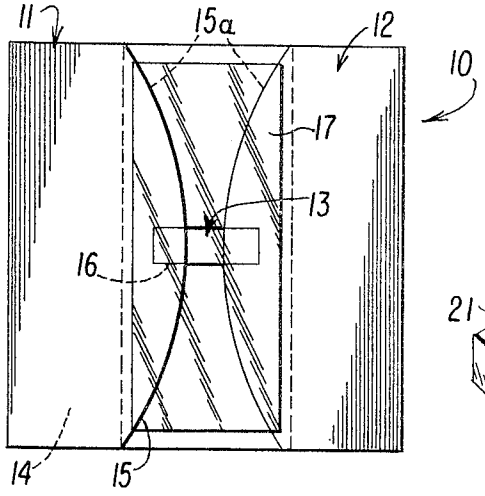


FIG. 3

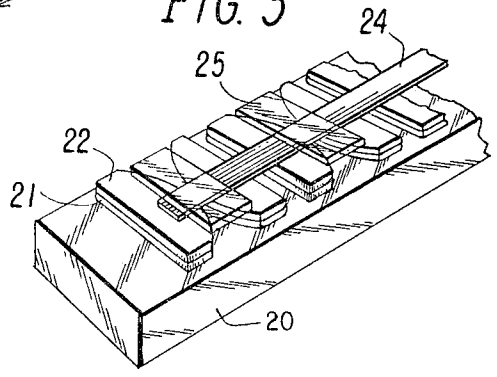


FIG. 2

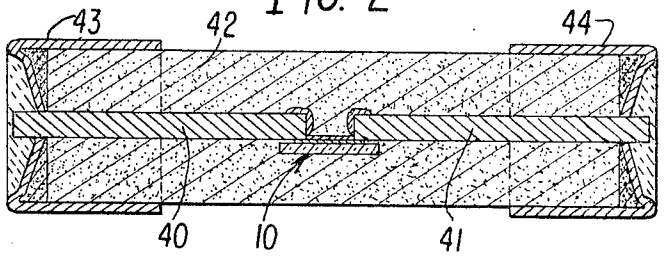
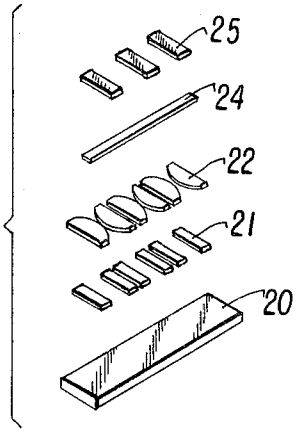


FIG. 4



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FIG. 5a

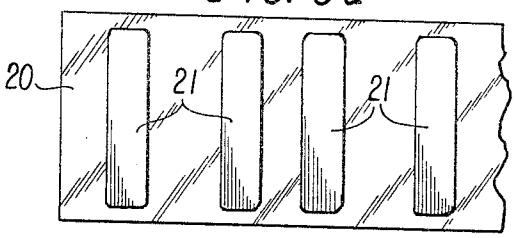


FIG. 5b

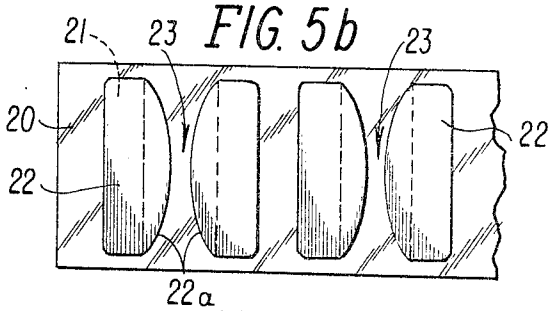


FIG. 5c

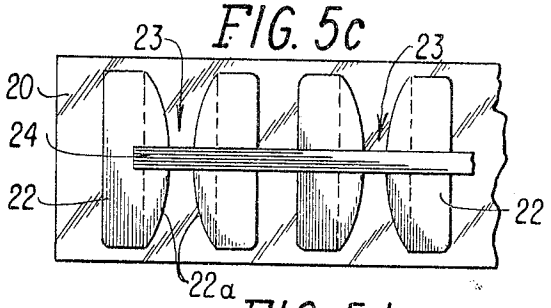


FIG. 5d

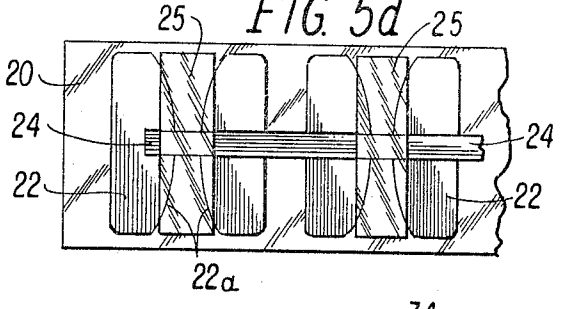


FIG. 6

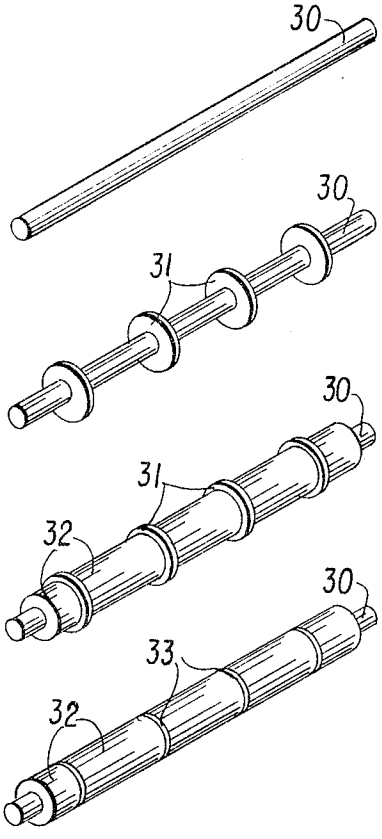
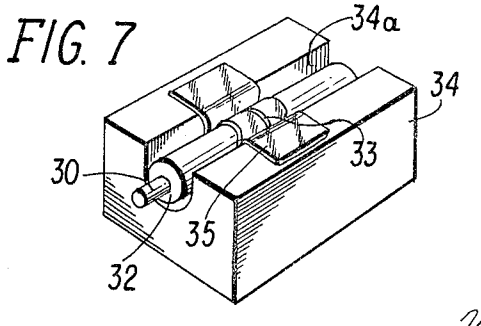


FIG. 7



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3,271,544

PRECISION ELECTRICAL FUSE

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Filed Apr. 14, 1964, Ser. No. 359,569
5 Claims. (Cl. 200—135)

This application is a continuation-in-part of my copending application Serial No. 779,605, "Precision Electrical Circuit Elements," filed December 11, 1958, which in turn is a continuation-in-part of my application Serial No. 618,728, "Precision Electrical Circuit Elements," filed October 29, 1956, now abandoned.

This present invention relates generally to electrical fuses and, more particularly, to an improved precision electrical fuse.

It is a primary object of this invention to provide an improved miniature electrical fuse which produces a fast and decisive break at the rated breaking current. A related object is to provide such a fuse which completely eliminates any arcing across the blown fuse element. Thus, it is another object to provide such a fuse which may be used in high voltage circuits with assured reliability of current cut off. Still another object is to provide such a fuse which fires fast enough to protect rapidly responding semiconductor devices.

It is another object of the invention to provide an improved miniature electrical fuse which is precise and accurately reproducible for the most exacting applications, and yet is inherently simple and economical to manufacture. A connected object is to provide such a fuse which can be produced in a wide range of current ratings.

It is a further object of the invention to provide a precision electrical fuse which is extremely stable, both electrically and physically, over extended periods of operation. Thus, it is an object to provide such a fuse which maintains its rated breaking current even when operated for extended periods at relatively high temperatures. Another object is to provide such a fuse which is highly resistant to corrosion and abrasion. Yet another object is to provide such a fuse which is capable of withstanding current spikes of short duration without changing its rated breaking current.

A still further object of the invention is to provide an improved miniature electrical fuse which can be used in multiple arrangements in either series or parallel. In this connection, it is an object to provide such fuses which, when connected in series in high voltage circuits, distribute the voltage evenly among the series connected units. A related object is to provide such fuses which can be conveniently assembled in multiple arrangements on a single compact substrate.

Other objects and advantages of the invention will become apparent upon reading the following description and appended claims and upon reference to the drawings, in which:

FIGURE 1 is a plan view of a miniature electrical fuse embodying the present invention;

FIG. 2 is a sectional elevation view showing the fuse of FIG. 1 housed in a suitable fuse capsule;

FIG. 3 is a perspective view of a series arrangement of fuses similar to the fuse of FIG. 1 formed on a single substrate;

FIG. 4 is an exploded view of the series arrangement of fuses shown in FIG. 3;

FIGS. 5*a*, 5*b*, 5*c* and 5*d* is a sequence of enlarged fragmentary plan views illustrating the various steps of a preferred method of forming the series arrangement of fuses shown in FIGS. 3 and 4;

FIG. 6 is a sequence of perspective views illustrating

the various steps involved in forming a modified series arrangement of fuses embodying the invention; and

FIG. 7 is a fragmentary perspective view of the final product made according to FIG. 6 and mounted on an insulating substrate.

While the invention will be described in connection with a preferred embodiment, it is to be understood that the invention is not to be limited to the disclosed embodiment but, on the contrary, it is intended to cover the various modifications and equivalent arrangements included within the spirit and scope of the appended claims.

Turning now to the drawings, in FIGS. 1 and 2 there is shown a miniature electrical fuse including an elongated substrate **10** formed of an electrically insulating material, a pair of spaced apart electrically conductive fuse electrodes **11** and **12** supported on the substrate **10** in intimate contact therewith, and a fuse element **13** extending between and electrically connecting the leads **11** and **12**. In order to insure a rapid and decisive electrical break in the fuse element **13** when the current exceeds the rated maximum load, the substrate **10** should have a low thermal conductivity and high surface and volume electrical resistivity, both before and after the blowing of the fuse element. The low thermal conductivity minimizes heat losses from the fuse element to the substrate. Thus, when an overload in the electric circuit increases the temperature of the fuse element, practically all the heat is retained in the fuse element, and the fuse is heated to its blowing point instantaneously. The high surface and volume electrical resistivity of the substrate concentrates all the effective resistance of the fuse in the fuse element **13**, and insures a complete and decisive electrical break upon blowing of the fuse element, with no residual conductivity in the substrate. In addition to the low thermal conductivity and high electrical resistivity, the substrate should have a smooth surface so as to permit the deposition of substantially uniform films thereon.

The preferred substrate material is glass, such as soda-lime glass or lead-boro-silicate glass. It has been found that these glasses have high surface and volume resistivity and provide excellent thermal insulation for the fuse element, even when used as extremely thin wafers having a thickness of approximately 0.030 inch for example. Moreover, these glasses provide a smooth surface for film deposition and are low in cost and easy to fabricate. A typical glass which has been found to be especially useful as a substrate material in this invention is soda-lime glass having a composition as follows:

	Percent
Silicon dioxide	71.96
Iron oxide	0.037
Aluminum oxide	1.42
Calcium oxide	8.11
Magnesium oxide	4.23
Sodium oxide	13.62
Potassium oxide	0.29
Sulfur trioxide	0.29

Alternatively, the substrate **10** may be made of any other suitable thermally stable insulating material such as, for example, electrical porcelain, steatite, fosterite, mica and other ceramic materials having the necessary chemical, electrical, and physical properties for the particular use intended. The substrate must, of course, be capable of withstanding the action of any chemicals used in the deposition of the electrodes **11** and **12** and the fuse element **13**, as well as any changes in temperature encountered during manufacture and use of the fuse. Most organic plastics and certain ceramics such as alumina and beryllia are not satisfactory substrate materials because of their comparatively high thermal conductivity.

The fuse gap which is occupied by the fuse element **13** is formed by the spaced apart fuse electrodes **11** and

12 supported on the surface of the substrate 10. In order to concentrate substantially all the effective resistance of the fuse in the fuse element 13, the electrodes 11 and 12 should be made of a highly conductive metal so that their electrical resistance is as low as possible. If the leads 11 and 12 have any substantial electrical resistance, they represent another variable to be considered in manfacturing and testing the fuse, and also alter the time-temperature curve of the finished fuse.

The preferred electrode material is silver, because it requires the minimum amount of material for any given conductivity, but any other suitable highly conductive metal may be employed. When silver is used for the entire electrode, however, it has been found to have a deleterious effect upon the blowing of the fuse, as described in more detail hereinafter. Thus, in the preferred embodiment of FIG. 1, each electrode 11 and 12 is composed of a base layer 14 of silver and an overlay 15 of gold. The fuse gap between the two electrodes is defined by a pair of curved edges 15*a* which facilitate adjustment of the width of the fuse gap and also provide a convergent path of high conductivity. It should be noticed that the curved portions of the gold overlays 15 protrude beyond the silver layers 14, thereby providing a pair of gold electrode terminals which are compatible with proper operation of the fuse. In general, the silver should be kept at least about 0.025 inch away from the fuse element.

In the practice of the present invention, there is provided a composite metal-glass fuse element comprising an electrically conductive fuse metal extending between and electrically connecting the spaced apart fuse electrodes, and a layer of electrically insulating glass covering the metal layer in intimate contact therewith for quenching the fuse metal after it has been blowen by a current overload, whereby any arcs which tend to develop across the blown metal are effectively suppressed. Thus, referring to FIGS. 1 and 2, the fuse element 13 includes a metal layer 16 extending between and electrically connecting the electrodes 11 and 12, and a glass coating 17 which completely covers the metal 16 in intimate contact therewith. In the particular embodiment illustrated, the glass coating also covers the adjacent end portions of the electrodes 11 and 12, and is bonded to the substrate 10 on both sides of the metal 16.

This invention stems in part from the unexpected discovery that if a composite metal-glass fuse element is made from certain compatible metal and glass components, the glass component completely suppresses any arcs which normally tend to develop after the blowing of a fuse in a high voltage circuit, without any inhibiting effect whatever on the rapid blowing of the fuse metal. Indeed, the glass coating has actually been found to increase the firing speed of the fuse. This effect is especially surprising when one considers that the fuse metal is completely encased at the time of firing, i.e., there are no voids into which the fuse metal can be blown. Although the explanation for this phenomenon is not entirely clear, it is believed that the blowing of the fuse softens the glass coating and permits the blown metal to migrate or be absorbed within the glass coating. Consequently, little or no metal vapor remains within the fuse junction, and there is no opportunity for a conductive plasma or highly ionized gas path to develop between the fuse electrodes. Furthermore, the softening of the glass permits migration of the metal into the glass thereby slightly derating the unit so that it breaks decisively. This effect, combined with the added thermal insulation provided by the glass coating, leads to a rapid firing rate so that the fuse does not "hang on" at a current near the breaking point.

In order to insure that arcing is completely suppressed upon blowing of the fuse metal, it is important that the metal and glass components of the composite fuse element be such that the blown metal readily migrates into the glass coating, thereby effectively preventing subsequent vaporization and ionization of the blown metal. The preferred metal component is gold. Gold not only migrates readily into most low melting glass coatings, but also has a high positive temperature coefficient of electrical resistivity and, therefore, blows rapidly under overload conditions. In other words, the gold increases in resistivity as the temperature is increased, thereby providing an avalanche or snowballing effect which produces substantially instantaneous blowing. In addition, gold has many properties which are desirable in the manufacture and normal operation of the fuse. Thus, for example, gold has good electrical conductivity, does not oxidize, is chemically and electrically stable, and is compatible with the ceramic processes which are preferably used in the manufacture of the fuse.

In contrast with gold, silver has been found to be completely useless as a metal component in the composite fuse element of this invention, in spite of the fact that silver is generally considered a close relative of gold. Indeed, when silver is used as the fuse metal in this invention and is blown by a current overload, it causes the surrounding glass to become highly conductive and to support higher and higher current until sufficient heat is generated to melt all parts of the circuit in the immediate vicinity of the fuse. In some cases, the silver actually causes an explosion. It is for this reason that the silver electrodes must be provided with terminals made of gold or other nondeleterious metal which keep the silver at least about 0.025 inch away from the fuse element, as described above.

Another metal which may be used as the metal component of the composite metal-glass fuse element is platinum. Although platinum has the disadvantages of a higher vaporization temperature and higher electrical resistivity than gold, it has been found that platinum will blow and migrate into a glass coating the same as gold when subjected to a current overload.

It will be recognized that the size and shape of the metal component of the composite metal-glass fuse may be adjusted to tailor the fuse to particular operating conditions and to provide different time-current curves. For example, a relatively thin and wide metal film covering a large substrate area will have greater immunity to current spikes of short duration than a relatively thick and narrow film covering a smaller substrate area, because of the difference in the heat dissipation capacities of the two types of film. Of course, the exact size and shape of the metal film required in any given fuse depend not only on the particular characteristics desired in the final fuse, but also on the particular materials employed. In the case of pure gold used as the fuse metal in a fuse suitable for most conventional applications, a metal layer 0.005-inch square may be .0006 inch thick in a 5-ampere fuse and .0002 inch thick in a 1/32-ampere fuse.

In accordance with one aspect of this invention, it has been found that the response time of the fuse, i.e., the time required for the fuse to blow when subjected to a current overload, generally decreases as the length and/or the width of the fuse metal layer is decreased. Also, the minimum response time for any given fuse is achieved when the length and width of the exposed portion of the fuse metal layer are substantially equal, as illustrated in FIG. 1. For example, in a typical fuse rated at 3 to 5 amperes, the metal layer 16 is suitably five mils square.

In order to provide a precise and accurately reproducible fuse, the two electrodes 11, 12 and the fuse film 16 should be deposited with consistently uniform thicknesses and compositions. This may be accomplished by a number of suitable film deposition methods such as, for example, thermal decomposition of metal-containing compounds, electrodeposition, vacuum evaporation, cathode sputtering and the like. One particularly preferred method of depositing the metal films is by thermal decomposition of metal resinates. In this method, the resinate is initially deposited in liquid form, being applied to the desired

areas of the substrate by a suitable stencilling technique, such as silk screening for example, or by the application of ordinary printing, engraving, and lithographing techniques and the like. After the liquid resinate has been deposited, it is heated to its decomposition temperature in an oxidizing atmosphere to drive off the volatile reaction products and deposit a solid metal film bonded firmly to the substrate. This method permits accurate control of the thickness and other properties of the metal film and is capable of depositing extremely thin films which are uniform and continuous. The exact thickness of the various films will, of course, vary with different fuses, but the thickness of the fuse film **16** is generally in the range of about 0.0005 to 0.005 inch. In certain cases where it is desired to increase the conductivity of the film deposited from the resinate, such as in forming gold overlays or terminals on silver electrodes for example, fine metal powder, such as gold powder for example, may be mixed with the liquid resinate. Also, it is often desirable to metallize the substrate surface, as with a thin silver coating, prior to the application of the resinate for the purpose of providing an electrically conductive and mechanically stable base for the subsequent welding of wire leads to the fuse.

In order to insure that the blown fuse metal migrates quickly into the arc-suppressing glass coating **17**, the coating is made of a low melting glass, i.e., an inorganic product of fusion cooled to rigidity without crystallization. More particularly, the coating **17** should be made of a glass having a melting point below that of the substrate **10**. As in the case of the substrate **10**, the glass coating **17** should also have a low thermal conductivity and high surface and volume electrical resistivity, both before and after the blowing of the fuse metal **16**. The low thermal conductivity minimizes heat losses from the fuse metal, while the high resistivity concentrates the effective resistance of the fuse in the metal layer **16**.

In order for the composite fuse element **13** to remain useful over extended periods of operation, it is important that the particular material employed for the insulating coating **17** remain electrically nonconductive upon extended operation at relatively high temperatures. In this connection, it has been found that certain insulating materials are satisfactory when first applied, but tend to decompose or char and become conductive during use. This, of course, renders the fuse useless even though the metal layer has not blown. Examples of such unsatisfactory insulating materials are Teflon, ethyl cellulose, and epoxy resin. Various powdered materials have also been tried as arc suppressors, but the air spaces throughout the powdered material have been found to permit the formation of the conductive plasma which leads to destructive arcing in high voltage circuits.

The preferred material for the fuse coating **17** is a low melting point glass such as lead-boro-silicate glass (e.g., 1:8:1 ratio of B_2O_3, PbO, and SiO_2, respectively). This glass provides effective thermal and electrical insulation, remains stable over extended periods of operation at elevated temperatures, and readily absorbs the blown fuse metal. Other suitable glasses are the low melting soda-lime glasses, phosphate glasses, and various modified lead-boro-silicate glasses. Certain water soluble alkali silicate glasses, such as sodium silicate and potassium silicate glass, may also be used, provided they are thoroughly dried in order to reduce the moisture content to a satisfactorily low level to provide high electrical resistivity.

In order to prevent cracking and crazing of the glass coating **17** during alternate heating and cooling of the fuse either in the process of manufacture or in use, the coefficient of thermal expansion of the coating should be adjusted to correspond with the coefficient of thermal expansion of the substrate **10** to which the coating is bonded. For example, in the case of the preferred lead-boro-silicate glass, the coefficient of thermal expansion may be adjusted by the addition of zirconium oxide.

The arc-suppressing glass coating **17** may be formed by printing, spraying, or otherwise depositing a finely ground glass flux over the previously deposited fuse metal **16**, and then heating the glass flux to its fusing temperature. The fused flux forms a continuous impervious glassy coating which is bonded firmly to the substrate **10** on both sides of the metal **16**. In order to achieve the desired glassy coating, the flux must be fired to its fusing point, but overfiring has been found to produce an uncontrollable increase in the resistance of the underlying metal. Also, overfiring causes bubbling or blistering of the glass which may destroy the continuity of the arc-suppressing coating. The firing temperature and time employed in any given case depends on the particular coating composition used, and it will be understood that a number of different firing procedures may be devised for any given coating. For example, in the case of the preferred lead-boro-silicate (1:8:1) glass coating, the flux may be fired at about 830° F. for a period of about 5 to 10 minutes. The thickness of the coating will vary for different applications, but in general the glass coating should have a thickness of at least about one mil, preferably at least 2 to 3 mils.

In one aspect of the invention, the voltage rating of the fuse is increased by providing a plurality of the composite fuse elements in series with each other, preferably on a single substrate, as illustrated in FIGS. 3–5. In a preferred method of forming this construction, an elongated glass substrate **20** is initially provided with a plurality of small spaced apart films **21** of silver, as shown in FIG. *5a*, by the thermal decomposition of silver resinate. After the silver films **21** have been deposited and solidified, a plurality of corresponding gold overlay films **22** are deposited on top of the silver films. As shown in FIG. *5b*, alternate pairs of the gold films **22** have opposed curved edges **22***a* which define a plurality of fuse gaps **23**.

It will be appreciated that the silver films **21** and the gold films **22** form a plurality of highly conductive composite silver-gold electrodes having terminals **22***a* of pure gold. In order to achieve high conductivity in the terminals **22***a*, the gold films **22** are preferably deposited from a mixture of gold resinate and fine gold powder. In the case of relatively high amperage devices, it may be necessary to deposit the gold in multiple coatings to achieve the desired conductivity. Alternatively highly conductive gold films may be deposited by electrodeposition.

After the deposition of the gold films **22** has been completed, each fuse gap **23** is inspected to insure that all the gaps are of the desired uniform width, typically about five mils. In actual production, the gaps are originally made somewhat less than the width actually required in the final product, and then adjusted to the exact required width by a scribing technique under a magnifying device. Next, the metal component of the composite metal-glass fuse element is deposited in the form of a narrow strip **24** of gold film which bridges the various fuse gaps **23**, as shown in FIG. *5c*, so as to electrically connect the curved gold terminals **22***a*. The gold strip **24** is preferably deposited by thermal decomposition of gold resinate.

To complete the composite fuse element, a small strip **25** of low melting glass is deposited over each fuse gap and that portion of the gold strip **24** bridging the gap, as in FIG. *5d*. The glass strips **25** form the arc-suppressing coatings of the respective fuses, and are firmly bonded to the substrate **20** on opposite sides of each fuse gap between the gold films **22**. The glass strips **25** may be formed by stencilling a suitable glass flux onto the desired areas and then fusing the deposited flux to form smooth glassy coatings. This completes a multi-element series fuse ready for encapsulation in the manner described hereinafter.

A modified series arrangement of fuses which is especially adapted to carry relatively high currents and simplify production procedures is shown in FIG. 6 and 7.

In this construction, a small gold wire **30** is initially provided with a plurality of annular plastic spacers **31** equally spaced along the axis of the wire. To provide the desired fuse electrodes, the wire **30** is electroplated or otherwise coated with a gold coating **32** which is broken only by the spacers **31**. The plastic spacers are then dissolved by means of a suitable solvent, thereby providing a plurality of spaced fuse gaps **33** occupied only by the exposed portions of the gold wire. These exposed portions of the gold wire form the metal components of the series arrangement of composite fuse elements, while the highly conductive coated sections of the rod form the fuse electrodes. This entire assembly is then seated in a groove **34***a* of an insulating glass substrate **34**, and each fuse gap **33** is coated with an arc-suppressing glass coating **35**. It will be appreciated that the relatively large metallic cross section achieved by this construction provides a large current-carrying capacity.

In accordance with one aspect of this invention, a pair of leads is connected to the fuse electrodes, and the entire assembly is placed in a standard form package that will fit conventional circuit hardware. Thus, referring to FIG. 2, a pair of wire leads **40** and **41** is soldered to the fuse electrodes on the surface of a glass substrate **10**, and then both the fuse and the leads are embedded in a solid insulating cylinder **42** with ends of the leads **40**, **41** protruding from the ends of the cylinder. This construction not only provides additional mechanical support for the leads **40**, **41**, but also insures that any arcs or other effects from an accidental failure of the arc suppressor are contained within the encapsulating package. The package is finished by fitting a pair of end caps **43** and **44** over the ends of the cylinder **42** and soldering them to the protruding ends of the wire leads.

In order for the insulating cylinder **42** to protect the fuse without affecting its operation, the cylinder **42** must have high dielectric-strength and high electrical resistance. In addition, the cylinder should be made of a material which is resistant to moisture, thermal shock, vibration, or any other environmental hazards which may be encountered in use. A preferred material for the encapsulating cylinder is epoxy casting resin, or an epoxy compression or transfer molding material, which may be formed in a molding shell fitted around the fuse assembly. Of course, it will be appreciated that the encapsulating package is not limited to the cylindrical form shown in the drawing, but may be formed in any suitable shape.

While various specific forms of the present invention have been illustrated and described herein in some detail, it will be understood that the same are susceptible of numerous modifications within the spirit and scope of the invention. Thus, although the multiple arrangements of the subject fuse have been described with particular reference to series arrangements to increase the voltage rating of the fuse, the invention is equally applicable to parallel arrangements of the composite fuse elements to increase the current-carrying capacity of the fuse.

It can be seen that this invention provides an improved miniature electrical fuse which produces a fast and decisive break at the rated breaking current. The effective thermal insulation provided on both sides of the fuse metal by the nonconductive substrate and the arc-suppressing coating, combined with the high positive temperature coefficient of electrical resistivity of gold, produce an avalanche effect which causes practically instantaneous blowing at the breaking current. Moreover, the arc-suppressing coating completely eliminates any arcing across the blown fuse, thereby providing a fuse which may be used in high voltage circuits with assured reliability of current cut off.

What is claimed is:

1. A precision electrical fuse for protecting an electric circuit, said fuse comprising the combination of an electrically insulating substrate which has a low thermal conductivity and is resistant to high temperatures, a pair of spaced apart electrically conductive fuse electrodes deposited on the surface of said substrate in intimate contact therewith, a composite metal-glass fuse element extending between said electrodes and including a thin layer of electrically conductive fuse metal selected from the group consisting of gold and platinum on the surface of said substrate, said metal layer extending between and electrically connecting said electrodes, said fuse metal being adapted to blow when the electrical current therethrough exceeds a predetermined level, and a layer of electrically insulating glass having a melting point below that of said substrate bonded to said substrate on opposite sides of said fuse metal and covering said fuse metal in intimate contact therewith for quenching and absorbing the fuse metal as it is blown whereby any arcs which tend to develop between the fuse electrodes are effectively suppressed, said substrate and said fuse element being adapted to maintain an electrical connection between said electrodes until the current through said metal layer increases sufficiently to vaporize the same.

2. A precision electrical fuse for protecting an electric circuit, said fuse comprising the combination of a glass substrate having low thermal conductivity and high surface and volume electrical resistivity, a pair of spaced apart silver electrode films deposited on the surface of said substrate in intimate contact therewith, the opposed ends of said silver films being provided with a pair of spaced apart gold terminal films deposited on the surface of said substrate, a composite metal-glass fuse element comprising a thin film of electrically conductive fuse metal selected from the group consisting of gold and platinum on the surface of said substrate, said metal layer extending between and electrically connecting said gold terminal films on the surface of said substrate, said fuse metal being adapted to blow when the electrical current therethrough exceeds a predetermined level, and a coating of lead-boro-silicate glass having a melting point below that of said substrate bonded to said substrate on opposite sides of said fuse metal and covering said fuse metal in intimate contact therewith for quenching and absorbing the fuse metal as it is blown whereby any arcs which tend to develop across the blown fuse metal are effectively suppressed, said lead-boro-silicate coating having a coefficient of thermal expansion corresponding to the coefficient of thermal expansion of said glass substrate, said substrate and said fuse element being adapted to maintain an electrical connection between said electrodes until the current through said metal layer increases sufficiently to vaporize the same, and a pair of electrical leads connected to said silver films for connecting the fuse into the electric circuit to be protected.

3. A precision electrical fuse for protecting an electric circuit, said fuse comprising the combination of a glass substrate having low thermal conductivity and high surface and volume electrical resistivity, a pair of spaced apart electrically conductive fuse electrodes deposited on the surface of said substrate in intimate contact therewith, a composite metal-glass fuse element comprising a thin layer of electrically conductive fuse metal selected from the group consisting of gold and platinum on the surface of said substrate, said metal layer extending between and electrically connecting said electrodes, said fuse metal being adapted to blow when the electrical current therethrough exceeds a predetermined level, the length and width of said fuse metal being substantially equal, and a coating of low melting electrically insulating glass having a melting point below that of said substrate covering said fuse metal in intimate contact therewith for quenching the fuse metal as it is blown and preventing subsequent vaporization of said metal whereby any arcs which tend to develop between the fuse electrodes are effectively suppressed, said coating being bonded to said substrate on opposite sides of said fuse metal, said substrate and said fuse element being adapted to maintain an electrical connection between said electrodes until the current through

said metal layer increases sufficiently to vaporize the same, at least the end portions of said fuse electrodes being made of a metal which does not substantially increase the electrical conductivity of said coating upon the blowing of said fuse metal, and a pair of electrical leads connected to said fuse electrodes for connecting the fuse into the electric circuit to be protected.

4. A precision electrical fuse for protecting an electric circuit, said fuse comprising the combination of an elongated glass substrate having low thermal conductivity and high surface and volume electrical resistivity, a plurality of pairs of spaced apart electrically conductive fuse electrodes deposited on the surface of said substrate in intimate contact therewith, the opposed edges of alternate pairs of said electrodes having gold terminals thereon to define a plurality of predetermined fuse gaps in series along the surface of said substrate, a thin layer of electrically conductive fuse metal selected from the group consisting of gold and platinum deposited within each of said fuse gaps so as to extend between and electrically connect said gold terminals, said fuse metal being adapted to blow when the electrical current therethrough exceeds a predetermined level, and a layer of electrically insulating glass covering said fuse metal at each fuse gap in intimate contact therewith for quenching and absorbing the fuse metal as it is blown, whereby any arcs which tend to develop between the fuse electrodes upon the blowing of said fuse metal are effectively suppressed.

5. A precision electrical fuse comprising the combination of an elongated glass substrate having low thermal conductivity and high surface and volume electrical resistivity, an elongated gold wire having an electrically conductive metal coating around axially spaced portions of said wire so as to form a plurality of fuse electrodes

with the exposed portions of said gold wire between said electrodes forming a series of metal fuse elements adapted to blow when the electrical current therethrough exceeds a predetermined level, said coated wire being supported on the surface of said glass substrate, and a layer of electrically insulating glass having a melting point below that of said substrate bonded to said substrate on opposite sides of said fuse metal and covering the exposed portion of said gold wire between each pair of said electrodes for quenching and absorbing the fuse metal as it is blown, whereby any arcs which tend to develop between the fuse electrodes upon the blowing of said fuse are effectively suppressed, said substrate and said fuse element being adapted to maintain an electrical connection between said electrodes until the current through said metal layer increases sufficiently to vaporize the same.

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