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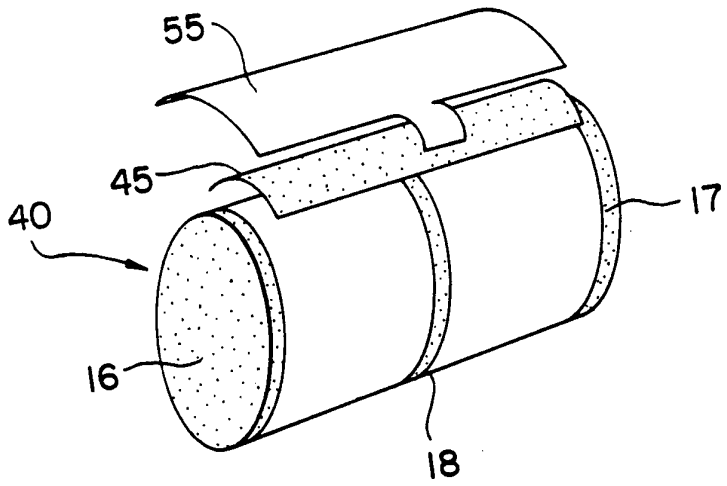
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(57) Abstract

A vent-safe protector (40) for a telecommunications gas tube (12) includes two electrodes (16, 55) (61, 63) separated by a non-linear resistive material (45). Each electrode is connected to a gas tube protector terminal (16, 18) to provide an alternate discharge path if the gas tube (12) fails. The non-linear resistive material (45) is substantially non-conductive when the electrical potential between the electrodes is less than the material's breakdown voltage V_B. Above that voltage it becomes conductive and supports a plasma discharge therethrough, effecting a sudden increase in conductivity between the electrodes for discharging high energy potentials with a plasma voltage foldback functionally analogous to the foldback behavior of the gas tube protector.

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GAS TUBE VENT-SAFE DEVICE

Background of the Invention

The present invention relates to the telecommunications industry, and more particularly to backup devices for gas tube protectors. Gas tube protectors are used to protect telecommunications equipment from electrical interference or damage resulting from high voltage lightning pulses. A gas contained in the tubes ionizes at high voltages to divert such pulses to ground. The tubes also maintain a limited sustained ionization in the presence of a continuing high current overload, such as from an accidental power line crossover. To assure the performance of such tubes in the rare event that the ionizable gas vents from the tube, and to add protection in the case of overheat failure during sustained over-current conditions, prevailing industry practice is to require so-called "vent-safe" and "fail-safe" mechanisms along with the basic gas tube protector itself. (The term "vent-safe" now commonly refers to backup over-voltage protection if the gas "vents" or is lost to the atmosphere. The term "fail-safe" now commonly refers to thermal overload protection, although the term taken literally cloaks this connotation.)

Fail-safe protection is now commonly afforded by a fusible metallic or plastic material that, when heated due to the energy from the current overload, yields to a biased shorting member to provide a permanent current shunt around the gas tube. Vent-safe protection is usually provided by an air-gap in the external structure of the device. The air-gap is carefully dimensioned to require a firing potential considerably above the normal firing potential of the gas tube itself, so that a properly functioning gas tube will prevent the air-gap from firing. This is important since an over-voltage pulse usually fires harmlessly through a properly functioning gas tube, but may damage the air-gap (which is intended only as a safety backup). Such air-gaps are typically

designed to fire at about twice the design firing voltage of the gas gap. An example of such a device may be found, for example, in U.S. Patent No. 4,212,047 (Napiorkowski, issued July 8, 1980).

Unfortunately, it has been found that air-gap vent-safe protection schemes can become unreliable. Telecommunications installations are intended to remain serviceable, without attention or maintenance, for decades. Understandably, environmental conditions often cause the electrical characteristics of these air-gaps to become unstable over such long periods of time. For example, penetration of moisture into the backup air-gap lowers the discharge voltage level and ultimately leads to shorts at low voltage levels. The insulation resistance between the signal conductors and ground deteriorates, hindering regular performance of the network. Corrosion can induce shorts and cause corrosive destruction of the mechanism. The reduced firing voltage of the air-gap converts the gap from the secondary to the primary discharge path. Correct performance of the telecommunications network is thus compromised. These effects are most pronounced when the air-gap is directly exposed to the atmosphere, suffering seasonal as well as daily environmental effects, and further becoming contaminated by air pollution, insect infestation, and so forth. Even when efforts are made to isolate the air-gap from the environment, such as locating the device in a sealed container, it will be appreciated that, over a course of years, moisture often still finds its way into the air-gap.

Previous efforts to resolve this problem have included configurations in which the internal, normally gas-filled space was designed to act as an air-gap upon venting of the gas. However, manufacturers ran into problems meeting the close tolerances required of such devices. Other approaches included improving the quality control and tolerances for the air-gaps themselves: film thickness, die cutting quality of the film, air-gap diameter, anti-humidity coating, and so on. This increased the cost and manufacturing difficulty for these already intricate devices, but still left them vulnerable to the effects of humidity. Similarly, efforts at encapsulation were unsuccessful, whether using waxes, potting compounds, conformal coatings,

encapsulants, gels, and so forth, all of which tended to penetrate or migrate into the air-gap and change the discharge voltage levels.

A need therefore remains for an improved gas tube vent-safe device that can readily and inexpensively be utilized in place of existing air-gap vent-safe mechanisms, and which will be reliably environmentally stable over extended periods of unattended service life. Advantageously, the vent-safe device should also be functionally compatible with the latest environmental sealing and encapsulation technologies, such as gel encapsulation, to support advances in these technologies and to provide improved environmental isolation of the entire gas tube assembly.

Summary of the Invention

Briefly, the present invention meets the above needs and purposes with a new and improved vent-safe mechanism for gas tube protectors, in which the air-gap has been replaced with a layer of solid material having particular non-linear electrical resistive characteristics. In the preferred embodiment, a solid, carbon black filled polycarbonate based extrusion grade compound is used. The film has a thickness from about 0.001 inches to about 0.010 inches or more, and preferably from 0.002 inches to 0.005 inches. The film is non-conductive, having an insulation resistance greater than 10^9 ohms when placed between two electrodes, regardless of geometry. The breakdown voltage (v_B) of the film is greater than 600 and less than 1000 volts, and can be controlled to a narrow band (e.g., $800 < v_B < 850$ volts, or roughly twice the design breakdown voltage of the gas tube), if desired. (Once a discharge has fired through the film, subsequent breakdown voltages tend to be lower.) The initial breakdown voltage proves to be largely independent of contact with encapsulating materials (e.g., silicone gel). Because the film is a thin (1 to 5 mil) insulating plastic, it can be readily substituted for the fusible insulating plastic films in existing designs, such as described in the '047 patent (above). In addition to extreme environmental stability (even when immersed in water the breakdown voltage and insulative properties of the film do not change significantly), the invention significantly

improves and simplifies manufacturing tolerances and procedures by eliminating the need to form precise holes and precisely position them in the gas tube vent-safe structure. The preferred plastic material has a high heat deflection temperature (ASTM D648), so that it avoids possible deformation during thermal exposure in manufacturing, and exhibits less creep under compression and during temperature cycling.

A major feature of the present invention has to do with the discharge mechanism itself. Filled polymer films have been used in other technical areas for discharging static electricity (e.g., such as used for discharging static electricity in small personal computers). See, for example, U.S. Patents Nos. 4,977,357 (Shrier, issued December 11, 1990) and 5,068,634 (Shrier, issued November 26, 1991). However, these have been low energy applications where the devices were designed for reliable repeatability after many discharge events. That is, the performance had to be non-destructive. A major distinction, and an important new feature of the present invention, is the realization and expectation that the present device will perform in a manner which will be destructive to itself. By making this a feature of the present invention (which is acceptable since this is a backup device that normally should not be called upon to fire), the present invention can handle and discharge high voltage pulses having significant energy, such as caused by lightning pulses. In contrast, prior art devices in other technical applications have not been considered capable of handling such impulses. This has important implications. The actual discharge mechanism is a plasma which the high energy of the electrical pulse forms through the plastic film, once the plastic film begins to conduct. This plasma results in a nearly direct short to ground, which is required for effective protection in telecommunications protector devices, and closely mimics the performance of a normal gas tube. This sudden plasma-induced increase in conductivity (or reduction in resistance) provides a voltage foldback effect to an extent not seen in non-destructive static load situations, where similar films have been used in other technologies, as mentioned.

This leads to an additional advantageous feature of the present invention. In another preferred embodiment, the vent-safe gap (and

preferably the entire gas tube device) is encapsulated in an environmentally sealing gel. A telecommunications terminal showing such a gas tube (but without the present vent-safe mechanism) encapsulated in a gel, is disclosed, for example, in U.S. Patent Application Serial Number 776,501 (Baum, et al., filed October 11, 1991), assigned to the assignee of the present invention, the disclosure of which is incorporated herein by reference for all purposes. When thus environmentally sealed, the gel encapsulant advantageously protects the vent-safe mechanism from environmental contaminants, excludes oxygen from the region of the plasma discharge, and acts as a heat sink. This gel encapsulated plasma discharge substantially reduces the degradation of surrounding materials, prevents combustion, and draws thermal energy away from local hot spots.

It is therefore an object of the present invention to provide new and improved methods and apparatus for providing vent-safe protection for telecommunications gas tube protectors, and more particularly for providing gas tube vent-safe methods and devices which include a first electrode for electrical connection to a terminal on the gas tube protector, a second electrode for electrical connection to another terminal on the gas tube protector, and a non-gaseous, non-linear resistive material separating the electrodes, the non-linear resistive material being substantially non-conductive when the electrical potential between the electrodes is less than a predetermined breakdown voltage v_B, being conductive when the electrical potential is greater than v_B, and supporting a plasma discharge therethrough after becoming conductive to effect a sudden increase in conductivity between the electrodes for discharging high energy with a plasma voltage foldback functionally analogous to the foldback behavior of the gas tube protector; wherein the first electrode may be at least a portion of the first gas tube terminal and thus located thereon; wherein the predetermined breakdown voltage v_B may be greater than the design breakdown voltage of the gas tube protector at least prior to the first discharge through the non-linear resistive material; wherein the non-linear resistive material may be a solid, filled polymer film which is a composition comprising a polymer and, dispersed in the polymer, a particulate conductive filler; wherein

the film may be a carbon black filled polycarbonate based extrusion grade compound having a thickness from substantially 0.001 to 0.010 inches or more, and preferably from 0.002 to 0.005 inches; wherein the particulate conductive filler may be carbon black, the primary size of the bulk (90%) of the carbon black filler being in the 30 to 60 nanometer range and the total carbon black content being 30 to 35% by weight of the total composition; wherein the electrodes and the non-linear resistive material may be environmentally encapsulated to protect them from environmental contaminants, to exclude oxygen from the plasma discharge, and to act as a heat sink to draw thermal energy away from local hot spots; wherein the encapsulant may be chemically inert to the film material; wherein the encapsulant may be a gel; which may include a third electrode for connection to a third terminal on the protector; wherein at least part of at least one of the electrodes may be at least partially rolled away from another of the electrodes; and to accomplish the above objects and purposes in an inexpensive, uncomplicated, durable, versatile, and reliable method and apparatus, inexpensive to manufacture, and readily suited to the widest possible utilization in telecommunications protector circuits.

These and other objects and advantages of the invention will be apparent from the following description, the accompanying drawings, and the appended claims.

Brief Description of the Drawings

Fig. 1 is a schematic illustration showing a typical 3-element gas discharge tube incorporated into a one pair telecommunications line;

Fig. 2 is a cross-sectional view of a gas tube such as used in the Fig. 1 circuit;

Fig. 3 shows a prior art gas tube equipped with an air-gap type vent-safe device;

Fig. 4 illustrates the behavior of an air-gap vent-safe device such as shown in Fig. 3, the effects of water and oil on the breakdown voltage of the air-gap being indicated thereon;

Fig. 5 is an exploded somewhat figurative illustration of a vent-safe device according to the present invention associated with a gas tube protector;

Fig. 6 is a slightly exploded end view of the assembly shown in Fig. 5;

Fig. 7 is a detail of the ground electrode/film retainer shown in Figs. 5 and 6;

Fig. 8 is a cross-sectional view similar to Fig. 2 showing the vent-safe device of Figs. 5 and 6 assembled onto the gas tube;

Fig. 9 shows another embodiment of the invention in which the vent-safe device is separate from and electrically connected to the gas tube;

Fig. 10 illustrates another embodiment of the present invention in which the gas tube and vent-safe device of Figs. 5-8 is encapsulated in a gel;

Figs. 11-13 depict the IV-curves for different thicknesses of non-linear resistive films of the type used in the present invention;

Fig. 14 shows the IV-curve for a gas tube vent-safe device constructed according to Figs. 5-8 and used as a replacement for the air-gap of a commercially available three–element gas tube vent-safe device;

Fig. 15 shows the IV-curve for a more conductive film;

Fig. 16 depicts an IV-curve for an extruded commercially available film; and

Figs. 17-19 depict the electrical impulse breakdown behavior of the Fig. 16 film as a function of current loading.

Description of the Preferred Embodiments

With reference to the drawings, the new and improved gas tube vent-safe method and device for telecommunications systems will now be described. Fig. 1 schematically illustrates a typical telecommunications circuit 10 incorporating a gas tube 12 in a telecommunications line 15. The gas tube protector 12 has end terminals 16 and 17 (Fig. 2) for connection to the tip and ring sides of the telecommunications circuit, and a center ground terminal 18. The

main body of the gas tube protector 12 is a ceramic shell 19 (Fig. 2). The interior of the tube 12 contains an ionizable gas 20 which ionizes to form a discharge plasma at a predetermined design potential, such as 350-450 volts, as indicated in Fig. 4.

Fig. 3 shows a typical prior art air-gap gas tube vent-safe device 25. The end terminals 26 and 27 on device 25 also function as the electrodes for the air-gap vent-safe operation. Each of the end terminals/electrodes 26, 27 has a non-conductive film 28 perforated by holes 29 which separate the electrodes 26, 27 from a ground electrode 30 which is connected to the center ground terminal 31 of the gas tube 12. As already indicated, such air-gap vent-safe mechanisms are well known.

Fig. 4 illustrates the typical breakdown voltage v_B for a gas tube (usually around 350-450 volts), and the corresponding breakdown voltage for the air-gap vent-safe system 25. As illustrated by the arrows in Fig. 4, pointing respectively left and right, water which invades the holes 29 will reduce the breakdown voltage of the air-gap vent-safe device; oil will increase it. Thus, the deleterious effects of environmental pollution, humidity, insect infestation, etc., can cause the air-gap vent-safe device 25 to start firing at voltages comparable to those of the gas tube. This is effectively a system failure. On the other hand, efforts by the present inventors to seal the holes 29 from environmental effects by gel encapsulation, for example, have inevitably resulted in oil bleeding from the gel into the holes 29. This adversely raises the breakdown voltage beyond the specification design limit.

The gas tube vent-safe device 40 illustrated in Figs. 5-8 overcomes these prior art limitations. In particular, the insulating film 45 is solid, not perforated. Thus, it is essentially immune to environmental contamination. Similarly, it can readily be encapsulated, such as in a gel 50 (Fig. 10), without changing the design breakdown voltage of the device. Encapsulant 50 is selected of a material which is chemically inert to the film 45. For example, when the film is a polycarbonate, a silicone gel would be appropriate.

In the preferred embodiment illustrated in Figs. 5-8, the end terminals 16 and 17 of the gas tube 12 also function as electrodes for the

vent-safe device 40. On the side of the film 45 opposite the electrodes 16 and 17 is a ground electrode 55 connected to the ground terminal 18 on the gas tube 12. Further improvement of vent-safe performance is realized by judicious geometric design of the supporting ground electrode/film retainer 55 (Fig. 7) to produce controlled uniformity in the electric field which is developed throughout the film material 45 between the ground electrode 55 and the opposing gas tube electrode 16,17 before and during breakdown. If no special attention were paid to this aspect, the possibility of high variance in v_B exists. For example, in certain existing vent-safe designs, sharp edge discontinuities occur on certain stamped metal parts, producing uncontrolled field non-uniformity. Even when other parameters such as spacer material thickness and/or perforation hole diameters in certain air-gap designs are tightly controlled, slight manufacturing differences in electrode material edges of improper design can yield unacceptable v_B variance. Consequently, the preferred embodiment of the present invention incorporates such geometric design (in addition to the film material) in order to further improve performance. In Fig. 7, the ends of the ground electrode 55 are partially rolled away at 58 from the opposing gas tube electrode. This carries the sharp edge discontinuities of the ground electrode 55 away from the curved surface of the gas tube electrode, thus reducing localized field enhancement in the vicinity of the edges and producing smooth curved electrode surfaces at the minimum separation distance of the opposing electrodes. It also renders the part both simple to manufacture, without extreme tolerance constraints, and affords controlled, repeatable field uniformity for improved performance.

Device 40 may also be provided with electrodes which are distinct from the terminals 16 and 17 and are electrically connected thereto, such distinct electrodes also being located on the side of the non-linear resistive film 45 opposite the ground electrode. Fig. 9 illustrates such an alternative gas tube vent-safe device 60 having electrodes 61 and 62 for connection, respectively, to the gas tube end terminals 16 and 17, and a ground electrode 63 for connection to the gas tube ground terminal 18. Electrodes 61 and 62, in a fashion similar to device 40, are separated from ground electrode 63 by a film 65 (the same as film 45).

As indicated, Fig. 10 illustrates a gas tube vent-safe device 40 encapsulated in an environmentally sealing gel 50. The gel encapsulant 50 not only protects the device 40 from environmental contaminants, but it also excludes oxygen from the region of the plasma discharge and conducts heat away therefrom (acting as a heat sink). This substantially reduces the degradation of surrounding materials, prevents combustion, and attenuates local hot spots. Such gels are preferably selected from materials which are chemically inert to the film material 45. Proper selection of the gel material may also promote gradual, partial "healing" of the film 45 in the damaged region of a plasma discharge as the oil filler in the gel migrates to that region of the film.

The non-linear resistive films 45 and 65 are selected of a material which is substantially non-conductive when the electrical potential between the electrodes is less than the desired breakdown voltage v_B. The film is thus non-conductive in that state, having an insulation resistance greater than 10^9 ohms. Preferably, for telecommunications devices, the breakdown voltage v_B is greater than 600 and less than 1000 volts, and particularly in the vicinity of 800-850 volts.

In analyzing and developing a suitable non-linear resistive film, it was discovered that a homogeneous distribution of a rising electrical field can be obtained through the dispersion of small conductive particles in a non-conductive matrix, e.g., carbon black in a polymer. This in turn leads to more controllable high voltage discharges through solid materials. Non-linear resistive materials are already used as electrical stress dissipating layers at abrupt transitions in high voltage applications.

Suitable non-linear resistive materials are prepared from a composition which comprises a polymer and, dispersed in that polymer, a particulate conductive filler. In order to achieve an insulation resistance in use of greater than 10^9 ohms, the resistive material has a resistivity of at least 1×10^6 ohm-cm, preferably at least 1×10^7 ohm-cm, especially at least 1×10^8 ohm-cm. The type of polymer used is dependent on the desired physical properties of the resistive material in use, the type of particulate conductive filler, the anticipated use

conditions, as well as other factors such as ease of manufacture, maximum exposure temperature, and chemical resistance. Either thermoplastic or thermosetting polymers may be used. Polymers which are particularly useful are those which can be formed, for example by extrusion, calendaring, casting, or compression molding, into relatively thin films, e.g., 0.001 to 0.010 inch (0.025 mm to 0.25 mm), and preferably 0.002 to 0.005 inch (0.05 mm to 0.13 mm). Particularly suitable polymers include polycarbonates.

Dispersed in the polymer is a particulate conductive filler, i.e., a material which has a resistivity of less than 10^{-1} ohm-cm, preferably less than 10^{-2} ohm-cm, particularly less than 10^{-3} ohm-cm. Among those particulate fillers which may be used are carbon black, graphite, metals, metal oxides, or any of these materials coated onto at least part of an insulating particle such as a glass or ceramic particle. A single type of particulate filler may be used or the resistive material may comprise a mixture of two or more different fillers or two or more different sizes or types of the same filler. Generally particulate conductive particles which are suitable for use in the invention have an average particle size, i.e. the size of the primary particle, of less than 1 μm, preferably less than 0.5 μm, particularly less than 0.1 μm, e.g. 0.01 to 0.09 μm. For some compositions, it is preferred that the majority of the particles of the particulate filler, i.e. at least 50%, preferably at least 60%, particularly at least 70%, especially at least 80%, have an average particle size of 0.01 to 0.09 μm, preferably 0.02 to 0.08 μm, particularly 0.03 to 0.07 μm. If the particles are fused or otherwise associated in the form of an aggregate, e.g. as carbon black is, it is preferred that the aggregate size be less than 5 μm, preferably less than 3 μm, particularly less than 2 μm, e.g. less than 1 μm. Depending on the type of particulate conductive filler and its structure, particle size, density, and conductivity, the amount of particulate conductive filler in the resistive material is 5 to 70% by weight of the total composition, preferably 10 to 50% by weight, particularly 15 to 45% by weight, especially 20 to 40% by weight. When the particulate conductive filler is carbon black, the amount is often 20 to 40% by weight of the total composition, particularly 25 to 35% by weight, especially 30 to 35% by weight.

The above criteria were met during experimentation with non-linear resistive film materials from LNP Engineering Plastics Inc. (Exton, PA), available under the tradename "Stat-Kon". One suitable material was Stat-Kon DX7, a carbon black filled polycarbonate based extrusion grade compound with volume resistivity between 10E7 and 10E12 ohm-cm. Films were obtained at a 10 mil thickness and measured 10E7 ohms in insulation resistance at 250 vdc using the film thickness as electrode separation. In fact, any location of the two electrodes on the film always gave the same insulation reading. Thinner films were obtained by compressing the 10 mil film on a hot press down to 2.5 to 4.0 mil. Insulation resistance went up to above 10E12 ohms when measured as above.

As a test, these 2.5 to 4.0 mil films were inserted between the metal spring terminal/contact accessories of commercially available three-element gas tube integrated vent-safe/fail-safe protectors and tested for performance according to Bellcore TR-TSY-000073, which Bellcore spec. is incorporated herein by reference for all purposes. Insulation resistance as measured in the device remained at the high levels as measured before on the film only, and the tip-to-ground or ring-to-ground breakdown voltage of the vented gas tube protector (through the thin film) varied from 700 volts to 900 volts, whether or not encapsulated in silicone gel. However, gel encapsulation substantially reduces the oxygen source needed for combustion, and it acts as a heat transfer medium to effectively draw the thermal energy away from local hot spots. In this way, a smooth and safe operation is secured during these high energy transfers, substantially reducing the degradation of surrounding materials (gel encapsulated plasma discharge). As encapsulated in silicone gel, there was no interference with the fail-safe mechanical spring mechanism during a power-cross test (1A, 1000V, 60 Hz), a homogeneous heating took place without visible sparking or material degradation, and the metal spring moved through the melting polycarbonate film to form a metal to metal contact, dumping the current to ground.

Figs. 11, 12, and 13 depict the IV-curves for Stat-Kon DX7 films of different thicknesses. The interesting and very useful features of a Stat-

Kon DX7 type material are that the breakdown voltage levels remain relatively independent (as compared to an air-gap) from the film thickness, the insulation resistance remains at a high level, and for thin films around 3 mil, the trigger current is in the micro amp range. Fig. 14 shows the IV-curve of a 2.5 mil pressed Stat-Kon DX7 film as replacement for the air-gap of a commercially available three-element gas tube vent-safe device. Fig. 15 depicts the IV-curve for the more conductive 15 mil Stat-Kon DX3 film (resistivity 10^3 to 10^6 ohm-cm). Having an insulation resistance around 10E6 Ohms makes the DX3 film less preferable for telephone circuit applications.

As pressing of thin films lead to inconsistencies with regard to film thicknesses and electrical parameters, extrusion of thin films was pursued using polycarbonate based compounds with carbon black loadings from 30% to 32%. The carbon black used had a primary particle size mostly below 75 nanometers and an aggregate particle size centered around 0.5 microns. An example of such a film is the Stat-Kon DX9 material (resistivity 10^9 to 10^{12} ohm-cm). Fig. 16 depicts a typical IV-curve for this material. Figs. 17–19 depict the electrical impulse breakdown behavior as a function of current loading for this material. Material analysis of a single sample from the trial extrusion indicated that the material comprised 30 to 35% by weight carbon black with a particle size of 0.030 to 0.060 nm, 65 to 70% by weight bisphenol-A-polycarbonate, and 1 to 3% by weight filler.

As may be seen, therefore, the present invention provides numerous advantages. Principally, it provides an environmentally stable apparatus for a telecommunications gas tube protector. By eliminating the conventional air-gap, and especially when encapsulating (such as in a gel), the breakdown voltage v_B remains reliably stable over very extended periods of time. Once the gas tube fails and the present invention fires in its place, this will, of course, damage the film 45 in the region of the discharge. The inability of such non-linear resistive films to repeatably conduct such high currents without damage has heretofore been seen as an insurmountable barrier. As taught by the present invention, however, since under normal conditions the vent-safe device of the present invention never fires, and

the device is intended to be replaced once the gas tube 12 has failed, damage to film 45 is acceptable. In fact, if the film carbonizes leaving a low resistance path, this may actually be advantageous since it will assist in identifying a failed gas tube. In other words, it has been recognized that, in this technology, repeatability can be sacrificed for performance and environmental stability. This is a major conceptual and functional breakthrough heretofore unavailable.

Of course, various modifications of the present invention will occur to those skilled in the art upon reading the present disclosure. For example, other non-linear resistive materials having electrical characteristics similar to the filled polycarbonate films used in the preferred embodiment may be found suitable. These can include non-gaseous, but not necessarily solid, materials such as, for example, suitable gels having the desired electrical properties. In another modification, the present invention can be used with two element gas tubes, thus requiring only two electrodes on the vent-safe device itself.

Therefore, while the methods and forms of apparatus herein described constitute preferred embodiments of this invention, it is to be understood that the invention is not limited to these precise methods and forms of apparatus, and that changes may be made therein without departing from the scope of the invention.

What is claimed is:

CLAIMS:

1. A vent-safe apparatus for a telecommunications gas tube protector, comprising:

a) a first electrode for electrical connection to a terminal on the gas tube protector,

b) a second electrode for electrical connection to another terminal on the gas tube protector, and

c) a non-gaseous, non-linear resistive material separating said electrodes, said non-linear resistive material being substantially non-conductive when the electrical potential between said electrodes is less than a predetermined breakdown voltage v_B, being conductive when the electrical potential is greater than v_B, and supporting a plasma discharge therethrough after becoming conductive to effect a sudden increase in conductivity between said electrodes for discharging high energy potentials with a plasma voltage foldback functionally analogous to the foldback behavior of the gas tube protector.

2. The vent-safe apparatus of claim 1 wherein said predetermined breakdown voltage v_B is greater than the design breakdown voltage of the gas tube protector at least prior to the first discharge through said non-linear resistive material.

3. The vent-safe apparatus of claim 1 wherein said non-linear resistive material further comprises a solid, filled polymer film which comprises a composition comprising a polymer and, dispersed in said polymer, a particulate conductive filler.

4. The vent-safe apparatus of claim 3 wherein said film further comprises a carbon black filled polycarbonate based extrusion grade compound having a thickness from substantially 0.001 to 0.010 inches, and preferably from 0.002 to 0.005 inches.

5. The vent-safe apparatus of claim 3 wherein said particulate conductive filler is carbon black, the primary size of the bulk (90%) of said carbon black filler being in the 30 to 60 nanometer range and the total carbon black content being 30 to 35% by weight of the total composition.

6. The vent-safe apparatus of claim 1 further comprising an encapsulant environmentally encapsulating said electrodes and said non-linear resistive material to protect them from environmental contaminants, to exclude oxygen from the plasma discharge, and to act as a heat sink to draw thermal energy away from local hot spots.

7. The vent-safe apparatus of claim 6 wherein said encapsulant is chemically inert to said non-linear resistive material.

8. The vent-safe apparatus of claim 7 wherein said encapsulant further comprises a gel.

9. The vent-safe apparatus of claim 1 further comprising a third electrode for connection to a third terminal on the protector.

10. The vent-safe apparatus of claim 1 wherein at least part of at least one of said electrodes is at least partially rolled away from the other electrode.

11. A vent-safe apparatus for a telecommunications gas tube protector, comprising:

a) a first electrode for electrical connection to a terminal on the gas tube protector,

b) a second electrode for electrical connection to another terminal on the gas tube protector,

c) a non-gaseous, non-linear resistive, solid, carbon black filled polycarbonate based extrusion grade film having a thickness from substantially 0.001 to 0.010 inches, and preferably from 0.002 to 0.005 inches, said film separating said electrodes and being substantially non-conductive when the electrical potential between said electrodes is less than a predetermined breakdown voltage v_B, being conductive when the electrical potential is greater than v_B, and supporting a plasma discharge therethrough after becoming conductive to effect a sudden increase in conductivity between said electrodes for discharging high energy potentials with a plasma voltage foldback functionally analogous to the foldback behavior of the gas tube protector, said predetermined breakdown voltage v_B being greater than the design breakdown voltage of the gas tube protector at least prior to the first discharge through said non-linear resistive film, and

d) a gel environmentally encapsulating said electrodes and said non-linear resistive film to protect them from environmental contaminants, to exclude oxygen from the plasma discharge, and to act as a heat sink to draw thermal energy away from local hot spots, said gel being chemically inert to said non-linear resistive film.

12. In a telecommunications gas tube protector and vent-safe apparatus in which the gas tube has at least two terminals for connection to a telecommunications circuit, the improvement comprising:

a) a first electrode electrically connected to a first gas tube protector terminal,

b) a second electrode electrically connected to another of the gas tube protector terminals, and

c) a non-gaseous, non-linear resistive material separating said electrodes, said non-linear resistive material being substantially non-conductive when the electrical potential between said electrodes is less than a predetermined breakdown voltage v_B, being conductive when the electrical potential is greater than v_B, and supporting a plasma discharge therethrough after becoming conductive to effect a sudden increase in conductivity between said electrodes for discharging high energy potentials with a plasma voltage foldback functionally analogous to the foldback behavior of the gas tube protector.

13. The apparatus of claim 12 wherein said first electrode further comprises at least a portion of the first gas tube terminal.

14. The apparatus of claim 12 wherein said predetermined breakdown voltage v_B is greater than the design breakdown voltage of the gas tube protector at least prior to the first discharge through said non-linear resistive material.

15. The apparatus of claim 12 wherein said non-linear resistive material further comprises a solid, filled polymer film which comprises a composition comprising a polymer and, dispersed in said polymer, a particulate conductive filler.

16. The apparatus of claim 15 wherein said film further comprises a carbon black filled polycarbonate based extrusion grade compound having a thickness from substantially 0.001 to 0.010 inches, and preferably from 0.002 to 0.005 inches.

17. The apparatus of claim 15 wherein said particulate conductive filler is carbon black, the primary size of the bulk (90%) of said carbon black filler being in the 30 to 60 nanometer range and the total carbon black content being 30 to 35% by weight of the total composition.

18. The apparatus of claim 12 further comprising an encapsulant environmentally encapsulating said electrodes and said non-linear resistive material to protect them from environmental contaminants, to exclude oxygen from the plasma discharge, and to act as a heat sink to draw thermal energy away from local hot spots.

19. The vent-safe apparatus of claim 18 wherein said encapsulant is chemically inert to said non-linear resistive material.

20. The vent-safe apparatus of claim 19 wherein said encapsulant further comprises a gel.

21. The apparatus of claim 12 further comprising a third electrode electrically connected to still another terminal on the protector.

22. The apparatus of claim 12 wherein at least part of at least one of said electrodes is at least partially rolled away from the other electrode.

23. In a telecommunications gas tube protector and vent-safe apparatus in which the gas tube has at least two terminals for connection to a telecommunications circuit, the improvement comprising:

a) a first electrode on at least a portion of one of the gas tube protector terminals,

b) a second electrode electrically connected to another of the gas tube protector terminals,

c) a non-gaseous, non-linear resistive, solid, carbon black filled polycarbonate based extrusion grade film having a thickness from substantially 0.001 to 0.010 inches, and preferably from 0.002 to 0.005 inches, said film separating said electrodes and being substantially non-conductive when the electrical potential between said electrodes is less than a predetermined breakdown voltage v_B, being conductive when the electrical potential is greater than v_B, and supporting a plasma discharge therethrough after becoming conductive to effect a sudden increase in conductivity between said electrodes for discharging high energy potentials with a plasma voltage foldback functionally analogous to the foldback behavior of the gas tube protector, said predetermined breakdown voltage v_B being greater than the design breakdown voltage of the gas tube protector at least prior to the first discharge through said non-linear resistive film, and

d) a gel environmentally encapsulating said electrodes and said non-linear resistive film to protect them from environmental contaminants, to exclude oxygen from the plasma discharge, and to act as a heat sink to draw thermal energy away from local hot spots, said gel being chemically inert to said non-linear resistive film.

24. A method for vent-safe protecting a telecommunications gas tube protector having at least two terminals for connection to a telecommunications circuit, comprising:

a) electrically connecting a first electrode to a first gas tube protector terminal,

b) electrically connecting a second electrode to another of the gas tube protector terminals, and

c) separating the electrodes with a non-gaseous, non-linear resistive material which is substantially non-conductive when the electrical potential between the electrodes is less than a predetermined breakdown voltage v_B, is conductive when the electrical potential is greater than v_B, and which supports a plasma discharge therethrough after becoming conductive to effect a sudden increase in conductivity between the electrodes for discharging high energy potentials with a plasma voltage foldback functionally analogous to the foldback behavior of the gas tube protector.

25. The method of claim 24 wherein said step of electrically connecting a first electrode to a first gas tube protector terminal further comprises forming the first electrode on the first gas tube protector terminal itself.

26. The method of claim 24 wherein said separating step further comprises separating the electrodes with a non-linear resistive material having a predetermined breakdown voltage v_B which is greater than the design breakdown voltage of the gas tube protector at least prior to the first discharge through the non-linear resistive material.

27. The method of claim 24 wherein the non-linear resistive material is a solid, filled polymer film which comprises a composition comprising a polymer and, dispersed in the polymer, a particulate conductive filler.

28. The method of claim 27 wherein the film is a carbon black filled polycarbonate based extrusion grade compound having a thickness from substantially 0.001 to 0.010 inches, and preferably from 0.002 to 0.005 inches.

29. The method of claim 27 wherein the particulate conductive filler is carbon black, the primary size of the bulk (90%) of the carbon black filler being in the 30 to 60 nanometer range and the total carbon black content being 30 to 35% by weight of the total composition.

30. The method of claim 24 further comprising environmentally encapsulating the electrodes and the non-linear resistive material in an encapsulant to protect them from environmental contaminants, to exclude oxygen from the plasma discharge, and to act as a heat sink to draw thermal energy away from local hot spots.

31. The method of claim 30 wherein the encapsulant is chemically inert to the non-linear resistive material.

32. The method of claim 31 wherein the encapsulant is a gel .

33. The method of claim 24 further comprising electrically connecting a third electrode to still another terminal on the protector.

34. The method of claim 24 further comprising at least partially rolling at least part of at least one of the electrodes away from the other electrode.

35. A method for vent-safe protecting a telecommunications gas tube protector having at least two terminals for connection to a telecommunications circuit, comprising:

a) forming a first electrode on a first gas tube protector terminal,

b) electrically connecting a second electrode to another of the gas tube protector terminals,

c) separating the electrodes with a non-gaseous, non-linear resistive, solid, carbon black filled polycarbonate based extrusion grade film having a thickness from substantially 0.001 to 0.010 inches, and preferably from 0.002 to 0.005 inches, the film being substantially non-conductive when the electrical potential between the electrodes is less than a predetermined breakdown voltage v_B, being conductive when the electrical potential is greater than v_B, and supporting a plasma discharge therethrough after becoming conductive to effect a sudden increase in conductivity between the electrodes for discharging high energy potentials with a plasma voltage foldback functionally analogous to the foldback behavior of the gas tube protector, the predetermined breakdown voltage v_B being greater than the design breakdown voltage of the gas tube protector at least prior to the first discharge through the non-linear resistive film, and

d) environmentally encapsulating the electrodes and the non-linear resistive film in a gel to protect them from environmental contaminants, to exclude oxygen from the plasma discharge, and to act as a heat sink to draw thermal energy away from local hot spots, the gel being chemically inert to the non-linear resistive film.

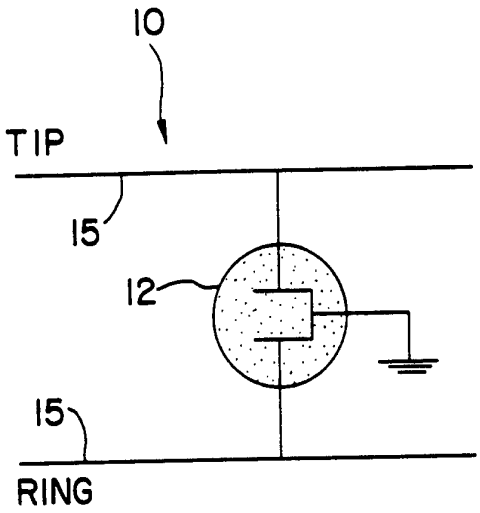


FIG.1

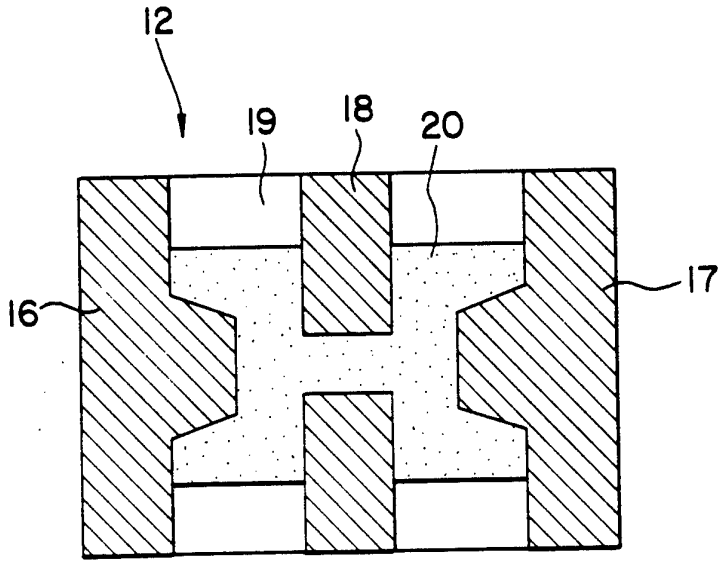


FIG.2

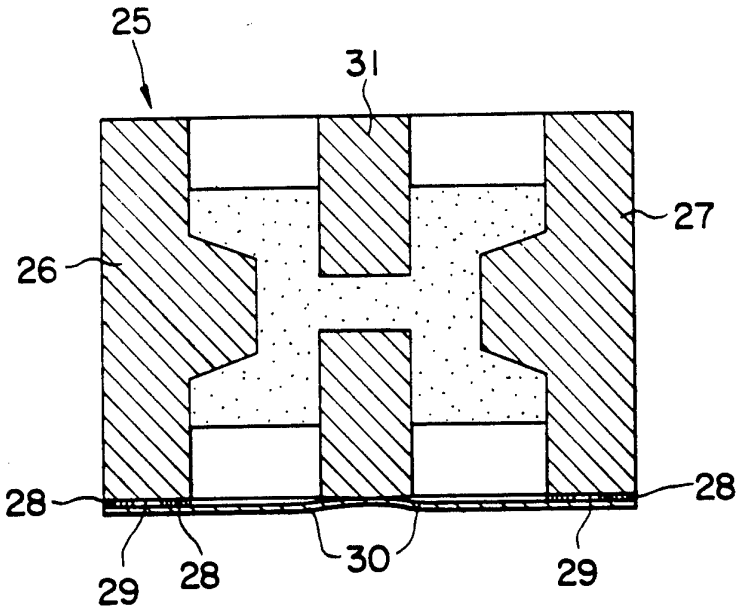


FIG.3
PRIOR ART

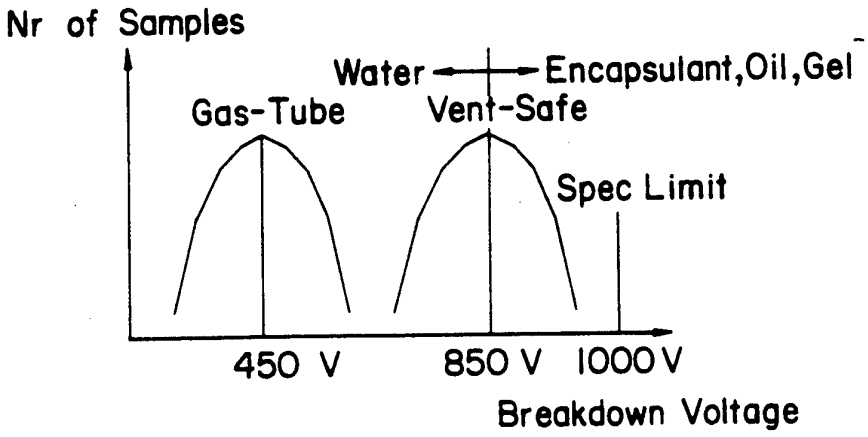


FIG.4

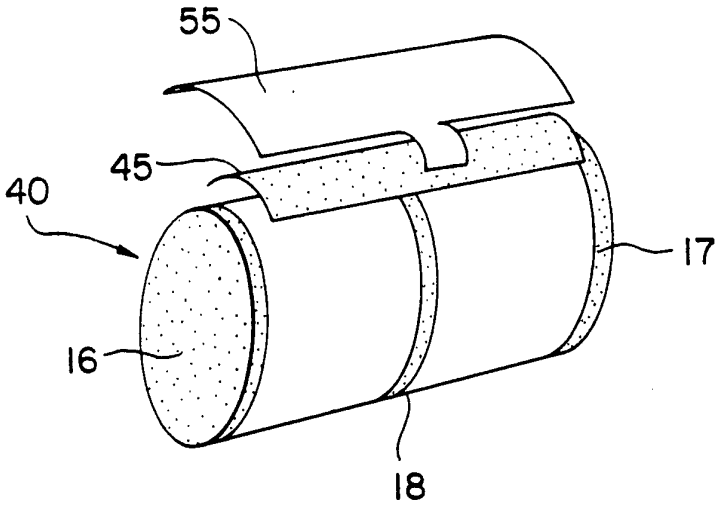


FIG.5

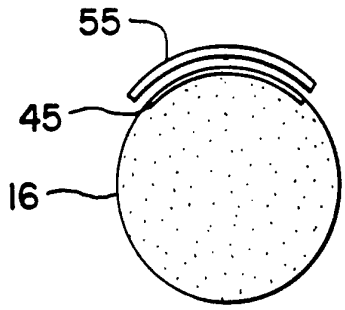


FIG.6

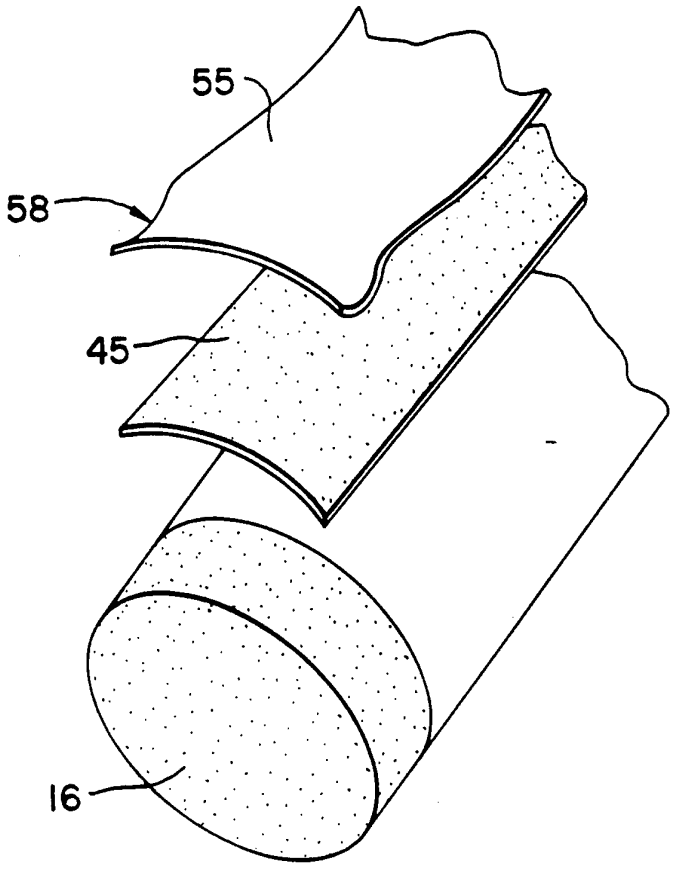


FIG.7

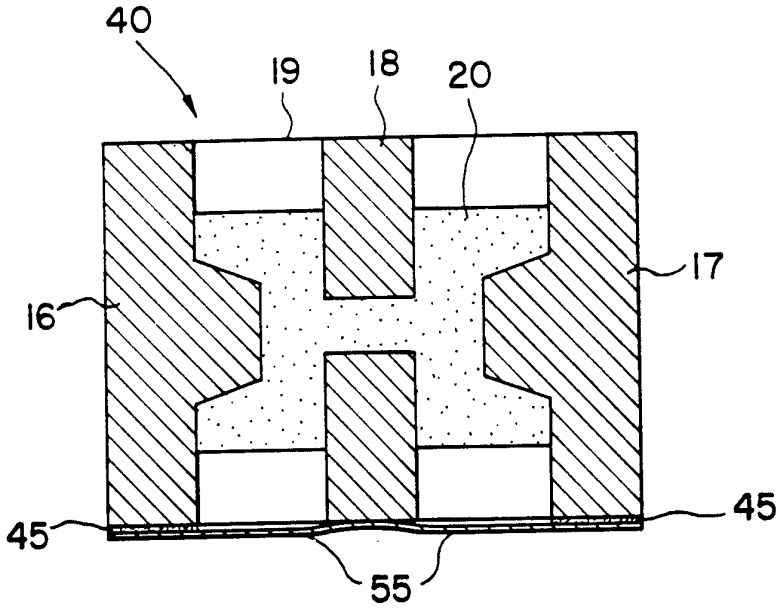


FIG.8

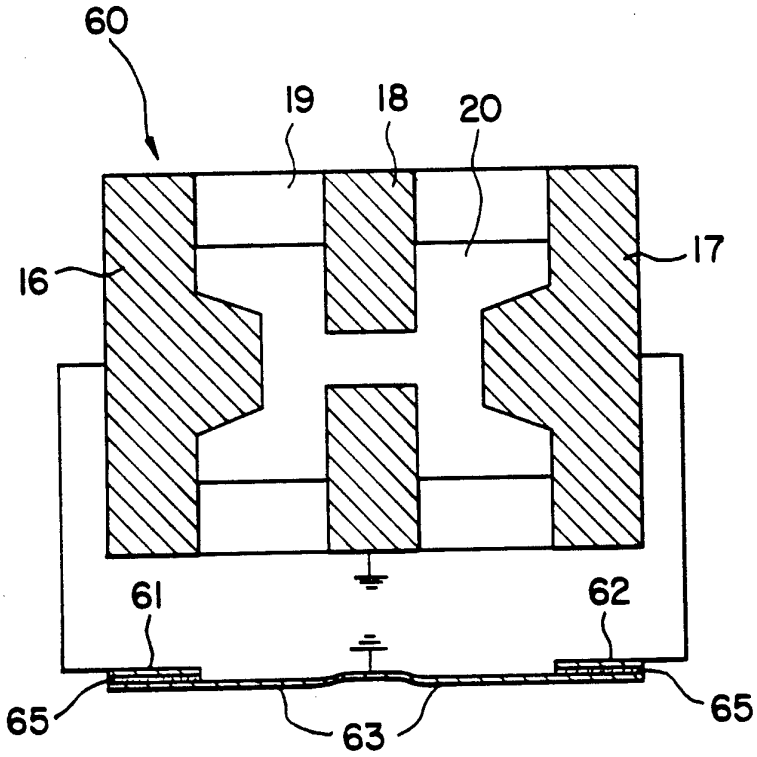


FIG.9

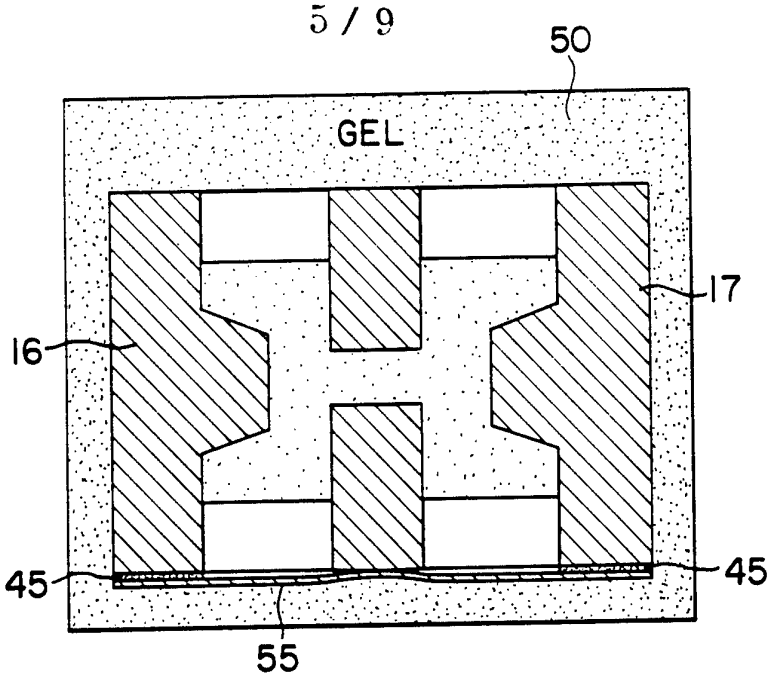

50
GEL
17
16
45
45
55

FIG.10

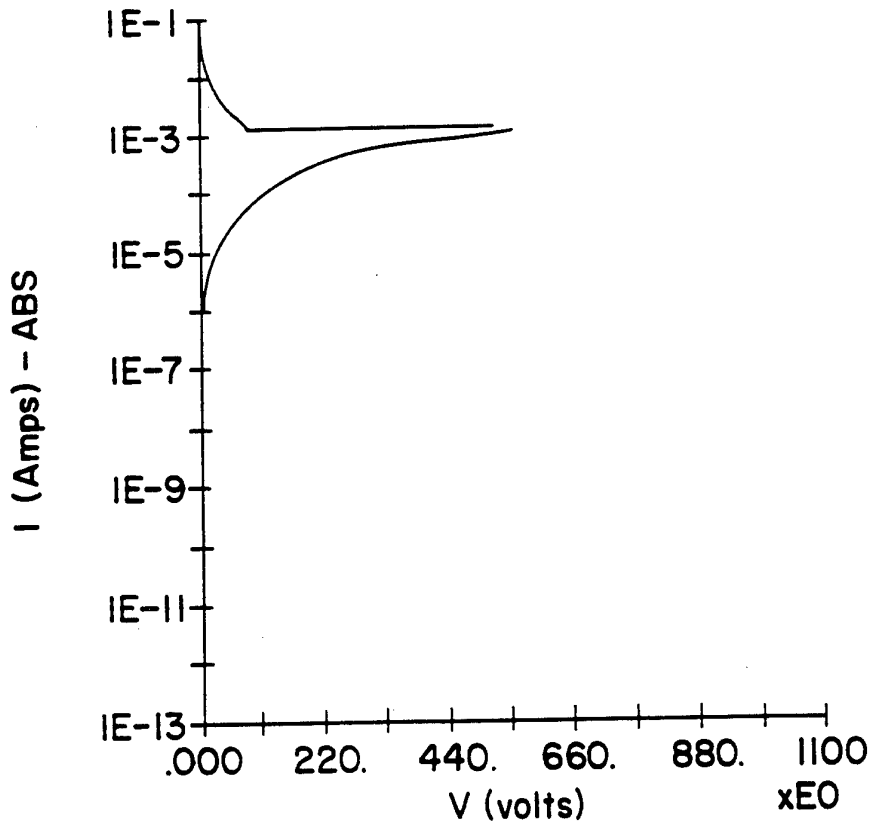

1E-1
1E-3
1E-5
1E-7
1E-9
1E-11
1E-13
I (Amps) - ABS
.000
220.
440.
660.
880.
1100
V (volts)
xE0

FIG.11

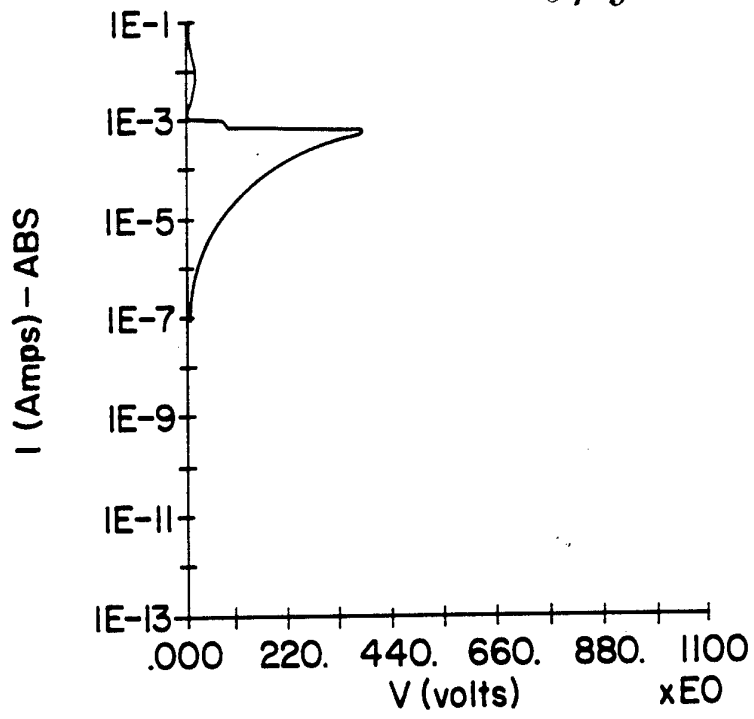

1E-1
1E-3
1E-5
1E-7
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1E-11
1E-13
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V (volts)
xE0

FIG.12

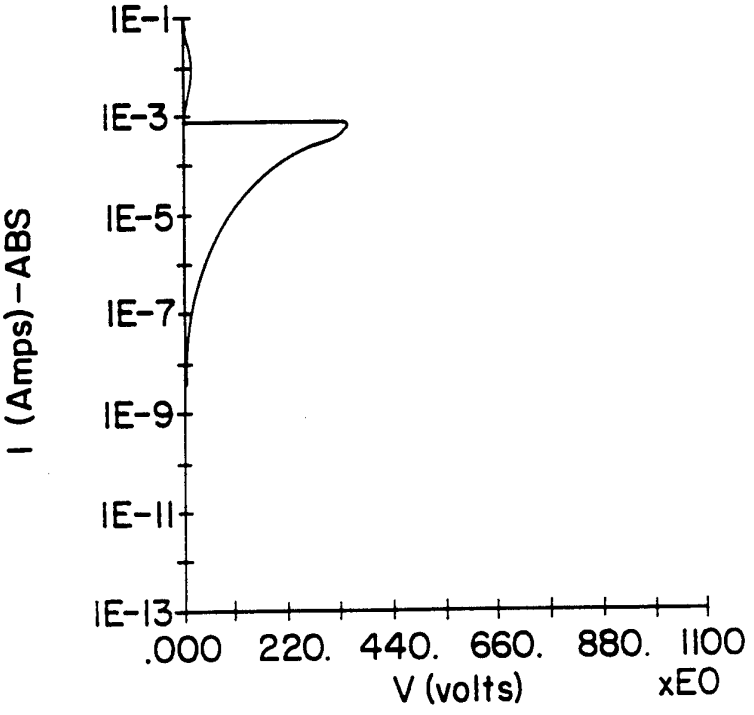

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1E-5
1E-7
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1E-11
1E-13
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V (volts)
xE0

FIG.13

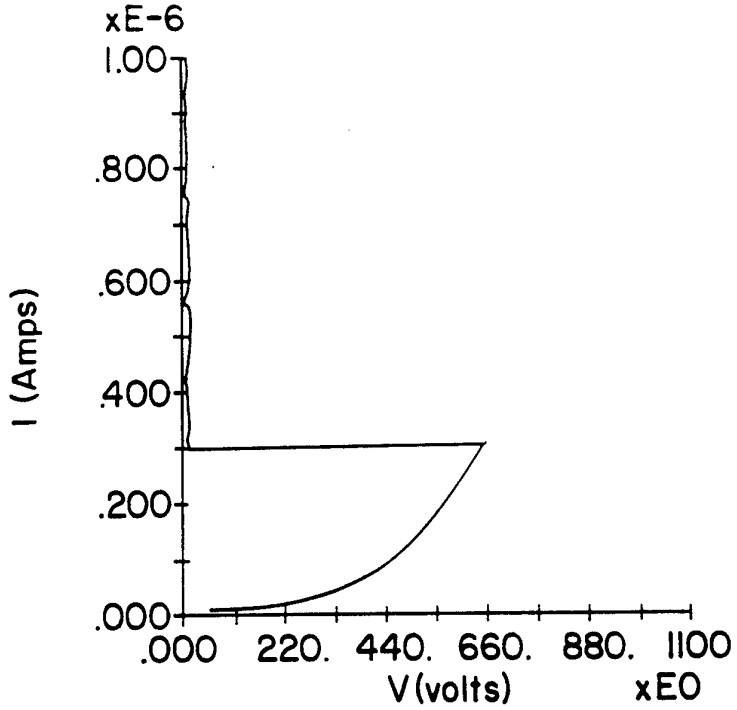

xE-6
1.00
.800
.600
.400
.200
.000
I (Amps)
.000 220. 440. 660. 880. 1100
V(volts)
xE0

FIG.14

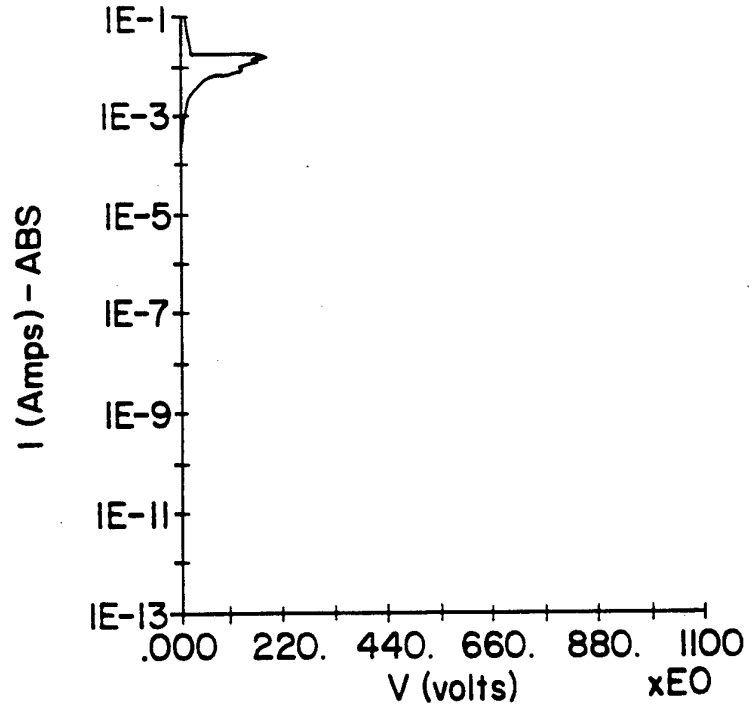

1E-1
1E-3
1E-5
1E-7
1E-9
1E-11
1E-13
I (Amps) - ABS
.000 220. 440. 660. 880. 1100
V (volts)
xE0

FIG.15

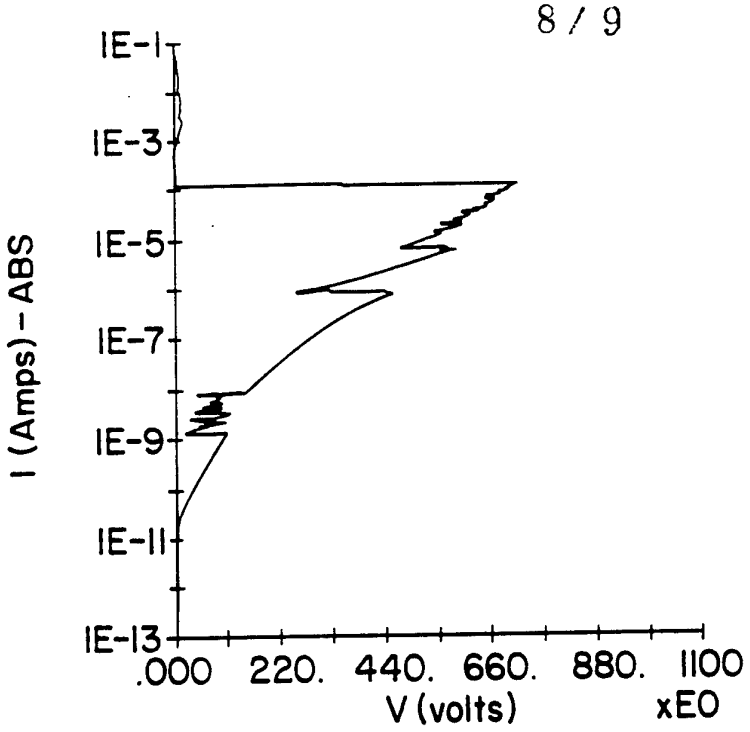

IE-1
IE-3
IE-5
IE-7
IE-9
IE-11
IE-13
I (Amps) - ABS
.000
220.
440.
660.
880.
1100
V (volts)
xE0

FIG.16

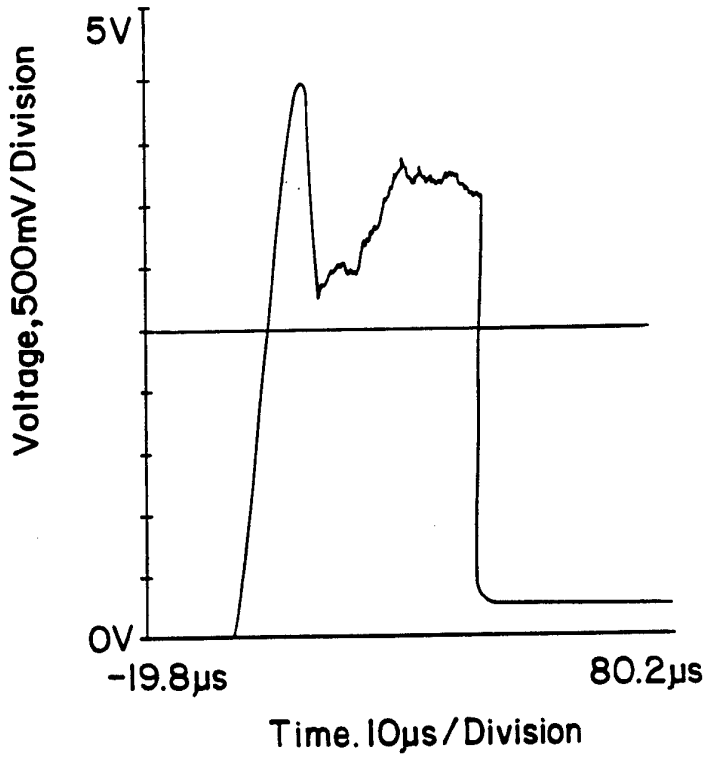

5V
0V
Voltage, 500mV/Division
-19.8µs
80.2µs
Time. 10µs / Division

FIG.17

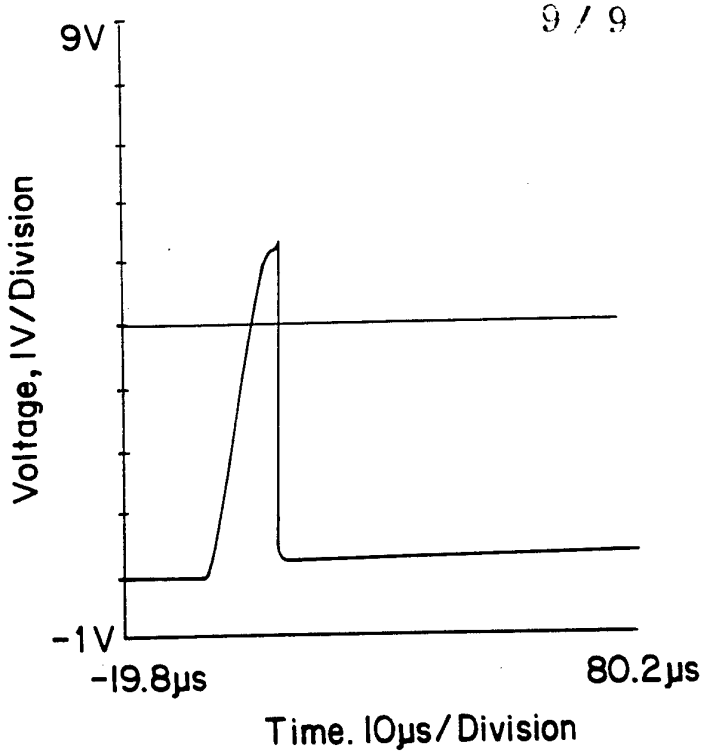

9V
Voltage, IV/Division
-1V
-19.8µs
80.2µs
Time. 10µs/Division

FIG.18

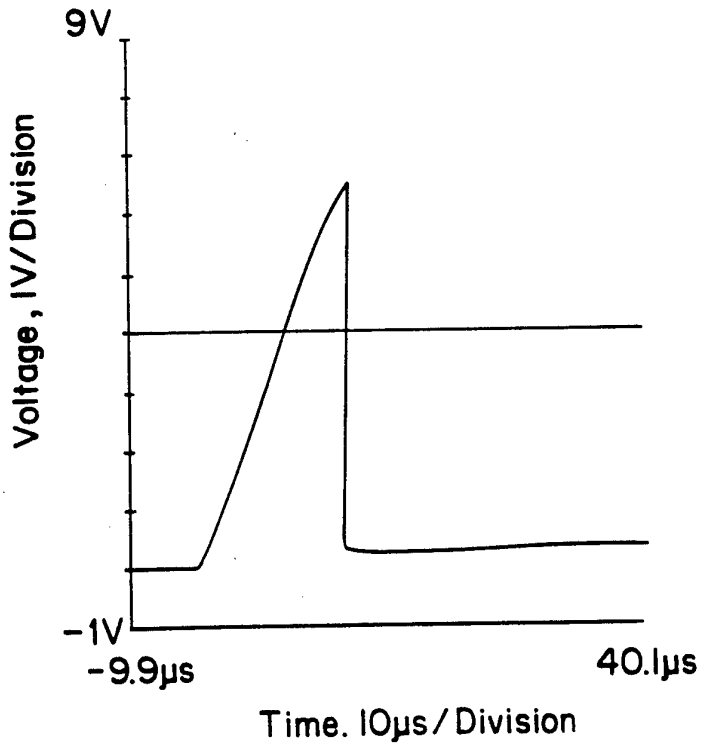

9V
Voltage, IV/Division
-1V
-9.9µs
40.1µs
Time. 10µs/Division

FIG.19

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/06218

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :H01C 7/12; H02H 9/04
US CL :328/8, 259; 361/119, 120
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 328/8, 76, 82, 259; 361/119, 120

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS,
Gas tube protect?, ventsafe

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 5,068,634 (SHRIER) 26 Nov 1991, Entire document.	1-5
A	US, A, 3,858,077 (BAZARIAN et al) 31 Dec 1974, Entire document.	
A	US, A, 3,898,533 (SCUDNER, Jr.) 05 Aug 1975, Entire document.	
A	US, A, 4,321,649 (GILBERTS) 23 Mar 1982, Entire document.	
A	US, A, 4,393,433 (ANDERSON et al) 12 Jul 1983, Entire document.	
A	US, A, 4,680,665 (BONNESEN et al) 14 Jul 1987, Entire document.	

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be part of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
05 October 1993	14 OCT 1993
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Authorized officer for JOHN ZAZWORSKY
Facsimile No. NOT APPLICABLE	Telephone No. (703) 308-4877

Form PCT/ISA/210 (second sheet)(July 1992)★

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/06218

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, A, 4,707,762 (YAPOUJIAN) 17 Nov 1987, Entire document.	
A,P	US, A, 5,195,015 (KACZMAREK) 16 Mar 1993, Entire document.	