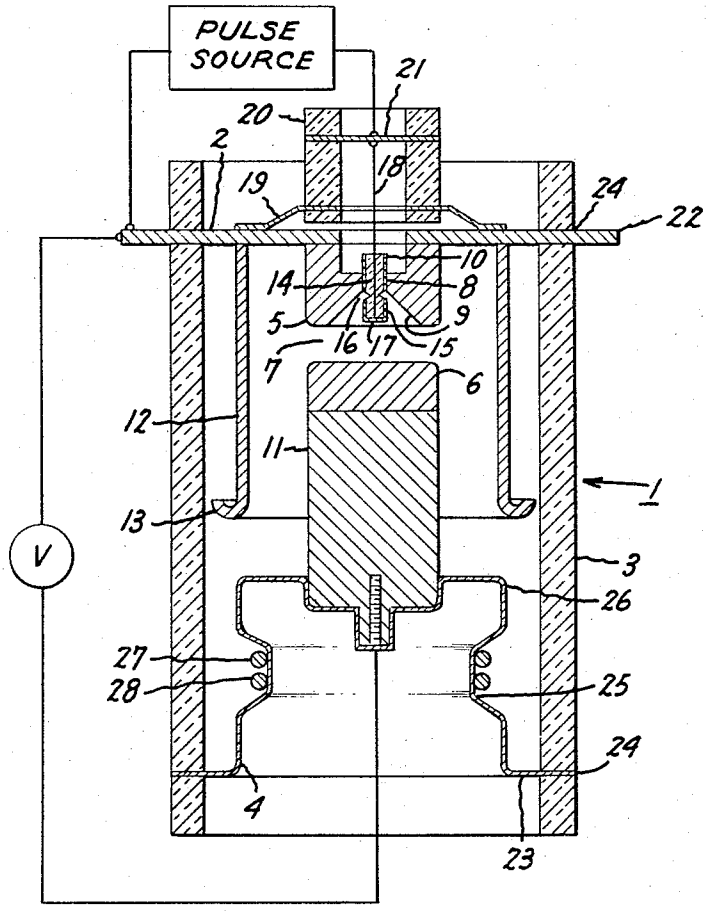
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METHOD OF EVACUATION FOR TRIGGERABLE VACUUM DISCHARGE DEVICES

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METHOD OF EVACUATION FOR TRIGGERABLE VACUUM DISCHARGE DEVICES

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Application Dec. 11, 1964, Ser. No. 417,562, now Patent No. 3,331,981, dated July 18, 1967, which is a continuation-in-part of application Ser. No. 357,089, Apr. 3, 1964. Divided and this application Mar. 24, 1967, Ser. No. 625,687
6 Claims. (Cl. 316—24)

ABSTRACT OF THE DISCLOSURE

Discloses a triggerable vacuum gap device containing a trigger assembly having a gas storage trigger member loaded with active gas which is evolved and ionized to cause breakdown of a primary gap and method of fabrication and evacuation thereof. Device also contains a remote active gas storage reservoir located remotely from heating effects of primary arc and means to selectively heat the reservoir at a predetermined time to facilitate replenishment of the trigger assembly. As the final step in fabricating the device, the interior thereof is flushed with the active gas at a predetermined pressure and the device heated and sealed. Upon cooling, the active gas at the predetermined pressure is completely absorbed by the trigger assembly and the gas reservoir to establish a hard vacuum within the device.

This invention is a division of my copending application, Ser. No. 417,562, filed Dec. 11, 1964, now Patent No. 3,331,981 which is a continuation-in-part of my then-copending application Ser. No. 357,089, filed Apr. 3, 1964, and now abandoned. The present invention relates to electric discharge devices adapted to switch high voltages and currents by triggering electric breakdown between a pair of electrodes separated by a gap in vacuo.

In my U.S. Patent 3,087,092, issued Apr. 23, 1963, entitled "Gas Generating Switching Tube," there is disclosed a triggerable vacuum discharge device which comprises a pair of primary discharge electrodes, fabricated from gas-free metal, separated by a primary gap and disposed in an envelope evacuated to a pressure of 10^{-5} millimeters (mm.) of mercury or less. A trigger assembly, composed of gas-charged metal, as for example titanium, and having a gap across which a discharge is easily started, is provided to release and ionize gas, as for example hydrogen, from the metal thereof and direct the electron-ion plasma formed thereby into the gap between the primary discharge electrodes to cause the primary gap to be broken down in the electric interaction between the injected plasma and the presence of a high voltage across the primary electrodes. When the primary discharge is terminated, the primary gap clears quickly due to diffusion of the electrode material (the ions and electrons of which are the arc-sustaining particles) and due to absorption of the triggering gas by the trigger metal and by evaporated electrode material. Due to these phenomena, the high dielectric strength of the original, evacuated gap is re-established rapidly. Until the trigger discharge is initiated again, the primary gap withstands very high voltages without breakdown.

In the conventional fabrication process for this type device, the device envelope is evacuated, after construction, by baking out at 400° C. or higher, depending on whether hard glass or ceramic construction is used. After bakeout, the trigger electrode is outgassed at a temperature of 1000° C. by passing current through a heater winding. After outgassing, hydrogen is let into the system

and the trigger is allowed to cool slowly. Hydrogen is taken up by the titanium and the trigger is "loaded." The device is then baked out again at a moderate temperature of, for example 200° C., which is high enough to remove a considerable amount of adsorbed gas from the electrodes and device walls, but not high enough to remove appreciable hydrogen from the trigger electrode. After cooling and low current sparking with high voltage to remove surface impurities from the electrode surfaces the envelope is sealed. The pressure within the device is 10^5 mm. of Hg or less, and is maintained at this value by its own getter until operation.

A method of evacuation has been proposed, in U.S. Patent No. 2,934,392—De Santis et al., issued Apr. 26, 1960, which comprises using titanium, or other absorbent metal, to absorb an active gas in the atmosphere of a vacuum tube so as to substantially evacuate the tube. This method has required the provision of large amounts of elemental titanium in order to accomplish evacuation of moderate or small volumes. While this is not a disadvantage in the fabrication of vacuum tubes and like devices it becomes uneconomical when practiced upon high current or high voltage switching devices.

The present invention therefore is directed to overcoming various difficulties associated with the fabrication of triggered vacuum discharge devices, and to an improvement in such devices.

Accordingly, it is an object of the present invention to provide an improved method of evacuating triggered vacuum gap switching devices.

Another object of the present invention is the provision of an improved method of manufacture of triggerable vacuum discharge devices which includes simultaneous evacuation and loading thereof.

Another object of the present invention is the provision of an improved triggerable vacuum discharge device, the trigger of which may be reloaded without violating the vacuum in the device.

Yet another object of the present invention is the provision of a method of reloading the trigger of a triggerable vacuum discharge device without the necessity of violating the vacuum therein.

Briefly, in accord with one aspect of the present invention, I provide a method of evacuating a triggerable vacuum discharge device adapted to have a discharge triggered by the release and ionization of an active gas therein, which method comprises the steps of providing a quantity of active-gas-charged material in the device, heating the device prior to hermetic sealing thereof to an elevated temperature in an atmosphere consisting essentially of the active gas, sealing the device and permitting the device to cool so that the metal absorbs the active gas, thus producing the requisite vacuum and simultaneously loading the trigger.

In accord with another aspect of the present invention, I provide as an additional element a further quantity of active gas charged material, having the active gas incorporated therein, located in the device in an area which remains relatively cool during operation. After the device has been fabricated by the above described method and after a period of use in which the quantity of active gas available in the trigger has been depleted, the trigger may be reloaded by heating at least that portion of the device containing the reservoir to the elevated temperature and permitting it to cool.

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, together with further objects and advantages thereof may best be understood by reference to the following description taken in connection with the appended

drawing which represents a device fabricated in accordance with the present invention.

The device illustrated in the figure comprises a gas-impervious insulating envelope **1** which is composed of a flanged disc end wall assembly **2**, a cylindrical sidewall member **3** and an end closure member **4**. A pair of main gap electrodes **5** and **6** are supported in spaced-apart relation within envelope **1** to define a primary gap **7**. Electrode **5** comprises a cylindrical member having an axial aperture therein. The aperture is tapered outwardly at the exterior portion thereof to provide a bore in the end of electrode **5** having an interior cylindrical portion **8** and an exterior conical portion **9**. Trigger assembly **10** is mounted within the aperture in electrode **5**.

Electrode **5** is supported within the envelope **1** by end wall assembly **2** while electrode **6** is supported from end closure member **4** by means of electrode support rod **11**, which is hermetically sealed to the closure member **4** by welding, brazing or other suitable techniques. Electrode **6** may be of any suitable size and configuration so as to properly maintain a discharge with electrode **5**.

A metallic shield **12** having a generally cylindrical shape with a ferruled open end **13** to prevent arcing, is suspended from end wall assembly **2** and extends well past the gap between electrodes **5** and **6**. Shield **12** is utilized to preclude metal sputtered or evaporated from electrodes **5** and **6** from completely coating the inner surface of cylindrical sidewall member **3** of envelope **1** and thus destroying the insulating characteristics thereof.

Trigger assembly **10** comprises a cylindrical ceramic member **14** coated with a thin layer **15** of an electrically conductive gas charged material, such as a hydride of titanium, hafnium, zirconium or thorium which has incorporated therein an active gas such as hydrogen. After layer **15** has been formed, a groove **16** is scored around the circumference of the cylindrical member so as to remove the material therefrom and expose the insulating ceramic. The position of groove **16** is chosen so that, when trigger assembly **10** is positioned within electrode **5**, the junction between the cylindrical bore **8** and the conical bore **9** is slightly below the lower edge of groove **16**. A metallic cap **17** is suitably affixed to the inner end of trigger assembly **10** so as to be in good electrical contact with layer **15**. A wire **18**, soldered or otherwise affixed to cap **17**, extends outwardly through the ceramic member **14** to provide a means for applying a trigger potential thereto.

An hermetic seal is completed over the aperture in end wall assembly **2** by means of dished member **19**, cylindrical ceramic member **20**, and metallic disc **21**. Hermetic seals are formed between each of these members and between disc **21** and wire **18**. End wall assembly **2** is provided with a flange **22**; end closure member **4** is provided with a flange **23**, the flanges being adapted to form hermetic seals **24** with ceramic sidewall member **3** during the process of evacuating the device, and electrode support member **11** is hermetically sealed to closure member **4**.

Envelope member **3** and ceramic member **14** are fabricated from a gas-impervious, non-conducting material which may be hermetically sealed to a metal member. More specifically, it is important that these members, particularly envelope member **3**, be impervious to helium since long-term helium diffusion through some envelope materials, as for example glass, can destroy the high vacuum necessary for these type devices. Generally, any gas-impervious ceramic may be utilized such as COORS V200 or American Lava T164. Alternatively, aluminum oxide or forsterite ceramic bodies may be used. It is to be understood, however, that although the specific materials have been enumerated, any gas-impervious ceramic or glass which may be hermetically sealed to metal members may also be utilized.

Electrodes **5** and **6** are fabricated from copper that is substantially free of all gaseous impurities or impurity which, upon decomposition, may produce gases. This copper is such that it meets a standard test, the criterion of which is such that when placed in a vacuumized test chamber, a few litres in volume, the subsequently deeply eroded by repetitive arcing, as for example, by a voltage of commercial power and current of 100 amperes or more, the pressure level in the container, a few cycles after arcing, does not rise substantially from its initial value, in the absence of getters and pumps, even when the initial value is 10^{-5} mm. of mercury or lower. Analytically this requirement may be stated by the relationship that the contact material must contain less than 10^{-6} atomic parts of all gases and gas-forming impurities.

The remaining metallic elements within the envelope such as electrode support member **11** need not meet this stringent requirement since they are not brought into contact with electric arc and therefore are not potential sources of vacuum-spoiling gases. They should nevertheless be of metal which is completely free of oxygen since, in fabrication, the device is subjected to hydrogen at elevated temperatures and it is undesirable to have oxygen as an impurity in any material exposed at high temperatures to a hydrogen atmosphere.

In fabricating devices such as illustrated, the individual constituents are prepared and assembled in any convenient fashion, for example, as described in my aforementioned U.S. Patent 3,087,092.

A particular feature of the present invention lies in the material of layer **15** as provided prior to evacuation and in the method of evacuating the device and loading the trigger. Specifically, it has been found that, while the provision of an elemental metal as the material of layer **15** is effective in absorbing limited quantities of the active gas in accord with the aforementioned U.S. Patent No. 2,934,392, a substantial increase in the quantity of active gas absorbed thereby can be achieved if the layer is in the form of the gas-charged metal rather than the elemental metal prior to final bakeout and loading. This is due in part to the removal of surface oxides from the elemental metal which are removed by the prior absorption and removal of active gas during bakeout and also in part to the opening of fissures or minute defects in the metal by such prior cycling through which additional active gas can enter and be adsorbed in an absorption process. In other words, the quantity of hydrogen absorbed by a given amount of titanium increases, up to a maximum, as the number of times the titanium is cycled or if the resulting titanium hydride is heated and cooled in the presence of hydrogen is increased.

Accordingly, prior to the final procedure of evacuation and loading, layer **15** is pretreated by charging at least once, and preferably several times with hydrogen. This cycling may conveniently be done before deposition.

A further advantage of utilizing a precharged getter, as for example titanium hydride ($TiH_{1.73}$) over an elemental metal, as for example titanium, and requiring the charging thereof during processing, lies in the relative ease of charging. Thus, if elemental titanium were used and hydrogen were introduced by heating the titanium, surface impurities on the titanium tend to retard absorption of hydrogen and requires repeated cycling to charge the trigger electrode. On the other hand when, in accord with the present invention $TiH_{1.73}$ is heated and then cooled, hydrogen is rapidly re-absorbed at the surface of the partially dissociated titanium hydride. Another great advantage of fabricating triggerable vacuum gap devices in accord with the invention is that it results in purer hydrogen being loaded into the trigger electrode. The hydrogen bound in the $TiH_{1.73}$ is extremely pure. When the entire device is enclosed in an atmosphere of hydrogen and heated to a temperature sufficient to form the seals which form the evacuated envelope, the hydride of the

trigger electrode partially decomposes, releasing extremely pure hydrogen which flushes the envelope interior of the hydrogen atmosphere so that when the envelope is sealed only extremely pure hydrogen is present. This precludes non-absorbable impurities from entering the envelope and limiting the vacuum characteristics of the device. As the sealed device is cooled, the pure hydrogen is re-absorbed by the trigger electrode.

In accord with this invention the hydride does not reabsorb all the hydrogen it held initially. Actual tests have shown the hydride alloy, after formation of seals to be approximately $TiH_{0.76}$, in the case of titanium hydride. This quantity of hydrogen is quite sufficient to produce a hydrogen ion-electron plasma to break down the main gap upon pulsing. Additionally, it leaves the hydride with the ability to absorb more hydrogen at room or quiescent temperature, should hydrogen be evolved from other parts of the device during arcing.

The final process of evacuation and loading then comprises the following steps: with the device completed except for the formation of seals **24**, the device is placed in a furnace in an active gas, as for example, hydrogen, and heated to an elevated temperature of about 850° C. By using an appropriate solder such as a copper-silver eutectic solder, the seals **24** are made at this temperature. During the heating, prior to the formation of seals **24**, the charged material releases a portion of the hydrogen and, with the hydrogen in the furnace, replaces any other atmosphere and any sorbed gases removed from the internal elements by the heating as well as the rather impure hydrogen of the furnace atmosphere. Since the pressure of hydrogen in the device is that of the furnace and the temperature is known, a known quantity of hydrogen is enclosed in the device. An appropriate material such as copper-silver eutectic solder is placed at seals **24** and, at the known temperature, the seals are completed, trapping the gas therein. The device is then allowed to cool slowly and the hydrogen sealed in the envelope is absorbed by the material of layer **15**. Since the quantity of hydrogen which must be removed to properly reduce the pressure is known, the amount of material **15** required can be predetermined. Specifically, sufficient material is provided so that, at room temperature, the hydrogen pressure will be less than 10^{-5} torr, preferably in the range of 10^{-7} torr. If it is desired that the equilibrium hydride alloy be an even better getter at room temperature for gaseous impurities released during arcing, a gold-nickel eutectic solder may be used and the sealing temperature raised to approximately 1000° C.

In one complete operation, the performance of the invention followed the following schedule. The ferrous and refractory parts are outgassed by heating to 1000° C. for ½ hour. The copper electrodes are outgassed at 900° C. for ½ hour. The trigger electrode and the reservoir stockings and particular getter parts **27** and **28** are charged with hydrogen by heating to a temperature of 1000° C. in an atmosphere of pure dry hydrogen and cooling slowly over a 2 hour period. This is repeated 5 times to assure complete charging. The stainless steel end assemblies are brazed with a .0005 layer of copper. Ceramic cylinders **3** are metallized at the end surfaces with a second layer of 0.0005 layer of copper over a 0.0001" first layer of molybdenum-manganese alloy (16 wt. percent Mn—remainder molybdenum). After plating the ceramic washers are heated for 10 min. at a temperature of 1000° C. to sinter the copper to the first layer.

The parts are assembled as shown in the drawing with a 500 g. weight to maintain sealing pressure and a 0.002" thick brazing ring of 28 wt. percent copper and 72 wt. percent Ag between metal and ceramic part. The assembly is placed in a gas-tight furnace chamber which is then flushed at room temperature for ½ hour with hydrogen to remove all other gases from the furnace. After flushing, the temperature is slowly raised at a rate of approximately 5°/min. to a temperature of 750° C. to cause the $TiH_{1.73}$ parts to evolve very pure hydrogen so as to fill the interior of envelope **2**. The temperature of the envelope is then raised as rapidly as possible to 820° C. and held for 2 minutes to cause the metal-to-ceramic seals to be formed. The furnace is then allowed to cool slowly (about 2 hours) to room temperature and the formed device is removed.

It can be seen from the foregoing that the process of the present invention accomplishes several objectives. Due to the provision of a charged layer such as titanium hydride in the device prior to the evacuation method, the fabrication of much larger devices having much larger volumes to be evacuated is permitted without the necessity of providing large quantities of titanium or other active metal. Such provision is expensive and may be quite inconvenient, as for example, in the case of the trigger layer of triggered vacuum discharge devices wherein an overly thick layer of titanium might interfere with proper operation of the device.

The higher absorption provided by the present invention also allows the incorporation of sufficient hydrogen for long life without causing a high partial pressure of hydrogen gas in the device. Furthermore, this method enables the evacuation of the device down to the extremely low pressure required for proper operation and simultaneously achieves final sealing of the device and loading of the trigger layer with the required active gas. The evacuation is accomplished without the use of any vacuum pumps or other evacuating apparatus.

The device illustrated also includes end closure member **4** which illustrates a further feature of the invention. Member **4** includes an annular groove **25**, shielded from the primary discharge by an overhanging annulus **26**. A quantity of metallic hydride is placed therein, as for example, in the form of particles **27** enclosed in a wire mesh stocking **28**. The stocking may, for example, be fabricated of molybdenum. Despite the use of a previously charged coating as described above, it may be inconvenient to provide sufficient active metal in layer **15** so as to properly absorb all of the charging gas in envelope **1**. The additional material **27** has the same characteristics as the trigger electrode in that it also absorbs hydrogen. By appropriate adjustment of the size of the envelope and of the quantity of metal, the pressure can be lowered and maintained in the range of 10^{-7} torr.

The provision of active metal particles **27** is also of great importance in devices designed for frequent or nearly continuous initiation and termination of the primary discharge. During such frequent use, the hydrogen in layer **15** may be depleted to the point where it is no longer sufficient to properly initiate the primary discharge. This may be due to entrapment of hydrogen ions on the shield or other walls and covering thereof with metallic particles sputtered from the electrodes. At this time, the device is simply heated to an elevated temperature, such as above 600° C. in the case of titanium and hydrogen, so that the particles **27** releases the gas therein to the atmosphere of the envelope. Upon cooling, the metal of layer **15** absorbs part of the gas and thus is replenished. After such an operation the percentage content of hydrogen in the trigger electrode will be the same as in particles **27**. With the mass of the latter much greater than the former, nearly complete replenishment of the trigger electrode may be accomplished many times during the useful life of the device.

It is noted that the specific illustration of the cylindrical surface **25** is only exemplary, and that any appropriate means of providing an additional quantity of gas-absorbent metal in a relatively cool portion of the device would be sufficient. For example, this "reservoir" may be conveniently located in a readily-heated appendage of the gap device.

For a more detailed description of the operation of triggerable vacuum discharge devices, reference is again

made to my U.S. Patent 3,087,092. In general, a source of triggering potential is applied between wire **18** and electrode **6** by connection through end wall assembly **2**. The primary voltage is applied between end wall assembly **2** and electrode support member **11** so as to create a strong electric field between primary electrodes **5** and **6**. Due to the hard vacuum within enevelope **1**, very high voltages may be applied between electrodes **5** and **6** without causing breakdown. When a trigger pulse is applied through wire **18** and gap **17**, a spark discharge is initiated across groove **20** and the establishment of a trigger arc causing a heating of the metal film **15** and a consequent discharge of hydrogen into the vicinity of the arc where the hydrogen atoms are ionized. Magnetic forces then propel the resultant hydrogen plasma into the primary gap, thus enabling initiation of the primary discharge. The exact time of breakdown of the main gap (which is controllable to a matter of microseconds) is when the plasma is injected into the gap.

It is noted that the pretreatment of layer **15** may be done prior to the application thereof to the ceramic member **14**, in which case the titanium hydride may be painted thereon, fired to the ceramic in a vacuum and heated in hydrogen to compensate for any loss during the firing. Alternatively, the elemental titanium may be adhered to the ceramic and the resultant assembly may then be cycled in hydrogen to accomplish the pretreatment.

Although this invention is shown and described in connection with two fixed electrodes and a fixed gap, it is noted that the invention is particularly applicable to devices wherein the normal position is open circuit and breakdown of the gap is pulsed in accord with the operation of a trigger vacuum gap and the arc initiated thereby may be extinguished by moving one electrode into direct physical contact with the other electrode, as for example, in a vacuum switch of the circuit-breaker type or re-closer type or other vacuum switches. As used herein, the term "vacuum gap device" is intended to include all such devices whether the electrodes are fixed or movable.

While I have shown and described several embodiments of my invention, it will be apparent to those skilled in the art that many changes and modifications may be made without departing from my invention in its broader aspects; and I therefore intend the appended claims to cover all such changes and modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A method of evacuating and forming a triggerable vacuum gap device including an hermetically sealed envelope and adapted to have a discharge across the main gap thereof triggered by injection of a gaseous plasma thereinto, said method comprising the steps of: assembling the unsealed components of said device and of said envelope including a predetermined quantity of active gas-charged metal in said envelope prior to hermetic sealing thereof; enclosing the assembled parts within a furnace capable of retaining therein a controlled atmosphere; flushing the interior of said furnace with a gaseous atmosphere of the same gas with which said metal is charged to fill the interior of said device therewith; heating said device to a first elevated temperature to remove substantially all sorbed gases from the inner portions of said device and simultaneously cause pure gas to be evolved from said metal to further flush the interior of said device of impurities and provide an atmosphere of the same active gas to displace substantially all other gases in said envelope; further raising said device to a second elevated temperature for a period of time just sufficient to cause bonding of the constituents of said envelope to seal said envelope; and slowly cooling said device to a temperature at which said metal absorbs sufficient active gas to lower the pressure to less than a predetermined value so that said envelope is evacuated to a hard vacuum and said gas for triggering said discharge is simultaneously stored therein.

2. A method of evacuating and forming a triggerable vacuum discharge device including an envelope, a pair of primary electrodes defining a primary gap therebetween and a trigger having a metallic element thereof adapted to inject a quantity of an active gas plasma into said primary gap to initiate a discharge, and of simultaneously charging said trigger, said method comprising the steps of providing a predetermined quantity of active gas-charged metal in said envelope prior to hermetic sealing thereof, said element of said trigger incorporating at least a portion of said active gas-charged metal; disposing the unsealed components of said device in an atmosphere of the same active gas to remove substantially all other gases from said envelope; heating said device to a first elevated temperature in said atmosphere at an elevated temperature to remove any sorbed gases therefrom and simultaneously evolving the charged gas from said metal to further flush said envelope with pure charged gas from said gas-charged metal; further heating said device to a second higher temperature to seal said envelope; and cooling said device to a temperature at which said metal absorbs sufficient of said active gas to lower the pressure in said envelope to less than 10^{-5} torr so that said device is evacuated and said trigger is simultaneously charged.

3. The method claimed in claim **2** wherein said portion of said active gas-charged metal, prior to the provision thereof in said trigger is placed in an atmosphere of said active gas in a highly pure state, and heated to a temperature range in which said metal absorbs a substantial quantity of said active gas.

4. The method claimed in claim **2** wherein said portion of said active gas-charged metal, subsequent to the incorporation thereof in said trigger and prior to said baking, is placed in an atmosphere of said active gas of high purity, and heated to a temperature range in which said metal absorbs a substantial quantity of said active gas.

5. A method of evacuating a triggerable vacuum discharge device including an envelope and adapted to be triggered by injection of an active gas plasma into a discharge gap therein, said method comprising the steps of providing a predetermined quantity of active gas-charged metal in said envelope prior to hermetic sealing thereof, a portion of said metal being located in an area of said envelope which remains relatively cool during operation thereof and another portion being located so as to inject said active gas plasma into said gap, disposing said device in an atmosphere of the same active gas to remove substantially all other gases from said envelope; heating said device in said atmosphere at a first elevated temperature to remove any sorbed gases therefrom and cause evolution of pure charging gas from said metal to further flush said envelope with gas from said gas-charged metal; further heating said device to a second elevated temperature to seal said envelope; and cooling said device to a temperature at which said metal absorbs sufficient active gas to lower the pressure in said envelope to less than 10^{-5} torr so that said envelope is evacuated and said triggering gas is simultaneously loaded in said metal.

6. The method of claim **5** wherein said gettering metal is titanium and said active gas is hydrogen.

No references cited.

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