Dec. 7, 1965 R. E. HUESCHEN 3,222,558

VANADIUM WINDOW FOR AN ATOMIC PARTICLE AND RADIATION EMITTING DEVICE

Filed May 22, 1961

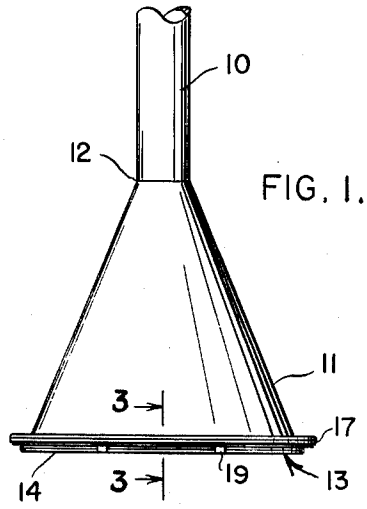


FIG. 1.

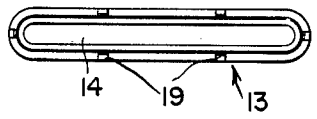
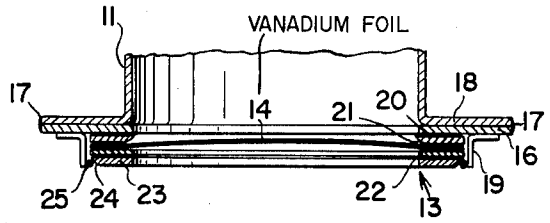


FIG. 2.

FIG. 3.



ITEMS 16, 18, 19, 20, 22 & 23 ARE STEEL OR STAINLESS STEEL

BRAZING METAL 25 MAY BE		
72% Ag	28% Cu	
50% Ag	50% Cu	
100% Ag		
38% Au	62% Cu	
	100% Cu	
35% Au	62% Cu	3% Ni

INVENTOR.
ROBERT E. HUESCHEN

BY Ralph G. Hohenfeldt

ATTORNEY

United States Patent Office

3,222,558

Patented Dec. 7, 1965

3,222,558

VANADIUM WINDOW FOR AN ATOMIC PARTICLE AND RADIATION EMITTING DEVICE

Robert E. Hueschen, Hales Corners, Wis., assignor to General Electric Company, a corporation of New York

Filed May 22, 1961, Ser. No. 111,706

7 Claims. (Cl. 313—59)

This invention relates to tubes that accelerate charged atomic particles and that issue them or accompanying radiation for utilization. In particular, the invention pertains to exit windows for such tubes and is descirbed primarily with reference to an electron and X-ray permeable window.

In conventional equipment for providing high energy electrons in the form of an electron beam, an electron gun, including an electron emitting filament and a control or focusing electrode provides electrons that are accelerated in a vacuum between high potential differences or on propagated electromagnetic waves. The beam is directed toward a metal foil window through which it emerges for penetrating a substance that is susceptible to being sterilized or affected physically or chemically by high speed electrons. Microwave linear accelerators, Van de Graaf generators and resonant transformers are typical power supplies for generating high speed electrons.

The efficiency of these devices, and indeed, the crucial factor in deciding whether a particular irradiation process is feasible or economical often depends upon minimizing the electron energy lost by absorption in the metal window. Not only does absorption subtract from the useful part of the beam but it heats the window, thereby weakening it sufficiently in some instances to cause its puncture from the unbalance of atmospheric pressure on one side and vacuum on the other side. Thus, in designing electron exit windows it has been necessary to balance requisite strength to resist atmospheric pressure against increasing window thickness and incident absorption losses.

Window absorption decreases disproportionately as electron energy, expressed in terms of electron volts, increases. Electron absorption is very nearly directly proportional to the density and thickness of the metal foil window. Hence, it is customary to make the windows as thin as possible of light metals such as aluminum and titanium so that the lowest number of grams per square centimeter of window metal are traversed by the beam.

The thin windows must be welded or brazed vacuum tight to the end of an accelerating tube whih may be of a different metal, like stainless steel. It is difficult to braze aluminum to steel alloys under any circumstances, and this is especially true when the aluminum is thin. Titanium, although easier to braze than aluminum, nevertheless, has some of the same undesirable characteristics, such as becoming embrittled and degraded during the brazing process as a result of crystal phase changes that take place at comparatively low brazing temperatures. In the case of titanium, especially, known brazing metals have a tendency to dissolve and penetrate into the parent metal while brazing. This weakens the titanium, particularly near its edges, so that prior art windows often cracked when subjected to preassembly pressure test.

Titanium windows have been made as thin as seven and one-half thousandths of an inch in sizes up to three inches by fifteen inches. This thickness exceeds that which is necessary to withstand atmospheric pressures, with an acceptable margin of safety, if one could get the full benefit from the actual thickness in practice. At elevated temperatures, titanium is very reactive and forms low melting point eutectics with many other metals. One such eutectic is copper-titanium which is liquid at

875° C. When this temperature is approached, solution of the brazing metal into the parent titanium metal increases, and if this temperature is reached, the brazing metal penetrates through the window completely, thereby reducing its strength to nothing. Even under optimum temperature conditions the silver-coper brazing alloy frequently used on titanium penetrates or dissolves into each side of it as much as a couple thousandths of an inch, reducing the strength of the penetrated cross section to such extent that less than half the original thickness is available for resisting rupture by atmospheric pressure.

It was mentioned earlier that titanium undergoes a crystal structure transformation in the vicinity of permissible brazing temperatures, more particularly at about 880° C. At this temperature it changes from a hexagonal structure to a body centered cubic structure. If the transformation temperature is reached, the grain growth of titanium is so great that the window leaks gas through itself although it is apparently imperforate. This combination of grain growth and braze alloy penetration embrittles the titanium at the joint area. Thus, when brazing titanium, one is limited to brazing alloys that melt below 880° C., and as a practical matter, this excludes almost all brazing materials except the silver-copper eutectic alloy which melts at 780° C.

It is not easy to escape exposing titanium windows to high working temperatures that cause degradation because it is often necessary to bake out, degas or braze the titanium with other metals in an electron tube assembly at high temperature. For example, when brazing titanium to stainless steel in a vacuum with induction or resistive heating, it is desirable to raise the temperature to 1015° C. in order to break down an oxide film that always forms on stainless steel at ordinary temperatures. This thermal decomposition of the oxide provides a clean surface to which the braze metal will "wet" and adhere. This temperature cannot be reached because of the previously mentioned allotropic transformation of titanium at 880° C.

To minimize oxidation during bake out of the tube, the costly and time-consuming step of nickel plating the titanium must be done. Vanadium, on the other hand, forms a dense oxide coating up to the oxide melting point of 680° C. Hence, vanadium need not be nickel plated as in the case of titanium.

An obvious solution to the aforegoing difficulties would be finding brazing materials that are more compatible with titanium, avoiding its degradation, and that would produce the necessary strength and vacuum tightness when joined with other metals. If this were possible it would be desirable because one could continue to benefit from the low electron absorption of titanium, resulting from its low density. However, the instant invention takes the less obvious approach of using a higher density metal, such as vanadium, for a window material in such manner as to allow realizing the low absorption of a material like titanium without being handicapped by its poor working and brazing properties.

In accordance with the present invention, extremely thin vanadium windows are employed, but total electron absorption is reduced despite the density of vanadium being 6.1 and greater than that of titanium which is 4.54. Thus, although a vanadium window must be about 75% as thick as a titanium window for equal electron absorption, it has been discovered that the actual thickness of vanadium can be reduced so much below the presently accepted minimum thickness for titanium that a significant reduction in electron absorption can be attained. In reality, a vanadium window .005 inch or thinner has advantages over a titanium window at its practical minimum thickness of .0075 inch. For reasons that will be clarified below, vanadium windows can be made as thin as .002

inch without encountering the serious brazing or working problems of titanium. Small vanadium windows .002 inch thick are vacuum tight after brazing with a nickel-copper-gold alloy at 1050° C.

Vanadium windows have many advantages. This metal has a high modulus of elasticity, 20×10^6 p.s.i. as compared with 15.5×10^6 p.s.i. for titanium. This is an important quality for it makes vanadium less subject to stress cracks in the high stress regions where the thin foil is joined with other metals and subjected to a high transverse force such as is applied by atmospheric pressure. Accordingly, larger windows can be made. Moreover, vanadium has a high melting point of 1900° C. compared with 1750° C. for titanium, and at normal brazing temperatures, it does not undergo degradation or dissolution by brazing metals. It preserves its body centered cubic structure up to its melting point rather than transforming to a different crystal structure at lower temperatures with attendant loss of strength, vacuum tightness, and other properties as is the case when titanium is used. Because the thermal conductivity of vanadium is 50% better than titanium it is much easier to dissipate the heat that accompanies electron absorption in the window.

Accordingly, it is an object of this invention to provide a new, improved and more efficient electron permeable window, and in particular, one that is made of vanadium foil. More specific objects are to provide a window that is more compatible for bonding with other metals, that conserves its desirable properties at any expected working and operating temperatures, to the end that reliable and inexpensive electron beam generator tubes may be obtained. Achievement of these and other objects will be evident throughout the course of the ensuing specification.

A more detailed description of the invention will now be set forth in reference to the drawing in which:

FIG. 1 shows a broken away portion of a front view of a charged particle accelerator tube;

FIG. 2 is a bottom view of the tube in FIG. 1 illustrating the shape and construction of the exit window assembly, and

FIG. 3 is a cross section of the window assembly taken on a line corresponding with 3—3 in FIG. 1.

To illustrate an application of the invention, FIG. 1 shows part of an accelerator tube comprising a broken off cylindrical tube 10 in which electrons or other charged particles may travel axially downward from an emitter, not shown, toward a hollow flared anode shell 11 from whence the particles emerge through a window assembly 13, and more specifically, the thin metal foil 14. A more complete tube assembly of a comparable type may be observed in U.S. Letters Patent No. 2,885,585, issued May 6, 1959 on the invention of M. J. Lunick et al.

When accelerating electrons, there is usually a hot cathode emitter or filament, not shown, at the end of cylinder 10 remote from exit window 13. The emitter may be supported on an insulated section so that anode shell 11 may be made relatively positive in voltage to accelerate electrons through a potential difference in a vacuum. Energies attained are usually in the range of 0.5 million electron volt to 15 million electron volts in which case most of the electrons emerge from the window to do useful irradiation.

The electron beam may be focused by any conventional means while in transit to the anode 11. In the vicinity of the junction 12 between flared portion 11 and tubular section 10 it is customary to locate magnetic deflection coils, not shown, for scanning the beam at high frequency over the narrow window dimension and at a lower frequency lengthwise of the window 14. This effects more even beam distribution on any product being irradiated and enlarges the area covered by the beam.

In most accelerators, electrons constituting the beam are not monoenergetic nor is the electron current density uniform across the beam. The high energy electrons

penetrate thin window 14 with little attenuation, but the lower energy electrons are more likely to be absorbed by the window, thereby reducing useful electron output and causing heating of the window. Because of irregularities in scanning, uneven cooling, and the differences in electron density across the beam, transitory hot spots may develop on the window 14. Spot temperatures are known to reach 450° C. and may go even higher. All of these factors make the choice of window foil 14 critical. In the present invention, window 14 may be made as thin as .002 inch out of the workable body centered cubic crystalline structure material vanadium.

As in FIG. 3, a sheet of vanadium is preferably preassembled with an oblong flat ring 16 which may be welded at 17 to a flange 18 formed integrally from the walls of flared anode body 11. Oblong ring 16 may be stainless or low carbon steel and flange 18 is preferably stainless steel. Weld 17 may be made with the well known tungsten inert gas process.

To facilitate locating on ring 16 the window subassembly which will be described below, the ring has spot welded on it a number of tabs 19 having a right angular cross section. FIG. 2 illustrates that six tabs 19 may be appropriate although the number chosen would depend upon window size. The window assembly may be prefabricated by placing an oblong ring 20, of small cross section, on the heavier ring 16 while the latter is inverted and before it is welded at 17. Then a sheet of vanadium 14, shown with exaggerated thickness in FIG. 3, of appropriate size may be placed with its margin bearing on ring 20. Note that ring 20 is slightly chamfered at 21 so as to alleviate concentrated stress that may develop in that region when window 14 is bowed slightly due to external air pressure after anode shell 11 is highly evacuated. Were it not for the high modulus of elasticity of vanadium, high stresses that are inclined to be generated in the region of the chamfered edge 21 might cause cracking or rupture of the extremely thin foil 14.

Another similar ring 22 may be placed on the edges of window 14 and still another ring 23 may be added in order that the composite thickness of rings 20, 22, 23 and window 14 is sufficient to allow clamping with large ring 16 between parallel planes without crushing angles 19. Except for vanadium window 14, all parts cited in this paragraph may be steel or stainless steel. For an effective window opening of three inches by fifteen inches the bearing width of rings 20, 22, 23 on the vanadium window foil edge may be around one quarter inch. The clamped assembly may now be brazed to form a rigid unitary structure before it is joined to flange 18 by welding ring 16 at 17.

The outer periphery of ring 23 may be beveled as at 24 to accommodate a suitable ring of brazing wire 25. When the window assembly is heated to an appropriate temperature in a vacuum furnace, for instance, the brazing wire flows along the edges and between the various rings and window foil 14. For the sake of clarity in FIG. 3, spaces are shown between layers constituted by window 14 and rings 16, 20, 22, 23 and at their edges next to angles 19. In reality these elements are tight and compact so that a small cross section brazing wire 25 is sufficient to fuse them together.

Because the vanadium window is not subject to phase transformations at any temperature nor does it melt up to 1900° C., it may be safely brazed without fear of reaching a critical temperature at which the brazing metal might dissolve in or degrade the vanadium. Consequently, it is now possible to select from a larger class of brazing alloys on the basis of what is most compatible with the material to which the vanadium window is to be joined.

Thus, the eutectic brazing alloy, 72% silver and 28% copper, which melts at 780° C. is no longer indispensable to staying far enough away from the critical allotropic transformation temperature as was the case with titanium. However, photomicrographs of vanadium windows brazed

with this eutectic alloy at temperatures over 780° C. show excellent bonding without any apparent solution of the brazing metal in the vanadium.

Other brazing metals that may now be used to make vanadium electron windows and their melting temperatures are: pure silver, 960° C.; 50% silver and 50% copper, about 850° C.; 62% copper and 38% gold, about 1,000° C.; and, 100% copper at 1083° C. Where brazing alloys consisting of a simple binary mixture of copper and gold are used, it may be desirable to limit the gold content to 38% because incipient solution of the gold in the vanadium may begin at this point. Excellent brazes are obtained, however, with an alloy known by the tradename Nicoro that consists of 62% copper, 35% gold and 3% nickel. This melts at 1020° C. and exhibits no perceptible solution in vanadium. In any case the vanadium window maintains its normally expected strength and ductility so that cracking near the window edges under the exceedingly high stresses created by air pressure is virtually eliminated. None of these brazing metals show any perceptible tendency to dissolve the vanadium nor does it suffer any loss of strength. Thus, vanadium windows need not be made thicker than what is necessary to withstand atmospheric pressure in order to obtain a margin of safety. Minimum electron absorption loss is thereby achieved.

Brazed window assemblies such as in FIG. 3, made in accordance with procedures set forth above, have been subjected to vacuum on the top side of a .002 inch vanadium foil **14** and a principally argon atmosphere on the bottom or outside and baker out or degassed for separate two hour periods at temperatures of 450° C. and 550° C. without leaks developing in the braze joints and without oxidizing the vanadium even though the argon contained some oxygen. Despite flexing of the extremely thin vanadium foil which results from cyclically pressurizing, de-pressurizing, heating and cooling the window, the braze joints remain vacuum tight. Thus, spoilage has been reduced drastically and greater electron transmission efficiency has been achieved than was experienced with heretofore known types of windows discussed earlier in this specification.

While the present invention has illustrated one manner in which a vanadium foil window may be mounted on an electron accelerating tube, such description is to be considered illustrative rather than limiting for the new vanadium window may be variously mounted, as for example in the window cited in the above mentioned patent, without departing from the fundamental concept of the invention.

In summary, the aforegoing specification has disclosed a new vanadium particle and radiation permeable window that reduces electron absorption beyond limits which could heretofore be attained, and that substantially eliminates what were heretofore considered as being substantially insurmountable problems of brazing and fabrication.

It is claimed:

1. A discharge device comprising wall means defining an evacuated chamber in which high speed electrons are produced, and a vanadium foil window disposed across an aperture in one of said wall means through which said high speed electrons may exit from said chamber.

2. The invention set forth in claim **1** wherein said wall means consists of a material comprising steel and said vanadium foil is brazed at its edge to said steel with a brazing metal comprising approximately 62% copper, 35% gold and 3% nickel.

3. The invention set forth in claim **1** wherein said wall means consists of a material comprising steel and said vanadium foil is brazed at its edge to said steel with a brazing metal constituting copper and no more than 38% gold.

4. The invention set forth in claim **1** wherein said vanadium foil has a thickness in the range of from .005 inch to .002 inch.

5. The invention set forth in claim **1** wherein said wall means comprises steel and said vanadium foil is brazed at its edge to said steel with a brazing metal selected from the class consisting of silver and copper and alloys of silver and copper.

6. The invention set forth in claim **5** wherein said wall means comprises stainless steel.

7. An electron discharge device comprising an evacuated chamber terminating in a lateral flange integrally formed therewith and defining an oblong opening to be traversed by high speed electrons, a window assembly including an electron permeable vanadium foil disposed substantially transverse to the direction of electron flight across said opening, a first oblong ring whose outside peripheral edge is directly welded to the edge of said flange, a second oblong ring with substantially the same opening as the first ring bearing on said first ring, a third ring similar to the second, the edge of said vanadium foil being engaged between said second and third rings, all of said rings and foil being brazed together as a unit with a brazing metal selected from the class consisting of silver and copper and alloys of silver and copper.

References Cited by the Examiner

UNITED STATES PATENTS

2,545,595 3/1951 Alvarez ..... 313—74 X

FOREIGN PATENTS

74,228 5/1932 Sweden.

GEORGE N. WESTBY, *Primary Examiner.*

ARTHUR GAUSS, ROBERT SEGAL, *Examiners.*