March 7, 1967 R. H. L. BIBB 3,308,332
RADIO FREQUENCY WINDOW COOLING STRUCTURE AND TRANSMISSION
DEVICES USING SAME
Filed July 16, 1963 2 Sheets-Sheet 1

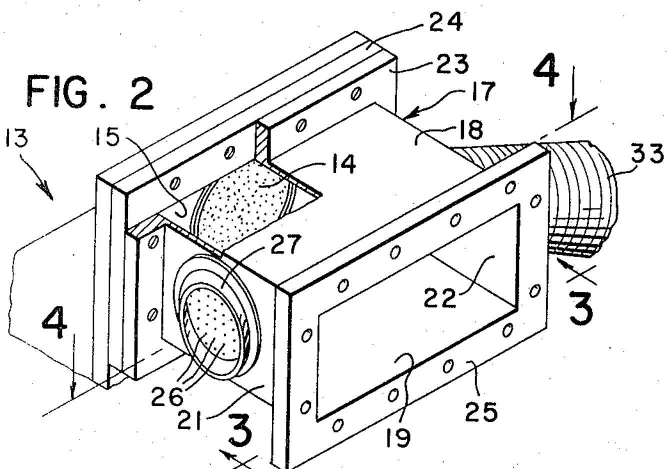

FIG. 2

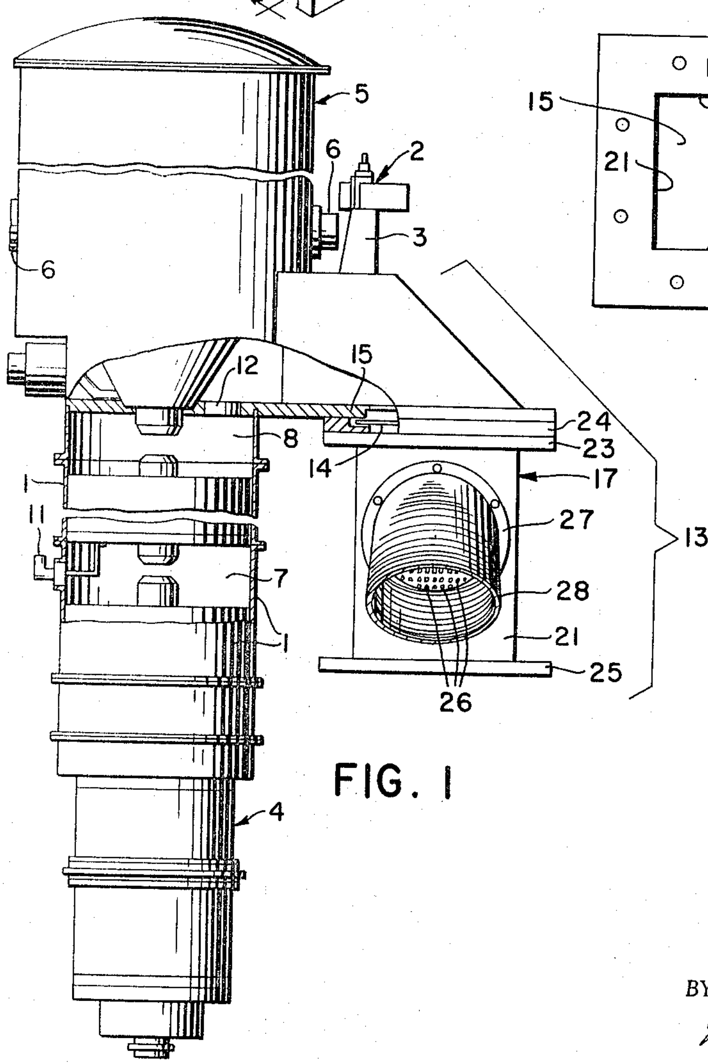

FIG. 1

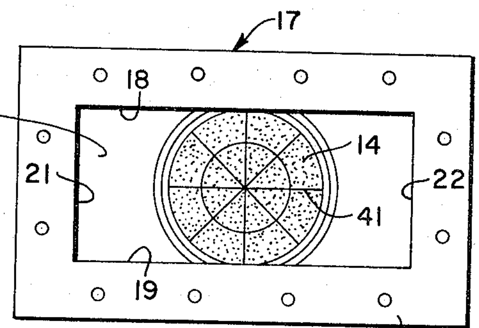

FIG. 3

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FIG. 4

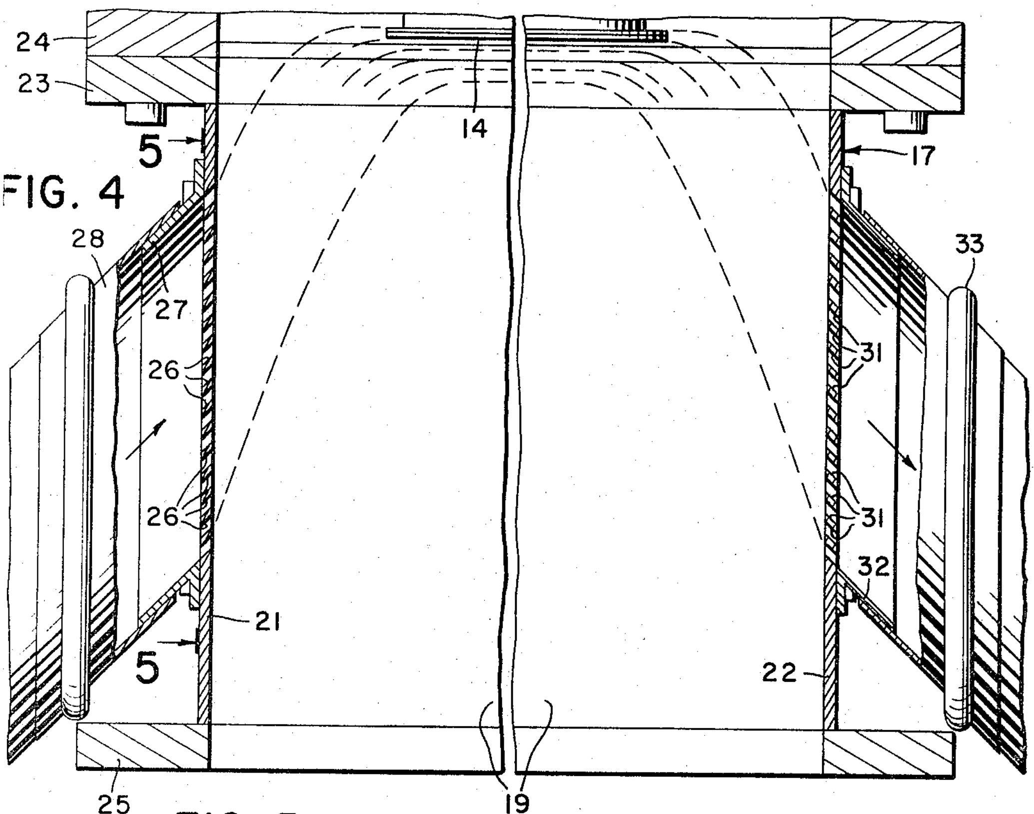


FIG. 5

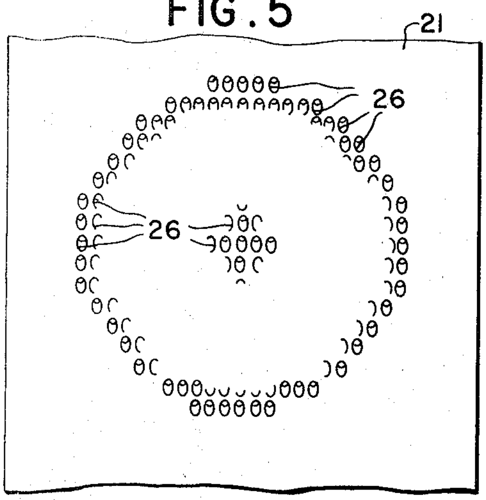
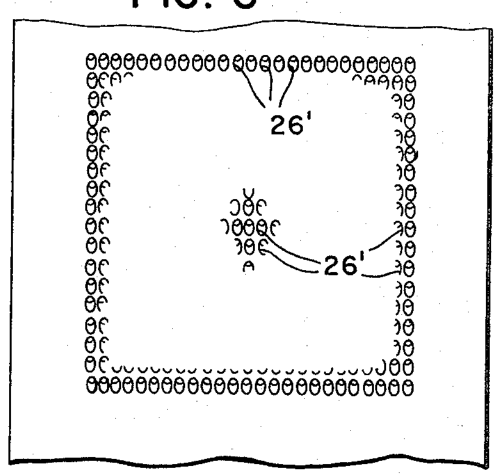


FIG. 6



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United States Patent Office

3,308,332

Patented Mar. 7, 1967

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Filed July 16, 1963, Ser. No. 295,481
12 Claims. (Cl. 315—5)

The present invention relates in general to high frequency electron tube apparatus and more particularly to an electromagnetic wave permeable window cooling structure.

As in all vacuum tubes, super power, microwave frequency tubes must provide therewithin a high vacuum to permit creation of an electron beam for the generation and amplification of microwave signals. High power microwave energy is extracted from these tubes via an output waveguide provided with an electromagnetic wave permeable window, typically of alumina ceramic, which is vacuum sealed within the output waveguide to maintain the vacuum within the tube and to permit passage of electromagnetic waves therethrough without substantial energy loss.

As the state of the art of microwave tubes has advanced, one of the limiting factors on the amount of microwave power that can be produced with a single tube is the wave permeable window in the output waveguide. The window must be able to transmit the high power microwave energy without cracking or rupturing while at the same time maintaining the high vacuum within the tube. For example, the output waveguide on a typical L band frequency microwave tube capable of producing 100 kilowatts of average power is approximately 7" diameter and the vacuum within such a tube is maintained at a level on the order of 1×10^{-9} mm. of Hg. Such high output powers necessarily dissipate, for example, several hundreds of watts of average power dissipated in the window as heat. The resultant temperature rise produces thermal stress which will rupture the window or supporting structure unless additional cooling is added.

Water and air-cooling schemes attempted heretofore for super power tube windows have caused uneven cooling of the window. Uneven cooling produces stresses across the window which have caused windows to crack and rupture with resultant loss of vacuum of the electron tube.

Previous water-cooling arrangements for cooling the periphery of the window have not solved the problem of temperature gradients in the center of the window. Furthermore, in the previous water-cooling schemes in which water or other coolants are passed through conduits in the window itself, the window is extremely difficult to fabricate, and the water passing through the window presents high loss to the electromagnetic wave passing therethrough.

Experiments with air streams on high power tube output windows have heretofore been relatively unsuccessful because of the lack of ability to get the majority of the air stream close enough to the window for effective cooling and because of uneven cooling of the window due to air vortices created in the waveguide at the window region.

In accordance with the present invention, to be described in greater detail below, the electromagnetic wave permeable window is positioned within a waveguide, and a plurality of closely grouped gas directive apertures are provided in one side wall of the waveguide with the apertures spaced from the window along the longitudinal axis of the waveguide and with the axes of the apertures directed substantially at the window. Another group of gas apertures is provided in the waveguide wall opposite

the one wall. It has been discovered that with the axes of the apertures inclined at an angle of between 30° and 60°, and preferably substantially 45°, with respect to the longitudinal axis of the waveguide, substantially more uniform and greater cooling over the entire window is achieved as compared to cooling obtained by other arrangements of apertures and coolant flow.

The principal object of the present invention is to provide an improved apparatus for cooling electromagnetic wave permeable windows, especially useful for super power electron discharge devices.

One feature of the present invention is the provision of an electromagnetic wave permeable window within a waveguide and a plurality of closely grouped gas directive apertures in one wall of the waveguide spaced longitudinally along the waveguide from the window and a plurality of closely spaced gas apertures in the opposite waveguide wall, the axes of the apertures in the one wall of the waveguide being directed at the window for directing a gas across the window and out the opposite side of the waveguide.

Another feature of the present invention is the provision of a cooling structure according to the preceding feature wherein the axes of the aperture in the first waveguide wall are inclined at an angle of between 30° and 60° and preferably substantially 45° with respect to the longitudinal axis of the waveguide.

Another feature of the present invention is the provision of the structure of the preceding feature having the wave permeable window mounted substantially transversely within a rectangular waveguide and having the apertures for directing gas across the window located in the narrow walls of the waveguide whereby waveguide arcs, if any, are blown away from the window.

Other features and advantages of the present invention will become apparent upon a perusal of the following specification taken in connection with the accompanying drawings wherein:

FIG. 1 is a longitudinal foreshortened view, partly in section, of a high frequency electron discharge device employing features of the present invention;

FIG. 2 is a perspective view of the output window and associated waveguide, partially broken away, illustrated in FIG. 1 with one air duct removed;

FIG. 3 is an end view of the structure shown in FIG. 2 taken along line 3—3 looking in the direction of the arrows;

FIG. 4 is a cross-sectional foreshortened view of the structure shown in FIG. 2 taken along line 4—4 looking in the direction of the arrows;

FIG. 5 is a view of the side of the structure shown in FIG. 4 taken along line 5—5 looking in the direction of the arrows; and

FIG. 6 is a view similar to FIG. 5 showing an alternative arrangement of the plurality of closely grouped apertures in the waveguide wall.

Referring now to FIG. 1, there is shown a high frequency electron discharge tube apparatus utilizing features of the present invention. More particularly, the tube comprises an evacuated tubular envelope **1** evacuated to a suitable low pressure as of, for example, 1×10^{-9} millimeters of mercury via the intermediary of an appendage ion pump **2** in gas communication with the interior of the tube envelope **1** via a suitable tubulation **3**.

An electron gun assembly **4** is disposed at one end of the tube envelope **1** and serves to form and project a beam of electrons over a predetermined path directed axially and longitudinally of the tube envelope **1**. A beam collecting structure **5** is disposed at the terminating end of the elongated electron beam path for collecting the electron beam. A coolant such as water is supplied to the beam collecting structure via fluid fittings **6** and circulates through suitable ducts, not shown, in the collector structure 5.

A plurality of re-entrant cavity resonators 7 and 8 are arranged along the beam path in axially spaced relation for electromagnetic interaction with the electron beam passable therethrough. Input wave energy to be amplified is supplied to the input resonator 7 via the intermediary of an input loop and a coaxial line 11. Amplified output wave energy is extracted in the conventional manner from the beam via output resonator 8 and propagated to a suitable load, not shown, via the intermediary of an output iris 12 and output waveguide 13 sealed in a suitable vacuum tight manner via the intermediary of a wave permeable vacuum tight window 14 mounted substantially transversely of the waveguide 13 by a window frame 15.

An electric solenoid (not shown) coaxially surrounds the elongated vacuum envelope 1 and provides an axially directed beam focusing magnetic field for confining the beam to its predetermined beam path.

Movable tuning structures (not shown) are provided within the cavity resonators 7 and 8 for tuning of the tube over the operating frequency range.

In operation, input signals are applied to the input resonator 7 via coaxial line 11. The signals are amplified in successive resonators and the amplified outward signals are derived from the tube 1 via the output waveguide 13. The window 14 is cooled during operation of the tube by means of an air stream directed into waveguide 13 across the outside surface of window 14 and then again out of the waveguide 13 as set forth in greater detail below.

As part of the output waveguide 13 a rectangular waveguide 17 outside the vacuum envelope is provided including a pair of opposed broad walls 18 and 19 and a pair of opposed narrow walls 21 and 22. The rectangular waveguide 17 is provided on one end with a flange 23 mating with a window flange 24 surrounding the window 14 and window frame 15. The other end of the rectangular waveguide 17 is provided with a flange 25 for coupling the tube to the load (not shown).

A plurality of closely grouped gas directive input apertures 26 are provided in the first narrow waveguide wall 21 for directing a cooling gas such as, for example, air onto the window 14. On the outside of the narrow wall 21 is provided a duct 27 constructed and arranged to receive an air pipe 28 from an air supply such as an air blower (not shown). Also a plurality of closely grouped outlet apertures 31 are provided in the opposite narrow waveguide wall 22 for permitting passage of the cooling air stream out of the waveguide 17. Although not necessary for proper operation of the invention, a duct 32 and an air pipe 33, similar to duct 27 and air pipe 28, respectively, are provided for convenience around the apertures 31.

The air stream from the air pipe 28 passes through the ducts 27 and is directed by the inlet apertures 26 across the window and out through the outlet apertures 31. The air flow path is illustrated in FIG. 4. Note how the coolant flow path decreases in thickness as it flows across the window member due to a venturi effect, i.e., a reduction in pressure at the center of the window. This pulling in of the coolant flow greatly facilitates cooling of the window as a greater volume of coolant is caused to flow in closer contact with the window member than otherwise obtained with coolant flows that do not exhibit the venturi effect.

As set forth in greater detail below, a certain inclination of the axes of the apertures 26 with respect to the longitudinal axis of the waveguide 17 as well as a spacing of the pattern of apertures from the plane of the window are preferred for evenly cooling the window.

The inlet apertures 26 serve to give directivity to the air stream directed therethrough and also serve as waveguides beyond cut-off for preventing R.F. leakage without producing large head losses to the air stream and without introducing a mismatch or encouraging spurious modes in the waveguide. It has been discovered that an open duct does not provide sufficient directivity to a cooling air stream to cool the window 14 properly and the use of baffles to accomplish this would deleteriously effect the R.F. characteristics of the waveguide.

It is preferred to have at least as many output apertures 31 as input apertures 26 and preferably, as many output apertures 31 as possible are provided so that the resistance presented to the air stream leaving the window is as low as possible.

While the apertures 26 and 31 can be in the broad walls 18 and 19 of the waveguide 17, it is preferable that they be located in the narrow side walls 21 and 22 since high power arcs might knock out the sections of waveguide between adjacent apertures. These arcs, which may be created within waveguide 17, take the shortest path between waveguide walls, between the broad walls 18 and 19.

It has been discovered that the group of gas directive apertures 26 should be spaced longitudinally of the waveguide 17 away from the plane of the window 14. If the group of gas directive apertures 26 is too close to the plane of the window, the air stream will follow a path that, after reaching the window, flows away from the window rather than parallel to it. On the other hand, a group of apertures spaced from the plane of the window directs the air stream to and then along the window. However, as the group of apertures 26 is placed further and further down the waveguide 17, the air stream will fail to adequately cool the closest edge of the window. Therefore, the group of apertures is preferably spaced longitudinally of the waveguide a distance which is dependent upon the waveguide and window dimensions in each particular instance. Also, the best pattern of the apertures 26 will depend upon the waveguide and window dimensions and therefore will usually be determined by trial and error. This pattern can either be circular as shown in FIG. 5, square as shown in FIG. 6 or of another shape dependent upon the window and waveguide dimensions.

It has been discovered that the inclination of the axes of the gas directive aperture 26 with respect to the longitudinal axis of the waveguide 17 is critical if efficient and even cooling of the window is to be achieved without the creation of air vortices within the waveguide. In this regard it has been discovered that when the axes of these apertures 26 are inclined at angles of 30° or less or at angles of 60° or more, air vortices are produced within the waveguide 17 while air vortices are not likely to be produced with angles of inclination between 30° and 60°. Furthermore, experiments have shown that an angle of inclination of substantially 45° produces the best results.

In tests made using a ⅜" thick, 7" diameter circular window in a 6" by 12" rectangular waveguide, two kilowatts of power were applied to the window, and temperature contours were plotted on the window using an air stream from a four horsepower blower directed across the window. Temperature sensitive wax was applied to the window in patterns such as shown at 41 on the window in FIG. 3. After testing a number of different inlet aperture entrance angles, the critical entrance angle of substantially 45° was established. A 6" diameter circular pattern of five hundred and fifty seven ⅛" diameter inlet apertures, centered in the narrow waveguide side wall, was moved toward and away from the plane of the window until an even cooling of the window was achieved. Even cooling was obtained when the pattern center was located 5" down the guide along the axis of the guide from the plane of the window.

With these parameters and with identical inlet and outlet patterns approximately 75% of the air flow was within ½" of the window with very little static air pressure loss in passing through the inlet apertures. Also with this construction the horsepower requirements were reduced by as much as the factor of 3 with a greatly improved cooling pattern over other cooling schemes tested. In addition with this cooling arrangement the window had a circular constant temperature contour of 350° C., 4" in diameter, centered only ¼" away from the center of the window.

Utilizing a fixed total aperture area, apertures with diameters of ½", ⅛", and 1/32" were tested with both ½" and 3/16" waveguide wall thickness. While ½" diameter holes in a ½" thick wall produced the highest flow rate across the window, this combination did not produce an air stream as close to the window as desired for best cooling. The ⅛" diameter apertures in a waveguide wall 3/16" thick produced the best flow rate at the window surface.

Cooling schemes of this general nature have been used successfully to cool windows on existing super power microwave tubes. The parameters for two such schemes are as follows:

	Example I	Example II
Rectangular waveguide inside dimensions.	9" x 18"	5¾" x 11½".
Window size	10" x 14" elliptical	7" diameter.
Inlet aperture pattern	Circular	Rectangular.
Inlet aperture pattern size	8" diameter	5" x 5½".
Inlet aperture pattern distance from window.	3"	1.3".
Inlet aperture inclination angle	45°	45°.
Inlet aperture diameter	5/32"	⅛".
Number of inlet apertures	557	500.
Outlet aperture pattern	Circular	Rectangular.
Outlet aperture pattern size	8" diameter	5½" x 7½".
Outlet aperture pattern distance from window.	3"	1".
Outlet aperture inclination angle	45°	45°.
Outlet aperture diameter	5/32"	⅛".
Number of outlet apertures	557	729.

While the invention has been described thus far as applied for use in rectangular waveguide, it is obvious that the invention is equally applicable to circular waveguide. Also, while the invention has been described as used with an air stream for cooling the window, any gas stream could be used.

While the angle of inclination of the outlet apertures is preferably the same as that of the inlet apertures this parameter is not as critical as the angle of inclination of the inlet apertures for even cooling of the window so long as sufficient apertures are provided to offer a low resistance to air flow leaving the window for preventing the generation of vortices.

While the invention has been described thus far with respect to the output window of a super power tube, it is obvious that the invention can be utilized for use with a window which must withstand high power anywhere in a microwave system.

What is claimed is:

1. A microwave transmission structure for transmitting high power electromagnetic waves comprising:
wall means defining a waveguide for the electromagnetic waves and having a longitudinal axis taken in the direction of power flow along said waveguide,
an electromagnetic wave permeable window,
means for supporting said wave permeable window within said waveguide,
said waveguide wall means provided with an array of apertures on a first side of said waveguide for passing gas into said waveguide toward said window and an array of apertures on a second side of said waveguide substantially opposite said first side for passing gas out of said waveguide, the axes of said apertures being directed toward said window,
and said array of apertures having a center spaced from said window along the longitudinal axis of said waveguide from said window, whereby gas directed into said waveguide through said apertures on the first side of said waveguide causes the gas to flow across said window and out of said waveguide

through said apertures on the second side to cool said window that is heated by electromagnetic wave energy dissipated therein.

2. The microwave transmission structure of claim 1 characterized further in that the axes of at least said apertures on said first side of said waveguide are inclined at an angle between 30° and 60° with respect to the longitudinal axis of said waveguide.

3. The microwave transmission structure of claim 1 characterized further in that the axes of at least said apertures on said first side of said waveguide are inclined at an angle of substantially 45° with respect to the longitudinal axis of said waveguide.

4. A microwave transmission structure for transmitting high power electromagnetic waves comprising:
wall means defining a waveguide for conducting electromagnetic waves, said wall means including first and second opposed side walls defining a longitudinal axis directed along the direction of power flow in said guide,
an electromagnetic wave permeable window,
means for supporting said wave permeable window in a vacuum tight manner substantially transversely across said waveguide whereby said waveguide on one side of said window can be maintained under substantial vacuum,
said first side wall of said waveguide wall means on the opposite side of said window from the vacuum being provided with an array of closely grouped inlet gas directive apertures,
said apertures spaced longitudinally of said waveguide from said window and the axes of said apertures directed substantially at said window for passing air into said waveguide toward said window,
said second side wall of said waveguide wall means on said opposite side of said window from said vacuum being provided with an array of closely grouped outlet gas apertures, and
means for directing gas into said waveguide through the inlet apertures in said first side wall whereby the gas flows across said window evenly to cool said window and out of said waveguide through the outlet apertures in said second side wall of said waveguide.

5. The microwave transmission structure according to claim 4 characterized further in that said axes of the apertures in at least said first side wall of said waveguide are inclined at an angle between 30° and 60° with respect to the longitudinal axis of said waveguide.

6. The microwave transmission structure according to claim 4 characterized further in that said axes of the apertures in at least said first side wall of said waveguide are inclined at an angle of substantially 45° with respect to the longitudinal axis of said waveguide.

7. An electron tube apparatus including:
a vacuum envelope,
means for forming and projecting a beam of electrons over an elongated predetermined beam path within said envelope,
means for collecting the beam at the terminal end of the beam path,
wave interaction means disposed within said envelope along the beam path intermediate said beam forming means and said beam collecting means for electromagnetic interaction with the beam,
waveguide output means for extracting electromagnetic wave energy from the beam including opposed first and second side walls defining a longitudinal axis directed in the direction of power flow in said waveguide,
an electromagnetic wave permeable window,
means for supporting said wave permeable window substantially transversely within said waveguide output means in a vacuum tight manner whereby said

window serves as a portion of said vacuum envelope,
said first side wall of said waveguide output means on the outside of said window provided with a plurality of closely grouped inlet gas directive apertures, said apertures spaced longitudinally of said output waveguide means from said window and the axes of said apertures directed substantially at said window for passing gas into said waveguide toward said window,
said second side wall of said output waveguide means on said outside of said window provided with a plurality of closely grouped outlet gas apertures for passing gas out of said waveguide, and
means for directing a gas into said waveguide through said inlet apertures in said first side wall of said output waveguide whereby the gas flows across said window evenly to cool said window and out of said waveguide output means through the outlet apertures in said second side wall of said waveguide output means.

8. The apparatus according to claim 7 characterized further in that said axes of the apertures in at least said first side wall of said waveguide are inclined at an angle between 30° and 60° with respect to the longitudinal axis of said waveguide.

9. The apparatus according to claim 7 characterized further in that said axes of the apertures in at least said first side wall of said waveguide are inclined at an angle of substantially 45°.

10. A microwave transmission structure for transmitting high power electromagnetic waves comprising:
wall means defining a rectangular waveguide for electromagnetic waves and having pairs of opposed broad and narrow side walls directed longitudinally of said waveguide,
an electromagnetic wave permeable window,
means for supporting said wave permeable window

substantially transversely within said waveguide in a vacuum tight manner whereby said waveguide on the inside of said window may be maintained under substantial vacuum,
one of said narrow side walls on the outside of said window being provided with a plurality of closely grouped inlet gas directive apertures, said apertures spaced longitudinally of said waveguide from said window and the axes of said apertures directed substantially at said window,
the other narrow side wall of said waveguide being provided with a plurality of closely grouped outlet gas apertures for passing gas out of said waveguide, and
means for directing gas into said waveguide through said inlet apertures in said one narrow side wall, across the window evenly to cool said window and out through the outlet apertures in said other narrow side wall.

11. The microwave transmission structure according to claim 10 characterized further in that said axes of at least the inlet apertures in said one narrow side wall are inclined at an angle between 30° to 60° with respect to the longitudinal axis of said waveguide.

12. The microwave transmission structure according to claim 10 characterized further in that said axes of at least the inlet apertures in said one narrow side wall are inclined at an angle of substantially 45° with respect to the longitudinal axis of the waveguide.

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