

[54] **METHOD OF MANUFACTURING A
CERAMIC BALL INSULATED DEPRESSED
COLLECTOR FOR A MICROWAVE TUBE**

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3,679,929.

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[58] Field of Search..... 29/600, 592, 522,
29/523

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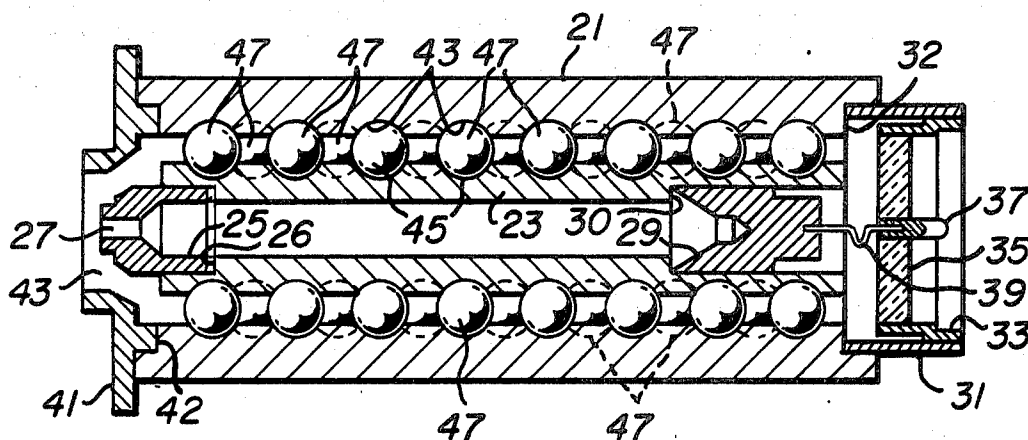
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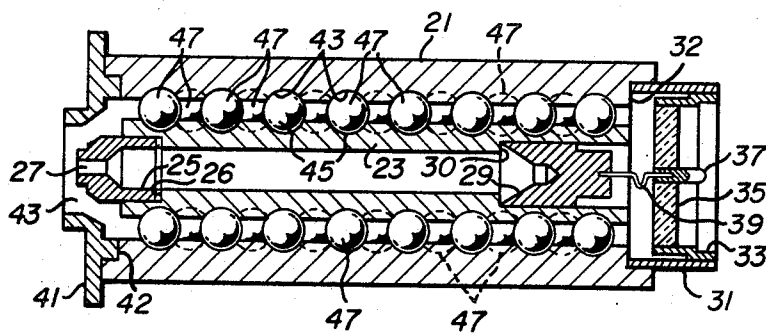
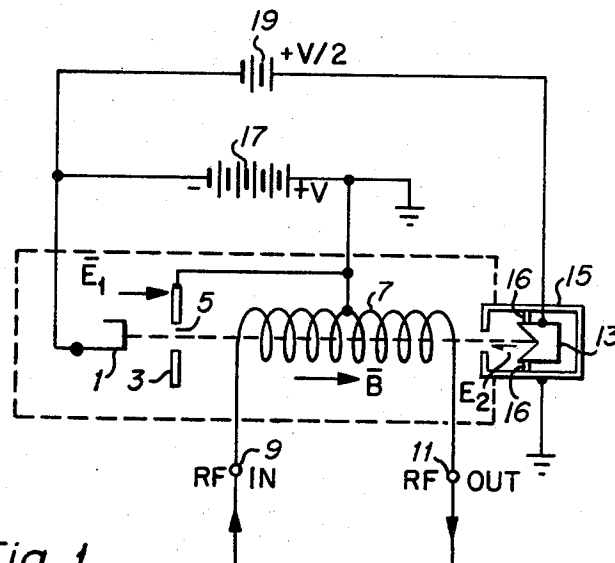
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ABSTRACT

In an improved depressed collector assembly for a microwave tube a pair of metal cylindrical members are arranged concentrically, one within the other, and in that relationship are supported spaced apart and electrically insulated from one another by a fill of dielectric ceramic balls or spheres, suitably aluminum oxide or beryllium oxide, located within and about and along the space between the cylinders. The spheres are maintained therein embedded in indentations in the opposed walls of the cylindrical members. The inner cylinder forms the major part of the depressed collector electrode which is in the tube maintained at a high voltage, and the outer cylinder forms the collector shield maintained at a much lower voltage, normally ground. In the novel method of fitting such ceramic spheres between the inner and outer metal cylinders the annular space between the concentric cylinders is first filled with the relatively incompressible ceramic spheres, and the outer surface of the inner cylinder is forced outward to embed said spheres primarily in that outer surface while the inner surface of the outer cylinder is forced inwardly to embed the spheres primarily in the inner surface of the outer cylinder so that the spheres are seated in place and cannot move and, conversely, the balls preclude relative movement between the inner and outer cylinders.

15 Claims, 10 Drawing Figures





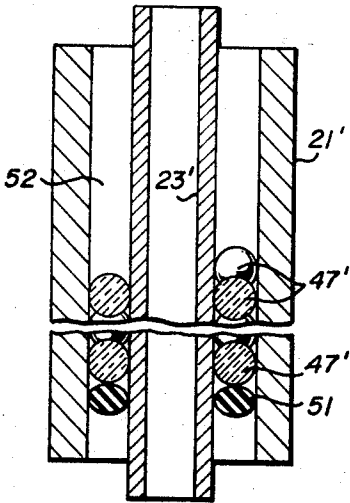


Fig. 3a

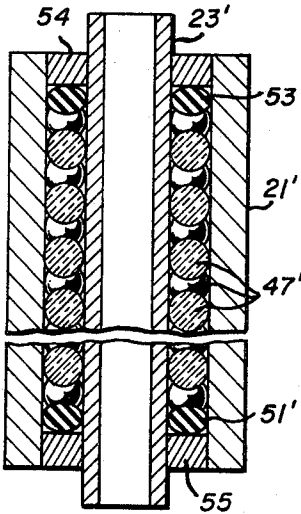


Fig. 3c

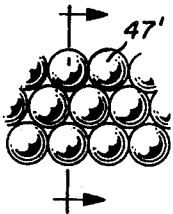


Fig. 3b

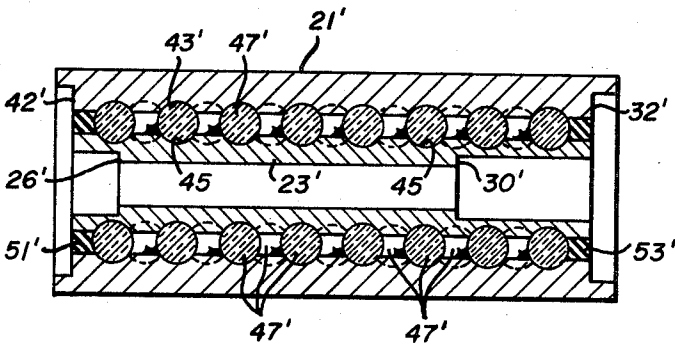
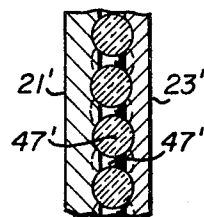
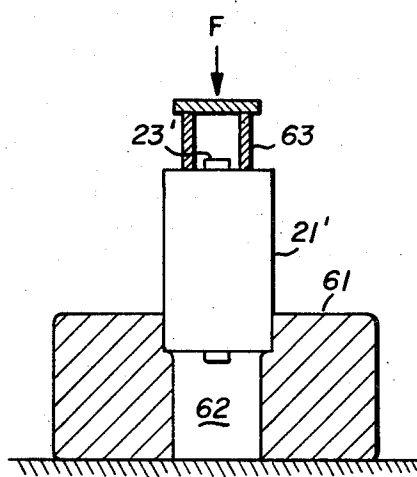
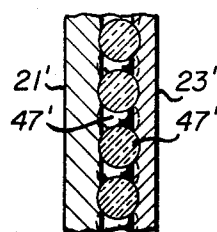
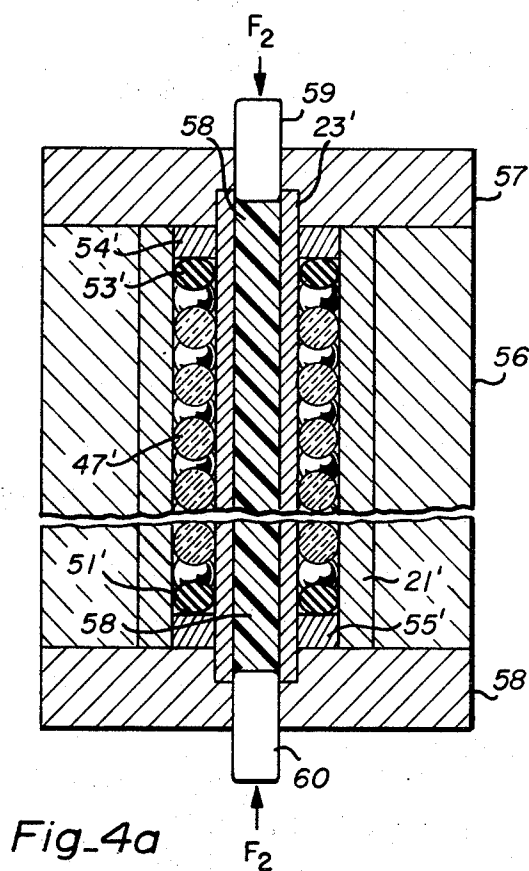


Fig. 6



METHOD OF MANUFACTURING A CERAMIC BALL INSULATED DEPRESSED COLLECTOR FOR A MICROWAVE TUBE

CROSS REFERENCE

This application is a division of our earlier filed patent application Ser. No. 94,387, filed Dec. 2, 1970 and now U.S. Pat. No. 3,679,929.

FIELD OF THE INVENTION

This invention relates to a method of manufacturing a collector assembly for a microwave tube and, more particularly, to a method of making a concentric cylindrical shield-collector assembly in which the collector and shield are supported together by ceramic balls.

BACKGROUND OF THE INVENTION

Numerous types of microwave tubes incorporate as an element thereof a "collector" to collect electrons during normal tube operation. Two prominent types of such microwave tubes are conventional and known as the O-type traveling wave tube and the klystron.

The O-type traveling wave tube is a conventional type of microwave tube used primarily as an amplifier of microwave frequency signals. Such a tube basically includes in an evacuated envelope a cathode for emitting electrons, an accelerating anode which accelerates the electrons to a predetermined velocity, an elongated electrically conductive helix, and a collector electrode. In this the electrons accelerated from the cathode enter the helix at a predetermined velocity. In traveling through the helix the electron "interacts" with or transfers energy to an electromagnetic signal applied at the input to the helix and which propagates along the helix to the output. Thereupon the electrons exit from the helix and are incident upon the collector electrode which provides the means through which the electrons are returned to the power supply. The kinetic energy possessed by the traveling electrons is normally released upon incidence at the collector electrode, thereby creating heat. Electrically, the loss of this energy is reflected as a lower electrical efficiency of operation than is desired. Mechanically, depending upon the power levels at which the tube is operated, the heat generated can be sufficient in amount to damage the collector electrode and the traveling wave tube if the heat is not or cannot be removed fast enough.

To internally minimize the generation of heat and increase electrical efficiency of operation in the basic traveling wave tube a "depressed" collector arrangement is employed. In this structure the collector electrode instead of being electrically at ground potential is operated at a high voltage, generally about one-half the voltage applied to the accelerator electrode, although "negative" with respect to the "positive" electrical ground. Since the helix and accelerator electrode are at ground potential (positive), and the collector at a high "negative" voltage relative thereto, an electric field is created between the collector electrode and the helix, which field is in a direction that decelerates the electrons as they approach the collector. Hence the collector is termed "depressed." With the depressed collector the electrons exiting from the helix are decelerated to a lower velocity. Accordingly, upon striking the collector they have a smaller kinetic energy and generate less heat. If operated at the same output power the tube has a substantially greater electrical ef-

iciency and minimizes the need for additional cooling or tube damage due to the generation of heat at the collector. Alternatively, the depressed collector arrangement allows the tube to be operated at higher output powers without damage than in the case of the conventional construction. To increase power output further the heat generation and removal again becomes a problem. A typical depressed collector assembly preferably includes a shield surrounding the collector and this shield is maintained at electrical ground potential. The prime purpose of the shield is as an outer covering at one end of the tube structure which permits the tube to be handled without danger of electrocuting any person touching same and to provide an electrically grounded surface which can be connected to an electrically grounded heat sink. Accordingly, factors in the design of the depressed collector assembly are that adequate voltage insulation be maintained between the collector and shield and that an adequate heat conducting path be provided to transfer heat from the collector to an external heat sink.

Typically, an insulator spacer is provided between the shield and collector to provide the requisite electrical isolation and heat conducting path. In one prior art construction spaced washerlike rings of an insulative ceramic material, suitably aluminum oxide or beryllium oxide, are brazed along its inner periphery to the cylinder comprising the collector electrode and is brazed along its outer periphery to the cylindrical body comprising the shield. It is noted that aluminum oxide ceramic provides a good high voltage stand-off and is also an adequate heat conductor, while the beryllium oxide provides a better heat conductor, but is more weak and brittle. However, because of the limited number of spaced ceramic washers there are only a discreet number of points of contact through which the heat can pass from the collector through the spacing washers to the shield (and thence to an external heat sink), and, thus, this construction has one disadvantage of a limited amount of heat transfer capability.

A second alternative construction is to provide an elongated cylindrical dielectric ceramic sleeve, suitably aluminum oxide or beryllium oxide, which fits within the annular space between concentrically arranged cylindrical collector and cylindrical shield, and is brazed to a surface of each to ensure good thermal mechanical contact. While theoretically a good construction, it has a prime disadvantage. The thermal coefficient of expansion of the metal cylinder comprising the collector is substantially larger than the thermal coefficient of expansion of the surrounding ceramic. Moreover, during operation of the tube the collector heats and attempts to expand first both radially and lengthwise. The lineal expansion of the collector creates a large tensile stress at the braze between the ceramic cylinder and output collector surface. Most often this results in a breaking of the bond with the collector or in cracking of the ceramic cylinder, either of which reduce the heat transfer path. Radially, the expansion creates a loop tensile stress which also cracks the ceramic cylinder radially, again reducing thermal conductivity. Depending upon the degree of cracking, an unknown, the capability and life of the tube are in this respect an unknown.

A compromise to the aforescribed choices is the use of small accurately placed and brazed wedges of dielectric ceramic material. If these wedges are properly placed within the space between the shield and collec-

tor and uniformly arranged and then brazed in place, it is possible to obtain a collector assembly which has a definite heat transfer capability. In this structure because the aluminum oxide is broken, so to speak, into bits and pieces there is little or no breaking away during a differential heating process, and accordingly the heat paths through the ceramic remains at a relatively constant area and number. Unfortunately, while it is possible to neatly and tediously stack and braze the large number of small ceramic wedges in the laboratory, it is not possible or practical to do so in production quantities in which the speed of construction is a vital factor. Accordingly, to provide a tube of the desired operating characteristics at a reasonable price that the customer can afford, those manufacturers using such minute ceramic wedges generally stack them in a rather random way so that the actual amount of contact area ultimately achieved between the wedges and the collector is not ultimately known. The obvious test is that if the tube fails during testing operation logic decrees there was insufficient contact, whereas in those tubes which perform a normal operational life the random stacking must, it can be concluded, be sufficient. Unfortunately, in practice the predictability of results from tube to tube is speculative and the yield of good tubes uncertain. A more certain, consistent and reliable or definite approach is desired.

In each of the foregoing constructions in which the ceramic is brazed in place to the collector, significant design limitations are imposed. The ceramic has a substantially lower coefficient of linear expansion than the copper collector. During differential linear expansion due to heating of the collector the expansion stress creates great tensile stresses on the braze. To minimize a tendency to break the bond the collector electrode is constructed to have very thin walls and this restricts flow of heat along the collector. Alternatively the collector electrode is constructed of Kovar, a material having a coefficient of thermal expansion more near that of the ceramic, but a poor heat conductor. The thinness of the collector electrode walls necessitated by prior art collector constructions thus reduces the maximum output power of the tube.

Moreover, as noted, any of the aforementioned constructions requires a braze material to bond the ceramic to the collector. After brazing the braze metal, microscopically, contains a rough surface having pointed edges and has penetrated into the ceramic. As is elementary, the voltage standoff capability between two flat surfaces is larger than that between pointed surfaces the same distance apart. In addition, the penetration of the braze material into the ceramic effectively decreases the spacing. Thus with the brazed ceramic structure the voltage standoff or isolation capability of the collector at any break or crack in the ceramic is less than the actual spacing might suggest.

Substantially similar problems and prior art techniques of attempted solution as have been described in connection with the O-type traveling wave tubes are experienced in the klystrons which contain depressed collectors.

In our co-pending patent application, Ser. No. 94,387, filed Dec. 2, 1970, for a Ceramic Ball Insulated Depressed Collector for a Microwave Tube, and now U.S. Pat. No. 3,679,929, of which the present application is a division, a novel structural arrangement is employed that departs from the structure of the prior art

and avoids the disadvantages attendant to the prior art structures. In that invention a cylindrical shield ensembles and is spaced apart by a cylindrical annular space from a depressed collector member having an outer cylindrical geometry and the space therebetween is filled with small ceramic balls each of which bridges the annular space and is in physical contact with both the collector and the shield. Suitably, the ceramic balls are seated or embedded between opposed indentations formed within the collector and shield members. The present invention relates to a novel process whereby the ceramic balls are inserted and maintained between the collector and shield electrodes without the use of brazing material or brazing operation.

OBJECTS OF THE INVENTION

Accordingly, it is an object of the invention to provide a method of manufacturing a collector-shield assembly for a microwave tube.

It is a further object of the invention to provide a process of manufacturing depressed collector and shield assembly in which the separating ceramic insulators are installed without the necessity for brazing.

It is another object of the invention to provide a method of manufacturing a collector-shield assembly for a microwave tube that is reliable, provides characteristics reproducible from tube to tube in production and which increases substantially the power output capability of the microwave tube.

And it is an additional object of the invention to provide a novel and unique method of assembling together in electrically isolated relationship two elongated concentrically arranged cylinders.

BRIEF SUMMARY OF THE INVENTION

The novel method of mechanically assembling together concentric metal cylinders in an electrically insulative, thermally conductive, and rigid relationship in which the space between the concentric cylinders is first filled with small ceramic spheres or balls and the balls are embedded to a predetermined depth in each of the opposed surfaces of the cylinders. In one variation of the invention the outer surface of the inner cylinder is forced outward to embed said spheres primarily in said outer surface, and the inner surface of the outer cylinder is forced inwardly to likewise embed the spheres primarily in the inner surface of the outer cylinder so that the spheres are firmly seated in place between opposed indentations in said respective cylinders and cannot move. Likewise relative movement between the inner and outer cylinders is precluded.

The foregoing objects and advantages, including additional advantages, modifications and variations of the invention, become more apparent from a consideration of the following detailed description of the preferred embodiment of the invention and its method of assembly taken together with the figures of the drawings in which:

DESCRIPTION OF DRAWINGS

FIG. 1 illustrates schematically an O-type traveling wave tube and circuitry which can include the novel collector assembly of the invention;

FIG. 2 illustrates in cross-section a complete collector assembly of a preferred embodiment of the invention;

FIG. 3a illustrates one of the first steps in manufacturing collector assembly of the invention in accordance with the novel methods devised;

FIG. 3b illustrates the stacking of the ceramic balls during assembly according to the novel method;

FIG. 3c illustrates in cross-section the final assembly after a step of filling with ceramic spheres;

FIG. 4a illustrates the apparatus and step of embedding the spheres into the collector portion during assembly;

FIG. 4b illustrates a segment in cross-section showing the relationship between the spheres and cylinder after the operation of FIG. 4a;

FIG. 5a illustrates a sizing die and press;

FIG. 5b illustrates the manner in which the spheres are embedded in the outer cylinder during assembly; and

FIG. 6 illustrates in cross section a collector assembly which has undergone the assembly procedures in FIGS. 3 through 5 and which has been faced and bored for inclusion of the final elements found in the complete assembly of FIG. 2.

DETAILED DESCRIPTION

FIG. 1 schematically illustrates the basic elements of a conventional depressed collector O-type traveling wave tube and ancillary power supplies. The dashed lines 2 represent symbolically a conventional envelope in which the elements are contained in vacuum. The tube contains a cathode 1. This provides the source or emitter of electrons. A filament normally included for heating the cathode to make the latter more emissive and the power supply for the filament are not illustrated but are understood as generally necessary elements. Spaced from cathode 1 is an accelerating anode 3. The anode contains an opening 5. To the right of anode 3 in FIG. 1 is a helix 7. The helix comprises essentially a helix of wire or tape of an electrically conductive material, suitably molybdenum or tungsten or other equivalent conductive material in which the turns are of a predetermined radius and are spaced at a predetermined helix pitch in accordance with well known design principles. An RF input connection 9 is made at the end of the helix nearest the cathode and an RF output connection 11 is made at the other end of the helix. A metal electrode 13, termed a collector, is provided at the output end of the helix. Spaced from and surrounding collector 13 is a metal shield 15. Insulators 16 maintain the collector and shield spaced. A source of high voltage represented by battery 17, suitably on the order of 6,000 volts, is connected with its negative terminal connected to cathode 1 and with its positive terminal connected to electrical ground, suitably a "positive" ground. An electrical connection is made between accelerator electrode 3 to the center of the helix and to electrical ground to place these elements at a high positive voltage relative to the cathode. A second high voltage source represented by battery 19 is connected at its negative polarity terminal to cathode 1 and at its positive polarity terminal to collector 13. Typically source 19 is with prior art collector constructions on the order of one-half the magnitude of the first source 17 and in the cited example would suitably be 3,000 volts. This places the collector at a lower or "depressed" voltage relative to the helix. The metal shield 15 which surrounds, encloses, and is insulated from collector 13 is connected to electrical ground. To-

gether the collector and shield are variously referred to as the "collector assembly" or "collector-shield assembly" and is understood to be the improved collector assembly of the invention, hereinafter described in greater detail, assembled together in an operative tube of otherwise conventional elements. It is conventional to provide external of the tube envelope a series of permanent magnets or an electrical solenoid to provide a focusing magnetic field, $\vec{B}$, axial of helix 7. For clarity this magnetic structure is not illustrated in detail, but is understood and is represented merely by the magnetic vector $\vec{B}$ in the figure.

In one conventional mode of operation of the O-type traveling wave tube a signal of electromagnetic energy, typically in the microwave frequency range, is coupled to terminal 9. A load or other circuit which uses the microwave signal is connected to output terminal 11. The microwave energy propagates along the helix from the input to the output terminal at a predetermined velocity. Relative to cathode 1, accelerating anode 3 although grounded is at a high positive voltage, V , creating a large electric field $\vec{E}$ illustrated, which acts to attract and accelerate electrons from cathode 1. The cathode emits electrons which are formed into a beam and are accelerated toward the anode. These electrons pass through passage 5 in anode 3 and, at the predetermined velocity, enter the region within the passage formed by the helix 7 or "interaction" region as variously termed. In this region the electrons in the beam interact with the electromagnetic energy which is applied to the helix input terminal and propagates along the helix at approximately the same velocity at which the entering electrons are traveling. The electromagnetic "interaction" results in the transfer of energy from the electrons to the wave, causing the electrons to slow down or decrease in velocity. Axial magnetic field $\vec{B}$ serves to prevent electrons from traveling in a transverse direction into the helix and hence prevents "beam spreading."

Ideally the slowed electrons proceed to pass through the helix on a collision course with collector 13. In the depressed collector arrangement illustrated in FIG. 1 both the helix and the metal shield 15 are electrically at ground potential while collector electrode 13 is, relative to the foregoing elements, at a high negative voltage, suitably $V/2$. This provides an electric field, $\vec{E}_2$, between the collector 13 and the entrance to the shield 15 and the helix 7 in a direction which repels the electrons or, more accurately, causes deceleration of the approaching electrons. The electrons thus are slowed down in the space between the shield entrance and collector 13 through a potential difference of $V/2$ and collide with collector 13 through which the electrons are returned to the appropriate power supply 19.

In striking the collector the electron's kinetic energy is released at collector 13 in the form of heat and the heat is conducted away through the collector by a heat conducting path through supporting insulators 16 and through shield 15 and therethrough to any appropriate heat sink, not illustrated.

The simple representations in the foregoing schematic of FIG. 1 amply illustrates both the utility of the collector shield assembly and the necessary practical considerations involved in its design. First, an electrical voltage on the order of $V/2$ or 3,000 volts exists between the collector 13 and shield 15 in the cited example so that collector 13 must be mounted within shield

15 with structure that maintains properly electrical isolation or insulation therebetween. Secondly, the heat generated at the collector by the colliding electrons must be removed via a heat conducting thermal path to an appropriate external heat sink to avoid damage to the tube.

Moreover while it has been chosen to illustrate the utility of a collector shield assembly in connection with the O-type traveling wave tubes, its utility in connection with other types of microwave tubes, particularly the klystron, is apparent. While the mode of operation of the klystron is different from that of the traveling wave tubes, its use of a traveling beam of electrons creates all the similar problems and prior art solutions regarding heat dissipation and voltage insulation with any of the included depressed collectors. Accordingly, the generality of application of the novel collector-shield assembly of the invention is understood by the reader, without the need to detail the mode of operation of that conventional tube.

The preferred embodiment of the improved collector shield assembly of the invention is illustrated in cross section and in somewhat greater detail in FIG. 2. It is understood as the preceding description notes that the collector shield assembly hereinafter described is to be incorporated to the metal envelope of an otherwise conventional traveling wave tube suitably by brazing. Inasmuch as the details of those elements are conventional and do not add to the understanding of the present invention such details are neither illustrated or further described.

The assembly includes a first hollow metal cylindrical member 21, suitably copper. Cylinder 21 corresponds to the metallic shield member 15 symbolically represented and discussed in connection with the schematic of FIG. 1. A second hollow cylindrical member 23, also a metal, suitably copper and of a smaller outer diameter, is concentrically mounted within cylinder 21. A collector nose assembly 25 of cylindrical geometry suitably constructed of molybdenum, a metal which resists heat erosion, is provided and is brazed to a rim 26 formed at the left end of cylinder 23. Nose assembly 25 contains a cylindrical passage 27 which during tube operation permits entry of electrons into cylinder 23. A collector plug 29 having a generally cylindrical outer shape suitably of a metal, and preferably copper, is provided. The plug is brazed to rim 30 and enlarged wall portions formed within the hollow of cylinder 23. Collector plug 29 as is typical includes a conical hollowed out portion and serves to plug the end of the cylinder. Collector cylinder 23, collector plug 29, and nose assembly 25 essentially completes the collector electrode and corresponds essentially to the collector 13, schematically represented in FIG. 1.

A hollow cylindrical member or extension sleeve 31, suitably of copper, is brazed in place to rim 32 and enlarged wall portion formed in cylinder 21. An electrically insulative window 35, suitably of aluminum oxide, is brazed in place within a ringlike metal sleeve 33. A metal terminal 37 extends through and is hermetically sealed within the window. These elements are termed the cup and wall assembly and this assembly is brazed in place at the wall of 33 to sleeve 31 to form a vacuum tight seal. An electrical lead 39 connects plug 29 in electrical contact with terminal 37.

A metal flange 41, suitably of Kovar, is brazed to rim 42 within a bored out portion of cylinder 21. Flange 41

contains an opening 43 which in tube operation permits passage of electrons into the collector. It is noted that the flange forms the means by which the collector assembly in practice is joined to other conventional elements of the elongated tube structure, particularly to the cylindrical metal envelope containing the helix, forming the traveling wave tube and schematically represented in FIG. 1.

A plurality of discreet spaced indentations 43 are formed within the inner cylindrical surface of cylinder 21. In the cross section of FIG. 2 two rows of these indentations are visible with each of the rows extending parallel to the axis of cylinder 43. Numerous other rows of spaced indentations are spaced around the inner periphery of this cylindrical surface and the indentations in any one row are spaced axially to fall in between the indentations of adjacent rows of indentations. Essentially indentations 43 are spaced all about and along the inner surface of the shield cylinder.

Correspondingly, a plurality of discreet spaced indentations 45 are formed within the outer cylindrical surface of the collector cylinder 23. As before, two rows of these indentations are visible in the cross section of FIG. 2 with each of the rows extending parallel to the axis of cylinder 23 and numerous additional rows are spaced around the outer periphery of the cylindrical surface with the indentations forming any one row spaced axially so as to fall in between the indentations of adjacent rows. Essentially indentations 45 are spaced all about and along the outer surface of the collector cylinder.

As is apparent, each indentation 43 has a corresponding indentation 45 in axial and radial (angular) alignment which forms a pair of indentations opposed or facing each other across the generally cylindrical annular space between the concentrically oriented cylinders 21 and 23. A plurality of balls or spheres 47, as may be variously termed, are fitted and located between the inner wall of cylinder 21 and outer wall of cylinder 23 and form the spacers between the cylinders. The spheres are of a dielectric or electrically insulative, as variously termed, and hard material which is an electrical insulator, a good heat conductor, and which can withstand large compressive forces without fracturing. A dielectric ceramic material, such as aluminum oxide or beryllium oxide, is used in the preferred embodiment. The spherical shape is desired since such a geometry best withstands compressive forces. In the preferred embodiment spheres 47 are essentially of the same diameter, $2R$, and are fitted within and between the opposed indentations in the respective cylinder walls. Suitably the shape of each indentation is such as to maintain a good mechanical contact between the surface of the balls received therewithin and is suitably a sphere segment so as to have contact fully over the area of the sphere surface embedded therein. In the preferred embodiment of FIG. 2 each of the indentations 45 are substantially of the same geometry and size. Likewise the indentations 43 in cylinder 21 are substantially all of the same geometry and size. The geometry of each of the indentations is that of a segment of a sphere of radius R , which corresponds with the geometry and size of ceramic spheres 47. Preferably the depth of each respective indentation in each wall is less than one-half the radius of the spheres primarily to maintain spacing between the cylinders and

desirably the depth of indentation on the order of $R/2$, where R is the sphere radius as is found in FIG. 2.

Essentially the spheres are seated or embedded in each cylinder between opposed indentations 43 and 45. The embedded spheres are maintained between the walls of cylinders 21 and 23, preferably, in compression at room temperature and are maintained in compression during normal tube operation. A sufficient number of ceramic balls 47 are located throughout the annular space in between cylinders 21 and 23 and maintain cylinders 21 and 23 electrically insulated from each other while maintaining the largest number of good heat conducting paths therebetween.

The relationship between the ceramic balls, shield and collector is perhaps better understood and easier to visualize from consideration of the following description of the novel and preferred method of manufacturing the collector shield assembly.

It is noted at this point that elements which in the figures hereafter discussed correspond to the elements of FIG. 2 are labeled with the same numerals but are primed. In this way the illustrations are more helpful in aiding the understanding of the reader. In addition, for purposes of clarity of illustration, the number of ceramic balls is reduced and the length of the collector assembly and the geometric relationships are exaggerated in the interests of providing better visualization of the invention.

The copper cylinders 21' and 23' are cut to size from stock with cylinder 23' having a slightly greater length than 21'. The diameters of the cylinders by design are such that the desired annular space is of the desired width when the cylinders are concentrically arranged as illustrated in FIG. 3a. Prior to initial assembly both cylinders are annealed to soften them so that they possess a desired softness. While it is preferred for the cylinders to be of the same hardness, it is also possible for inner cylinder 23' to be annealed to a greater extent so that it is softer than outer cylinder 21'. In addition ceramic balls 47' are thoroughly cleaned by appropriate means to eliminate any dirt or other particles.

Initially, cylinder 23' is fitted concentrically within cylinder 21' and an O-ring seal 51 is inserted in the annular separating space 52 to temporarily support the cylinders in the relationship illustrated in FIG. 3a and to provide a plug at this end of the space. Thereafter ceramic spheres 47' are deposited within the space and the assembly is tapped gently after each addition to ensure that the balls properly fall into place and nest. The nesting initially of the ceramic balls is better illustrated in FIG. 3b which shows a certain portion of balls 47' stacked or nesting.

After filling the space to the desired level with ceramic balls 47', a second O-ring seal 53, as illustrated in FIG. 3c, is inserted at the upper end to plug that end of the annular space. Thereafter a copper washer 54 is inserted at the upper end of the assembly to close or plug that end and compress the O-ring seal. A second copper washer 55 is inserted at the bottom end. The copper washers are then staked in place and the ends of the unit are painted with an acrylic binder to seal same.

The unit so assembled is put into a split die that has a net fit to the outer diameter of the outer cylinder 21' as illustrated in FIG. 4a. This die consists of a cylindrical member 56 surrounding cylinder 21' with a disklike top end 57 and bottom end 58, each of which has an

opening to permit access to the inner passage of cylinder 23'. A polyurethane slug 58 which just fits within and extends approximately over the length of cylinder 23' is inserted therewithin and a pair of punches 59 and 60 are inserted through die disks 57 and 58, respectively, into abutment with the ends of the polyurethane slug. The entire assembly is thereafter placed into a press. The press applies forces to punches 59 and 60, represented by the symbol F , while holding the die and end disks 57 and 58. In so squeezing the polyurethane slug, the slug "bulges" and applies a radial or expanding force upon the walls of cylinder 23', which in turn exerts similar high pressures upon ceramic balls 47'. This pressure is very large and may reach on the order of 40,000 psi. Inasmuch as the ceramic balls are relatively rigid and incompressible and capable of withstanding compressive forces about 340,000 psi for aluminum oxide and 275,000 psi for beryllium oxide while the copper forming cylinder 23' is relatively soft in relation thereto, the outer surface of inner cylinder 23' yields and in all or part permanently deforms to form sphere-segment shaped indentations which mate with abutting surface of balls 47'. Otherwise stated the balls 47' become embedded in outer wall of cylinder 23'. Desirably the balls are embedded within outer wall of cylinder 23' to a depth of $R/2$, where R is the radius of the balls 47'. Some slight indentation also occurs in the inner surface or wall of cylinder 21' but it is desired to more fully indent same as is more fully discussed hereafter.

FIG. 4b better illustrates a small cutaway portion in cross section showing a portion of cylinder 21', cylinder 23', and ceramic balls 47' at the conclusion of the squeezing operation just discussed, in which the balls are shown penetrating to a depth into the outer wall of cylinder 21' and corresponding sphere segment mating indentations are formed in cylinder 21'.

Thereafter the fixture and assembly are removed from the press, the punches 59 and 60 are removed, the polyurethane slug 58 is withdrawn, and the collector assembly is removed from the die elements 57, 56 and 58.

FIG. 5a illustrates schematically a sizing die 61. The sizing die contains a passage which diminishes in diameter from one radius at its entrance to a smaller radius at its exit, and in this instance is cylindrical to correspond to the outer diameter of cylinder 21' of the collector assembly. The collector assembly of FIG. 4b is then inserted into sizing die 61 as illustrated in FIG. 5a. A pressing jig 63 is applied to the top of the assembly and with a press a force, F , is applied to push the collector assembly through the passage 62 in sizing die 61. In so doing, the outer walls of cylinder 21' are placed under large radial compressive pressures and are squeezed together to reduce its radial dimension.

While the foregoing sizing operation is described here as a one-step operation, it is apparent that the desired reduction in diameter of cylinder 21' can be accomplished by a series of operations in which consecutively smaller sizing dies corresponding to sizing die 61 are employed.

The compressive forces exerted upon outer cylinder 21' are reflected along its inner wall surface and in turn the large compressive forces are applied to the enclosed ceramic balls. As before the ceramic balls are relatively more rigid and incompressible than (and inner cylinder 23' is of a greater hardness than) outer

cylinder 21', the inner wall of cylinder 21' yields at each location of a ceramic ball to form a sphere segment shaped indentation which mates with or embeds, as variously termed, the abutting surface of the balls within the inner wall of the outer cylinder 21' as illustrated in FIG. 5b. As before, this step in turn causes some slight further indentation in the outer wall of inner cylinder 21'. The depth of each such indentation or embedding depends, of course, upon the amount of size reduction which by design is desired. In the preferred embodiment of the invention it is desired to embed in both the inner and outer walls of cylinders 21' and 23', respectively, to a depth approximately equal to $(\frac{1}{2})R$, where R is the radius selected for the ceramic spheres 47'. During the foregoing process the balls spread apart somewhat with some small clearance between them and not with the close packing heretofore represented in FIG. 3b.

It is noted that the indentation in cylinder 23' in which an individual ball 47' is seated or fitted is axially, angularly, and radially aligned (from the cylinder axis) with the indentation in cylinder 21' in which the other side of ball 47' is seated or fitted.

It is possible to reverse these steps and first compress outer cylinder as desired. With special equipment, moreover, it is possible to expand inner cylinder 23' at the same time that cylinder 21' is being compressed.

As is apparent, design considerations permitting, it is also possible to eliminate one of the aforementioned embedding steps. Thus only the expansion or squeezing steps need be used if the slight embedding within one of the cylinders is acceptable.

The foregoing completes the novel aspects of the method by which the ceramic spheres are fitted within indentations and held in between the cylinders 21 and 23. All that remains is the finishing operation for adapting the structure constructed into the completed anode assembly of FIG. 2. Accordingly, reference is made to FIG. 6. As previously noted, liberty was taken in the foregoing description and illustration of reducing the size and number of elements in the exemplary structure. In FIG. 6, however, the illustration corresponds more closely with the completed anode structure of FIG. 2. In the final operations the ends of the assembly are sawed off. This eliminates the copper washers 55 and 54 in FIG. 3c and evens up the size or length of the cylinders 21 and 23'. The cut is not enough to cut away O-ring seals 51' and 53' which are retained in place. Thereafter the right end of the assembly is bored to provide a rim 32' along the surface of cylinder 21'. In addition, the inner cylinder 23' is also bored to form a rim 30' at the right hand side of FIG. 6. Two additional borings are made to form rim 42' in outer cylinder 21' and rim 26' in inner cylinder 23'. The O-ring seals, retained in place, prevent any metal chips from entering the annular space during boring. Upon completion of boring they are removed. Thereupon the plug assembly 29 and output window assembly elements 31, 33, 35, 37 and 39 are assembled in place as are the collector nose assembly 25 and flange 41, as previously described in connection with FIG. 2. These elements are then brazed in place to complete the operations resulting in the improved collector assembly illustrated in FIG. 2.

In operation the shield cylinder 21 of FIG. 2 is placed at electrical ground potential and the collector cylinder 23 is placed at a high negative voltage relative to the

shield. This creates the electric field, discussed in connection with the operation of the traveling wave tube in FIG. 1, between the nose 25 and shield flange 41 in a direction that decelerates approaching electrons.

While the distance in the figure appears to be small it is sufficient to decelerate the electrons. In comparison it is noted that the decelerating distance is on the same order of distance through which the electron is initially accelerated by the accelerating anode as discussed in connection with FIG. 1. Thus electrons which exit from the helix 7 of FIG. 1 are decelerated to a lower velocity and enter the assembly at the entrance 43 of flange 41 and passage 27 in the nose assembly 25 of collector 23. Within this inner hollow of cylinder 23 the electron finds itself in a field free region where it is neither attracted or repelled and is free to travel into the cylinder walls of cylinder 23 or to continue and be collected in the tapered portion of collector plug 29. The electrical circuit for the electrons continues through the plug, electrical lead 39, electrical terminal 37 to the appropriate terminal of the power supply not illustrated in this figure through which the high electrical voltage is applied to the collector. The traveling electrons release any kinetic energy upon collision with the collector and thereby generates heat. The heat raises the temperature of collector 23. However a thermal heat conducting path is maintained between the metal walls of cylinder 23 through each of the ceramic balls 43 to the outer metal cylinder 21 comprising the shield. By suitable means, not illustrated, such as heat fins attached to shield 21 or a water cooling jacket, the heat in turn is passed to a heat sink maintained at a lower temperature.

In being heated the cylindrical collector 23 expands both radially and linearly. In expanding radially the outer surface of cylinder 23 presses against the ceramic balls 47 and presses them tightly against the outer cylinder 21. During operation the balls are thus maintained in compression and ensures good contact between the cylinder and ceramic balls 47. As previously noted, the ceramic balls are relatively hard, rigid, and incompressible and withstand these high compressive forces. By contrast it is noted that in the structures of the prior art the ceramic material was placed under various tensile stresses, and ceramic material, while being able to withstand compressive forces, does not possess the ability to withstand adequately equivalent tensile forces.

In part, the ability to withstand compressive forces is due to the spherical shape of the balls. While it is apparent that the balls can be of other shapes and depart from spherical in geometry and still be within the invention, the sphere is long noted as the preferred geometry for withstanding compressive forces. As was previously noted in connection with the description of the structure, the shape of the indentations 43 and 45 in cylinders 21 and 23, respectively, is a sphere segment and mates with and embeds the surface portion of the corresponding embedded ball to maximize the area of contact and hence the size of the available heat path. The expansion of the inner cylinder 23 and compression of the sphere ensures a good physical mating contact and thus acts to improve a good thermal heat path between the collector electrode and the shield and thus reliably maintain the thermal heat transfer characteristic of the connector throughout the life of the tube. Moreover, because of the identical construction from

tube to tube and the physical reliability of the construction definite reproducible results are obtained.

As a result of the novel manufacturing process used to obtain the indentations and embedding of the spherical balls as heretofore described, it is noted that even at room temperatures many or all of the balls may be snugly seated or in compression, even if slightly. The indentations were formed by expansion of the inner cylinder 23 and compression of the outer cylinder 31. As each metal cylinder surface yields to form the indentation, effecting generally permanent deformation, there is still a possible additional range where the yield limit of the cylinder surface material is not exceeded. Thus some additional back portion of such indentation may retain some flexibility and is not permanently deformed. In this, therefore, the balls may be held in compression by the opposed cylindrical surfaces. Because the radius of the ceramic spheres is larger than the distance between the surface of the respective cylinders, outside the distance between opposed indentations, the balls cannot move out of the seat and hence remain in position. Alternatively, because the balls cannot move out of the seat it is apparent that it becomes impossible with normal force to move the outer cylinder 21 traversely with respect to the inner cylinder 23.

Thus the spacing spheres are installed without a braze. The absence of brazing material is a significant and distinct advantage in that a greater voltage insulating characteristic or standoff voltage is provided for the same collector cylinder to shield cylinder spacing than was heretofore available with prior art constructions. The brazing material used to join the metal cylinders to the ceramic insulator contains sharp edges microscopically which reduces the voltage breakdown or standoff characteristic for the apparent spacing. In addition the brazing operation inherently effects penetration into the ceramic insulator with metal brazing material which reduces further the effective cylinder to cylinder spacing and hence reduces the voltage standoff characteristics. The mere elimination of brazing material from the collector without any other change in tube structure improves the standoff voltage rating for a given collector spacing on the order of 50% which minimizes electrical arcing between the collector and shield and, alternatively, permits an increase in the decelerating voltage applied to the collector with effects noted hereinafter.

A further significant result is noted. The power output capability of a depressed collector O-type traveling wave tube is limited directly or indirectly to the heat dissipating or transfer characteristic, hence, size of the collector electrode and shield assembly. The more power output to be dissipated the larger and larger the collector can become until it becomes physically impractical for an amplifier system manufacturer to incorporate the tube of that power output level due to physical size and weight problems.

The structure of the present invention permits the collector cylinder such as 21 to have a thick wall construction or a wall thickness greater than that which could be properly used in the prior art structures. In the prior art structures design considerations required the wall to be relatively thin so as to be somewhat flexible. Thus under normal expansion forces during collector heating the tensile stress on the braze between the ceramic insulator would be minimized and not torn away.

However the thinness limited the capability of the collector to uniformly transfer heat.

The increase in the thickness dimension of the collector wall which can be used as a direct result of the elimination of brazes and braze bonds, seemingly minor, increases the size of the thermal path and thus permits the heat generated by electron collisions at any point along the collector to be quickly and uniformly dissipated or transferred over the entire collector to a heat sink. This change in dimension alone permits the input power to the collector and, hence, the output power of a collector of a given size to be increased on the order of 50 percent, other factors remaining constant and without any noticeable increase in the overall size or weight or geometry of the O-type traveling wave tube.

In addition the voltage insulation or standoff voltage between the collector and shield increases on the order of 50 percent with no noticeable change in spacing between collector and shield as a direct result of the elimination of the metal braze as previously noted. Thus by increasing both the decelerating voltage and the anode voltage typically on the order of 50% in a traveling wave tube with, of course, suitable adjustment in the pitch of the helix, and maintaining essentially the relationship between collector and anode voltage of $\frac{1}{2}$ to 1, and the same given collector shield assembly tube is used which thus permits without change in collector or tube size, weight or geometry of any significance a traveling wave tube capable of operation at output powers on the order of 50% larger than before.

Combining the foregoing separately discussed results, a 100% increase in the output power of the traveling wave is obtained without increase essentially in the size, geometry or weight of the tube.

The foregoing advantageous results are combined with the advantage that the collector operation is uniform throughout the entire life of the tube, will not burn out due to any association with the collector and provides consistent results from tube to tube during mass production.

The adoption of this structure avoids and eliminates wholly the problems of heat dissipation in collectors which have heretofore existed and thus permits an increase reliably in the output powers that can be obtained from O-type traveling wave tubes with depressed collectors. Moreover, because of its definite and certain construction the structure is the same from tube to tube, and because of the absence of cracking or the possibility of cracking of the ceramic insulating material the tubes so constructed remain reliable in this respect throughout their normal operating life and, in addition, the tubes are consistent from tube to tube during production.

The preferred embodiment has been presented as illustrative of the invention and not by way of limitation. As is apparent many changes in details, additions, substitutions and equivalents suggest themselves to one skilled in the art upon review of this specification which do not depart from the spirit and scope of the disclosed invention. Accordingly, it is understood that the invention is to be broadly construed and limited only by the breadth and scope of the appended claims.

What is claimed is:

1. The method of supporting together in concentric relationship a metal shield of hollow cylindrical geometry and a metal collector electrode having a hollow cy-

lindrical geometry of a smaller radius, comprising the steps of

- a. placing the shield and collector electrode in concentric relationship to provide an inner cylinder with said collector electrode and an outer cylinder with said shield and defining a cylindrical annular space therebetween;
- b. filling the space therebetween with a plurality of relatively incompressible ceramic spheres of the same predetermined radius; and
- c. forcing outward the outer cylindrical surface of the collector electrode and forcing inward the inner cylindrical surface of the shield to embed said balls in said outer and inner surfaces and retain said balls therebetween bridging the annular space between such surfaces.

2. The method of supporting together in concentric and electrically insulated relationship two metal cylinders comprising the steps of

- a. placing said cylinders in concentric relationship to provide an inner cylinder and outer cylinder;
- b. filling the space between said inner and outer cylinders with a plurality of relatively incompressible dielectric ceramic spheres having substantially the same predetermined radius;
- c. forcing outwardly the outer surface of said inner cylinder while confining the outer surface of said outer cylinder to embed said balls primarily in said outer surface of said inner cylinder; and
- d. forcing inwardly the inner surface of said outer cylinder to embed said balls primarily in said inner surface of said inner cylinder; whereby said balls are embedded in the surfaces of both cylinders and are thus fixed in location and support concentrically and insulate electrically said cylinders.

3. The method of supporting together in concentric electrically insulated relationship two metal cylinders comprising the steps of:

- a. placing the cylinders in concentric relationship to provide an inner cylinder and an outer cylinder and defining therebetween a cylindrical annular space;
- b. filling the annular space with a plurality of relatively incompressible small ceramic balls, each of said balls having the same predetermined radius approximately equal to the thickness of said annular space; and
- c. embedding said ceramic balls to predetermined depths in the opposed surfaces of said cylinders.

4. The method as defined in claim 3 wherein the step of embedding includes the step of expanding radially said inner cylinder, said inner cylinder being of a material softer than the hardness of said ceramic balls.

5. The method as defined in claim 3 wherein the step of embedding includes the step of squeezing radially said outer cylinder, said outer cylinder comprising a material softer than the hardness of said ceramic balls.

6. The method as defined in claim 3 wherein the step of embedding includes the steps of expanding radially said inner cylinder and squeezing radially said outer cylinder simultaneously, said balls being of a relatively greater hardness than said cylinders.

7. The method as defined in claim 3 wherein the step of embedding includes the steps of squeezing radially said outer cylinder and then expanding radially said inner cylinder, said balls being of a relatively greater hardness than said cylinders.

8. The method as defined in claim 3 wherein the step of embedding includes the steps of expanding radially said inner cylinder and then squeezing radially said outer cylinder, said balls being of a relatively greater hardness than said cylinders.

9. The method of supporting together in electrically insulated and in heat conductive relationship two metal cylinders, comprising the steps of:

- a. placing the cylinders in concentric relationship to provide inner and outer cylinders and define therebetween an annular space;
- b. filling the annular space with a plurality of relatively incompressible dielectric thermally conductive ceramic spacer means; and
- c. embedding said spacer means to predetermined depths in the opposed surfaces of said cylinders.

10. The method of supporting together in concentric and electrically isolated relationship a first hollow metal cylinder and a second hollow metal cylinder of a smaller radius by means of small dielectric ceramic balls, said ceramic balls being hard and relatively incompressible, comprising the steps of

- a. placing said second cylinder within concentric relationship with said first cylinder to provide inner and outer cylinders and a cylindrical annular space therebetween;
- b. filling said annular space between the opposed cylindrical surfaces of said cylinders with a plurality of dielectric ceramic balls, said balls being relatively incompressible and of a uniform diameter slightly less than the thickness of said annular space;
- c. confining the outer surface of said outer cylinder in a die to prevent radial expansion thereof;
- d. inserting a polyurethane rod within said inner cylinder;
- e. applying pressure to at least one end of said polyurethane rod to cause said rod to bulge and provide a radial outward force along the inner surface of said inner cylinder sufficient to cause the surface thereof to expand and yield at the locations of and around said ceramic balls forming in said surface a plurality of sphere-segment indentations;
- f. removing said pressure, rod, and confining means;
- g. forcing said assembly of outer and inner cylinders through at least one sizing die, said die having an entrance for receiving the outer surface of said outer cylinder and an exit of smaller diameter than the outer diameter of said outer cylinder to cause a radially inward force on the surfaces of said outer cylinder sufficient to cause the inner surface thereof to yield around said ceramic balls forming in said surface a plurality of sphere-segment indentations, whereby the indentations in opposed cylindrical walls seat corresponding balls and said balls cannot move out of said seat.

11. The method of manufacturing a collector subassembly in which a collector is mounted within a shield and is electrically insulated therefrom but in heat conductive relationship therewith for use in a microwave tube which includes the steps of:

- a. placing first and second open hollow metal cylinders in concentric spaced relationship to define inner and outer cylinders and a cylindrical annular space therebetween;
- b. plugging one end of said annular space with first retainer means;

- c. inserting a plurality of relatively incompressible dielectric ceramic balls of a uniform diameter approximately slightly less than the thickness of said annular space within said annular space to fill said annular space to a predetermined level; 5
 - d. plugging the remaining end of said annular space with second retainer means thereby preventing said balls from exiting from said annular space or dirt from entering said annular space; 10
 - e. embedding said balls to a predetermined depth in each of the opposed cylinder surfaces bordering said annular space to fix the spacing between said cylinders and fix the location of said balls; 15
 - f. finishing said assembly of inner and outer cylinders to desired dimensions; and
 - g. removing both said retainer means.
12. The method as defined in claim 11 wherein the step of embedding comprises further the steps of:
- e1. confining the outer surface of said outer cylinder in a die to prevent radial expansion thereof and 20
 - e2. inserting a polyurethane rod within said inner cylinder to fill substantially said inner cylinder; 25
 - e3. applying pressure to the ends of said polyurethane rod sufficient to cause the rod to bulge and force radially outward said outer surface of said inner cylinder causing said wall to yield around said ceramic balls to a predetermined depth and force said balls to indent slightly said inner surface of said outer cylinder; and
 - e4. removing said pressure, said rod, and said die. 30
13. The method as defined in claim 11 wherein the step of embedding comprises further the steps of:
- e1. forcing the assembly of said inner and outer cylinder through a sizing die, said die having an en-

- trance for receiving the outer surface of said outer cylinder and an exit of a smaller diameter of said outer cylinder to cause a radially inward force on said outer cylinder and the inner surface thereof to yield around said ceramic balls forming in said surface a plurality of indentations and causing said balls to indent slightly the outer surface of said inner cylinder.
14. The method as defined in claim 11 wherein the step of embedding comprises further the additional steps of:
- e5. forcing the assembly of said inner and outer cylinder through a sizing die, said die having an entrance for receiving the outer surface of said outer cylinder and an exit of a smaller diameter of said outer cylinder to cause a radially inward force on said outer cylinder and the inner surface thereof to yield around said ceramic balls forming in said surface a plurality of indentations and causing said balls to further indent slightly the outer surface of said inner cylinder.
15. The method as defined in claim 14 wherein the step of finishing further comprises the steps of:
- f1. sizing said cylinders to a uniform length without removing said retainer means;
 - f2. successively boring said inner cylinder to shorten said inner cylinder relative to the length of said outer cylinder without removing said retainer means; and
 - f3. boring out predetermined end portions of inner and outer cylinders to form rims at predetermined locations therein.

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