Aug. 15, 1961 J. A. McCULLOUGH ET AL 2,996,347

METHOD AND APPARATUS FOR MAKING ELECTRON TUBES

Filed Dec. 5, 1957 3 Sheets-Sheet 1

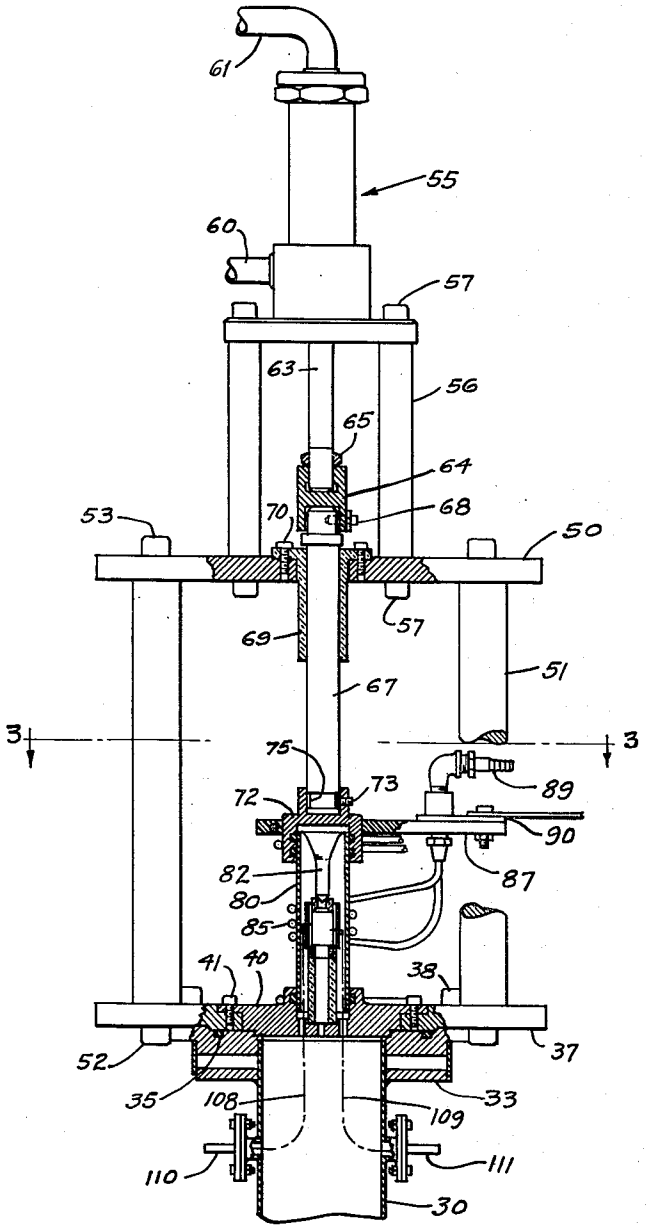


Fig. 1

INVENTORS.
Jack A. McCullough
BY William R. Stuart

Leon F. Herbert
ATTORNEY

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3 Sheets-Sheet 2

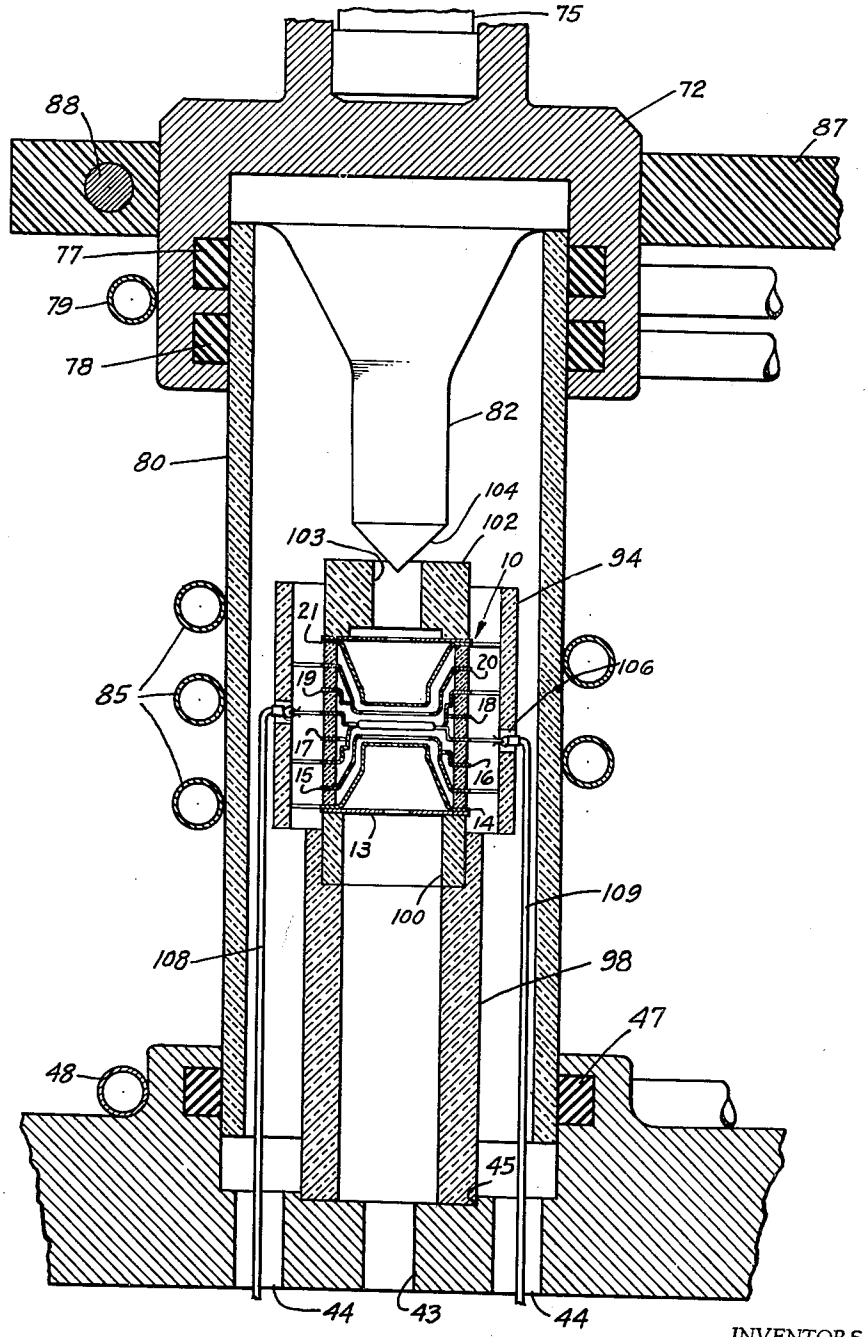


Fig. 2

INVENTORS.
Jack A. McCullough
BY William R. Stuart

Leon F. Herbert
ATTORNEY

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Filed Dec. 5, 1957 3 Sheets-Sheet 3

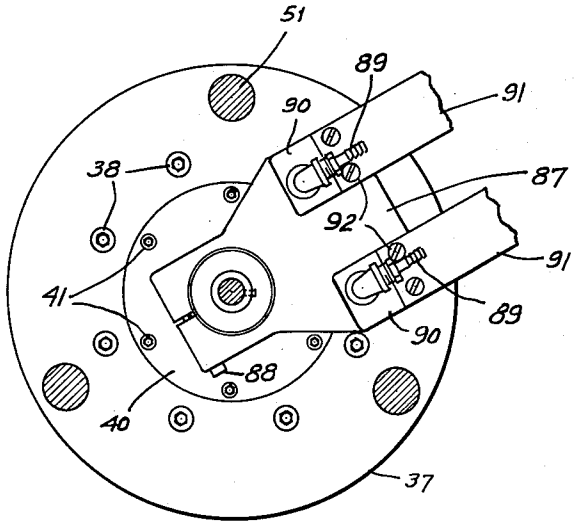


Fig. 3

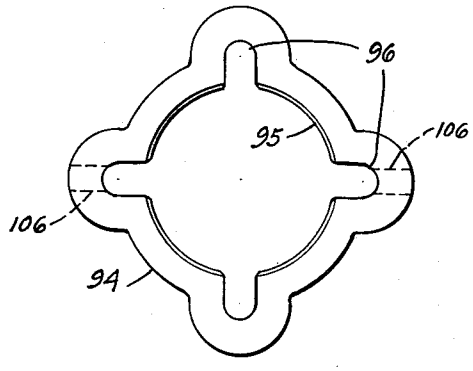


Fig. 4

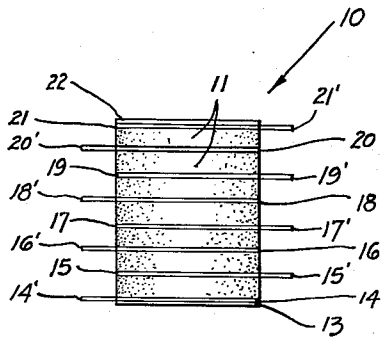


Fig. 5

INVENTORS.
Jack A. McCullough
BY William R. Stuart

Leon F. Herbert
ATTORNEY

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Patented Aug. 15, 1961

2,996,347

METHOD AND APPARATUS FOR MAKING ELECTRON TUBES

Jack A. McCullough, Los Altos, and William R. Stuart, Millbrae, Calif., assignors to Eitel-McCullough, Inc., San Bruno, Calif., a corporation of California

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10 Claims. (Cl. 316—19)

This invention relates to a method for making electron tubes and to apparatus for performing the method. More specifically, the invention relates to a method and apparatus for making electron tubes having pressure seals. The term "pressure seal" is defined for use herein as a permanent, vacuum-tight seal obtained by the application of pressure at temperatures below the melting point of any of the materials in the seal.

The construction of electron tubes is such that practically all types have a shell or envelope involving at lease two sections sealed together along an annular joint. In the past it has been standard practice to join envelope sections by means of fused or melted bonds, such as the conventional braze or weld joint. It has previously been proposed that a vacuum-tight seal could be made at temperatures below the melting point if the surfaces to be joined were given an optical polish. This optical polish technique has never been adopted commercially for a number of reasons including the fact that optical polishing is expensive.

The present invention has as a basic object the teaching of a method and apparatus by which electron tubes can be made with pressure seals on a commercially practical basis.

A more specific object of the invention is to provide a pressure sealing method and apparatus having a very short processing cycle. An associated object of the invention is to provide a pressure sealing method and apparatus in which heating of the seal is accomplished by inducing an RF current directly in the metal surfaces to be sealed together.

A further object of this invention is to provide a pressure sealing method and apparatus which does not involve the expense of obtaining an optical polish on the surfaces to be joined.

An additional object of the invention is to provide a pressure sealing method and apparatus which eliminates need for the usual exhaust tubulation on tubes. An associated object is to provide a pressure sealing method and apparatus which combines into a closely related system and apparatus for formation of the pressure seal and the normal tube processing procedures such as exhaust, bakeout, and cathode formation.

Another object of the invention is to provide an electron tube having an envelope comprising two members joined together by a pressure seal.

In essence, the invention resides in the making of electron tube pressure seals by the application of high pressures and high temperatures in a vacuum. Although high temperatures are utilized they are of course below the melting point of any of the materials involved in making the seal.

The invention possesses other objects and features of advantage, some of which, with the foregoing, will be set forth in the following description of the invention. It is to be understood that the invention is not limited to the disclosed species, as variant embodiments thereof are contemplated and may be adopted within the scope of the claims.

FIGURE 1 is a side view partly in section showing a vacuum chamber and pressure exerting ram in accordance with the invention. An electron tube is shown in the

chamber and the ram is positioned in pressure exerting contact therewith;

FIGURE 2 is a cross-sectional view showing the vacuum chamber of FIG. 1 on an enlarged scale. The tube is shown in cross section, and the position of the ram is such that it is not exerting pressure on the tube;

FIGURE 3 is a view on the line 3—3 of FIGURE 1;

FIGURE 4 is an enlarged top view of the tube holding jig of FIGURES 1 and 2; and

FIGURE 5 is a side view of a completed tube of the type shown in FIGURE 2.

Referring to the drawings in more detail, FIGURE 5 shows an example of a tube **10** made by the method and apparatus of the invention. The particular tube shown in the drawings is cylindrical in shape and has an envelope wall made of a plurality of ceramic rings **11** and a plurality of metal rings **13–22**. FIGURE 2 shows the tube **10** in cross-section, and the construction of the tube can be best understood by viewing both FIGURES 2 and 5. It will be noted that the tube is a double triode so that metal rings **14** and **21** both form anodes at the ends of the tube. Metal rings **15** and **20** form supports for control grids; rings **16** and **19** form cathode supports; and rings **17** and **18** form leads for the single heater which is inside the double cathode. The end rings **13** and **22** are merely to protect the anode rings against damage. Each of the electrode rings is provided with a terminal tab for which primed reference numerals are employed. The terminal tabs are arranged in two diametrically positioned rows.

Although a specific tube has been disclosed for convenience in describing the method and apparatus, it will be understood that other tube configurations can be made by the invention.

Coming now to the apparatus of the invention, FIGURE 1 discloses the stand pipe **30** of a conventional exhaust pumping system (not shown). At the upper end of pipe **30** a water cooled mounting disk **33** is attached as by brazing, and a sealing ring **35** is seated in a recess on the upper surface of the disk. A support ring **37** is attached to disk **33** by means of screws **38**. A base member or plate **40** is mounted in the center of support ring **37** by means of screws **41**. As shown best in FIGURE 2, the base plate **40** has a central aperture **43** and two side apertures **44**. In addition, the plate **40** has a central seating recess **45** and an annular recess in which sealing ring **47** is positioned. A coil of tubing **48** encircles plate **40** in the area of seal **47** to permit cooling of the seal.

A platform **50** is mounted on support ring **37** by means of three rods **51** which are attached to ring **37** by screws **52** and the platform **50** by screws **53**. In turn, platform **50** supports a conventional hydraulic cylinder and piston unit **55** by means of three rods **56** held in place by screws **57**. The cylinder and piston is connected by pipes **60** and **61** to a conventional hydraulic pumping system (not shown).

A piston rod **63** extends down from the unit **53** and is threaded into a coupling **64** and fixed by lock nut **65**. A rod **67** is accurately guided by a bushing **69** which is mounted on platform **50** by screws **70**. Rod **67** fits into coupling **64** with considerable play in order to accommodate any misalignment between bushing **69** and the piston rod **63**. A coupling **72** is mounted on the end of rod **67** where it is held in place by a screw **73** which engages a recessed wall portion **75** on rod **67**. The rod **67** has an accurately machined close fit in coupling **72**, and the recess **75** is provided so that the screw **73** will not roughen the accurately machined portion of the rod.

The lower end of coupling **72** has a recessed portion lined with two sealing rings **77** and **78**. A cooling tube **79** is attached to coupling **72** to prevent heating of the

sealing rings. A glass cylinder **80** is held in the end of coupling **72** by frictional engagement with sealing rings **77** and **78**. A ram **82** is held wedged between the recessed end of coupling **72** and the upper end of cylinder **80**. Ram **82** is made of ceramic or other dielectric material having high strength and low heat conductivity.

A tubular coil **85** surrounds cylinder **80** about at the center thereof. Radio frequency current is passed along the coil **85** and cooling water is passed therethrough. The coil is arranged to move up and down with the cylinder, as will now be described. A platform **87** of insulating material is split at one end and clamped to coupling **72** by means of screw **88**. The ends of the coil **85** are attached to platform **87** to support the coil and are provided with fittings **89** for connection to flexible water hoses. The ends of coil **85** and the fitting are joined to metal plates **90** which are attached to platform **87** and to which flexible copper strap leads **91** are attached by screws **92**. The leads **91** are connected to a conventional source of radio frequency power (not shown).

The structure thus far described provides the operating mechanism for making a tube according to the invention. The remaining structure shown within the cylinder **80** in FIGURES 1 and 2 consists of the tube and the jigging for it. The tube **10** has already been described. It will be seen best in FIGURES 2 and 4 that the tube parts are loaded in a cylindrical jig **94** having a central bore **95** and longitudinal grooves **96**. The grooves **96** must be at least equal in number to the number of rows of terminal tabs on the tube, assuming of course that the tube under construction has this type of terminal arrangement. It will be seen in FIGURE 4 that jig **94** has four grooves **96** whereas tube **10** has only two rows of terminal tabs. The two extra grooves are desirable for free passage of air from the tube to the exhaust chamber. Jig **94** is made of dielectric material such as ceramic.

The jig **94** is supported on a cylindrical stand **98** which is received in the seating recess **45** in plate **40**. A short elevating ring **100** is received in the upper end of stand **98**. A pressure ring **102** rests on the top of the tube and is provided with a central bore **103**. Ram **82** is provided with a tapered tip **104** which engages the rim of bore **103** to assure even application of pressure. Stand **98** and the rings **100** and **102** are made of ceramic or other dielectric material having high strength and low heat conductivity.

Jig **94** is provided with two apertures **106** opening into diametrically opposed recesses **96** so that electrical connection can be made to heater tabs **17'** and **18'**. The connection is made by leads **108** and **109** which pass through aperture **44** in plate **40** and are connected to terminals **110** and **111** which are mounted on but insulated from stand pipe **30**. The upper ends of leads **108** and **109** are provided with contact fingers which pass through apertures **106** and engage tabs **18'** and **17'**, respectively.

The method of using the hereinbefore described apparatus in the manufacture of a tube will now be explained. FIGURES 1 and 2 show a tube **10** positioned inside the vacuum-tight chamber formed by the base member **40** in cooperation with the wall structure comprising cylinder **80** and coupling **72**. Naturally, the first step is to insert the tube parts into the vacuum chamber. Preferably the tube parts, such as parts **13–22**, are loaded into the jig, such as jig **94**, before placing the jig in the vacuum chamber. In practice it is desirable to assemble stand **98**, ring **100**, jig **94**, the tube parts, and ring **102** outside the vacuum chamber and insert them as a unit. It will be apparent from FIGURE 1 that by operating the cylinder and piston unit **55** to raise piston rod **63**, the glass cylinder **80** can thereby be lifted so that its bottom edge is above the position of ring **102** to permit easy insertion of the tube and associated ceramic parts **98**, **100**, **94** and **102**.

After the tube and associated ceramic parts have been placed in processing position with stand **98** seated in recess **45**, the ends of heater leads **108** and **109** are inserted through slots **106** so that the contact fingers on the leads engage the heater terminals **118'** and **117'**. Next, the cylinder and piston unit **55** is operated to lower the glass cylinder **80** until its lower end makes sealing contact with sealing ring **47** but before ram **82** makes contact with ring **102**, as shown in FIGURE 2.

Next, the stand pipe **30** is connected, as by suitable valving, to a conventional vacuum system to obtain a vacuum in the cylinder **80** and hence within tube **10**. At this point it should be explained that the separate metal and ceramic envelope parts have sealing surfaces which are not provided with an optical finish. In fact, the sealing surfaces which are pressed together need not be polished at all, although coining to obtain flatness is desired.

In addition to saving the expense of optical polishing, the use of sealing surfaces which have a finish rougher than an optical finish permits the tube to be quickly and fully pumped in a vacuum chamber without resorting to some means for holding the sealing surfaces separated during pumping. It will be understood by those skilled in the art that if the sealing surfaces have an optical polish they will fit so closely together that the passage of gas therebetween will be at best so slow as to require an unreasonably long pumping period.

After connecting the vacuum chamber to the pumping system, the tube is heated and allowed to outgas for a period commensurate with its size. At this point it is desired to emphasize the fact that the heating is accomplished by inducing a radio frequency current directly into the metal portions of the tube. In addition to any beneficial effect the high frequency current may have in the action which causes the sealing surfaces to bond together upon the application of pressure, the direct induction of radio frequency current eliminates the prolonged heating and cooling period which would be required if a conventional oven type of heating were employed. In this connection it should be understood that one of the reasons for making parts **98**, **100**, **102**, **82**, and particularly jig **94** out of dielectric material is so that they will not prevent or diminish the induction of R.F. current in the metal parts of the tube. Similarly, it will be appreciated that the elimination of metal as the material for parts which are subject to high temperature makes it possible to raise cylinder **80** immediately after forming the pressure seals. If metal were used it would be necessary to have a cooling period within the vacuum, as otherwise oxides would form and destroy the tolerances for parts **98**, **100**, **102**, **104** and particularly **94**.

During the outgassing period any required cathode forming is accomplished. The particular tube shown in the drawings employs a conventional oxide coated cathode. Forming of the cathode is accomplished by applying power to the leads **108** and **109** which energizes the heater to the extent necessary to raise the cathode to forming temperature.

When forming of the cathode and outgassing has been completed, the next step is to make the pressure seals. The pressure seals are made by operating the cylinder and piston unit **55** to move piston rod **63** downwardly until ram **82** engages pressure ring **102** with sufficient force to apply to the sealing surfaces a unit pressure substantially in excess of that which would be provided by exposing the outside of the tube to atmospheric pressure with a vacuum on the inside. It should be understood that evacuation of the vacuum chamber and induction heating of the sealing surfaces are continued when the sealing pressure is applied. After the sealing pressure has been applied and a vacuum tight seal has been formed, the heating current in coil **85** is cut off, stand pipe **30** is disconnected from from the vacuum pump, cylinder **80** is raised, tube **10** and jig **94** are removed from

the vacuum chamber, and finally the tube is removed from the jig.

Although the exact nature of the sealing action may not be known with provable certainty, it seems reasonably clear that the practical success of the pressure sealing method of this invention depends primarily on the fact that the surfaces to be sealed together are heated in a vacuum prior to the application of pressure and are not handled or removed from the vacuum between heating and the application of pressure. The point is that surfaces to be pressure sealed must be almost entirely free of dirt, occluded gases, oxides and other impurities. One of the best ways of accomplishing such cleaning is to heat the surface in a non-oxidizing environment, as for example in a vacuum or inert gas. Incidental to this understanding is the realization that the method of the invention can be used to make gas filled tubes employing one of the inert gases such as helium, or other gases such as hydrogen where the other gas does not form compounds with any of the particular metals out of which the sealing surfaces are made. Naturally, it is not only necessary that the sealing surfaces be cleaned sometime prior to the application of pressure, but they must also be kept clean between the cleaning step and the pressure step. The present invention provides the only practical method of maintaining cleanliness; namely, the method of pressing the sealing surfaces together in the same chamber in which they were cleaned.

Perhaps in theory, perfectly smooth, perfectly clean sealing surfaces would bond together in a vacuum tight seal without the application of any pressure. However, the purpose of the invention being to provide a practical mass production method of making electron tubes does not admit of such perfection. Thus, it is proposed that substantial pressure be used. One purpose of the pressure is to overcome the lack of smoothness. Clearly, if sealing surfaces which are not perfectly smooth are brought together, they will not be in contact over their entire surfaces but only at a number of separate points. Although the points in contact may bond together to form a joint of appreciable strength, they will very likely not form a continuous wall, or vacuum tight seal. The invention requires, then, that enough pressure be applied to assure sufficient contact between the sealing surfaces to form a vacuum-tight seal. In addition, it has been found that the yield of good seals is increased if sufficient pressure is applied to actually cause radial deformation or extrusion of the sealing surfaces, or at least of the softer sealing surface where the surfaces are of different material. This improvement is believed to be explainable by the theory that any surface oxides which might not have been removed by the high temperature cleaning can be broken up by deformation to expose clean metal. This theory also provides an additional reason for using sealing surfaces having a finish which is rougher than an optical finish, the thought being that surface oxides can be more easily ruptured when relatively rough surfaces are pressed together than when optically smooth surfaces are used.

In connection with the application of pressure, it should be noted that the apparatus provides a very rapidly operating and simple arrangement. More specifically, the apparatus eliminates the need for complicated bellows arrangements by making the pressure exerting means or ram **82** movable with the chamber wall **80**. Thus, the movement which initially closes the chamber places ram **82** almost in pressure exerting contact, and the movement which removes the pressure of ram **82** also opens the chamber so a finished tube can be immediately extracted. It is also important to note that when pressure is applied to the tube it is done with poor heat conductors such as ceramic pieces **98**, **100**, **102**, and **82**. There are two reasons for preventing a good heat conducting path; one is that it would be undesirable to drain heat from the sealing surfaces at the exact period of sealing, and the other reason is that sudden cooling of the tube ceramics would cause them to crack.

Utilizing the basic teachings of the invention, it is possible by experimentation to determine the minimum temperatures, pressures and duration of application which are necessary to obtain satisfactory seals between the various materials which might be used. By way of example, experiments have been made with tubes which comprise the following envelope construction: a high alumina ceramic member such as rings **11**, a conventional molybdenum-manganese metallizing coating on the ceramic, and a nickel layer forming a sealing surface plated on the metallizing coating; a thin sealing ring of copper; and a metal envelope ring such as rings **13–22** of Kovar or nickel. The metallizing, the nickel plating, and the copper rings do not appear in the drawing because the invention is not limited to any specific materials and because they are extremely thin. For example, the copper ring is .003 inch thick and the metallizing and nickel plating are each only .0002 inch thick. Tubes having satisfactory seals with these materials have been made according to the following procedure utilizing the apparatus of the invention: Place the tube parts in the vacuum chamber, exhaust the chamber, induce R.F. current in the sealing surfaces for about three minutes to raise the temperature of the surfaces to about 750° C., lower ram **82** with sufficient force to deliver between 11,000 and 18,000 pounds per square inch pressure at the sealing surfaces, and maintain this pressure for about two and one-half minutes. The cathode must be formed prior to applying pressure and the earlier it is formed the longer will be the period for emptying the tube of the gases given off during forming.

Not only are the method and apparatus of the invention not limited to certain specific materials, they make it possible to effect pressure seals even using easily oxidized metals such as copper. The advantage of being able to use copper, which is a desirable metal in electron tubes, is made possible because the sealing surfaces are not removed from the non-oxidizing environment between the time they are cleaned by heating and the time they are pressed together.

Having thus described the invention, what is claimed as new and desired to be secured by Letters Patent is:

1. A method of making electron tubes of the type having an envelope in which metal sealing surfaces are joined together to form a vacuum-tight seal, said method comprising the steps of placing the tube parts in a vacuum-tight chamber, evacuating said chamber, heating said sealing surfaces while said chamber remains evacuated, and forcing said sealing surfaces together with a pressure substantially above the pressure obtainable by evacuating the interior of the tube and exposing the exterior to the atmosphere, the temperature to which said sealing surfaces are heated being less than the melting temperature of the surfaces.

2. A method of making electron tubes of the type having an envelope in which metal sealing surfaces are joined together to form a vacuum-tight seal, said method comprising the steps of forming said sealing surfaces with a finish rougher than an optical finish, placing the tube parts in a vacuum-tight chamber, evacuating said chamber, heating said sealing surfaces to clean them while said chamber remains evacuated, and forcing said sealing surfaces together with sufficient pressure to join them in a permanent vacuum-tight seal, the temperature to which said sealing surfaces are heated being less than the melting temperature of the surfaces.

3. A method of making electron tubes of the type having an envelope in which metal sealing surfaces are joined together to form a vacuum-tight seal, said method comprising the steps of placing the tube parts in a vacuum-tight chamber, evacuating said chamber, heating said sealing surfaces by inducing a radio frequency current therein, and forcing said sealing surfaces together while

maintaining said sealing surfaces heated and while maintaining said chamber evacuated, the temperature to which said sealing surfaces are heated being less than the melting temperature of the surfaces.

4. A method of making electron tubes of the type having an envelope in which metal sealing surfaces are joined together to form a vacuum-tight seal, said method comprising the steps of placing the tube parts in a vacuum-tight chamber, evacuating said chamber, heating said sealing surfaces, and forcing said sealing surfaces together with sufficient pressure to deform at least one of said sealing surfaces, the temperature to which said sealing surfaces are heated being less than the melting temperature of the surfaces.

5. A method of making electron tubes of the type having an envelope in which relatively hard and soft metallic sealing surfaces are joined together to form a vacuum-tight seal, said method comprising the steps of placing the tube parts in a vacuum-tight chamber, evacuating said chamber, heating said sealing surfaces by inducing a high frequency current therein, then forcing said sealing surfaces together with sufficient pressure to deform said relatively soft metal surface, the temperature to which said sealing surfaces are heated being less than the melting temperature of the surfaces.

6. A method of making electron tubes of the type having an envelope in which metal sealing surfaces are joined together to form a vacuum-tight seal, said method comprising the steps of forming said sealing surfaces with a finish rougher than an optical finish, placing the tube parts in a vacuum-tight chamber, heating said sealing surfaces by inducing a high frequency current therein, and forcing said sealing surfaces together with sufficient pressure to deform at least one of said metal sealing surfaces, the temperature to which said sealing surfaces are heated being less than the melting temperature of the surfaces.

7. A method of making electron tubes of the type having an envelope in which metal sealing surfaces are joined together to form a vacuum-tight seal, said method comprising the steps of forming said sealing surfaces with a finish rougher than an optical finish, placing the tube parts in a vacuum-tight chamber, obtaining a non-oxidizing atmosphere in said chamber, heating said sealing surfaces while maintaining said non-oxidizing atmosphere, and forcing said envelope parts together with sufficient pressure to form a permanent vacuum-tight seal, the temperature to which said sealing surfaces are heated being less than the melting temperature of the surfaces.

8. A method of making electron tubes of the type having an envelope in which metal sealing surfaces are joined together to form a vacuum-tight seal, said method comprising the steps of placing the tube parts in a gas-tight chamber, maintaining a nonoxidizing atmosphere in said chamber, heating said sealing surfaces while maintaining said nonoxidizing atmosphere, and forcing said sealing surfaces together with a pressure on said surfaces of at least 11,000 pounds per square inch while said sealing surfaces are heated, the temperature to which said sealing surfaces are heated being less than the melting temperature of the surfaces.

9. A method of making electron tubes of the type having an envelope in which metal sealing surfaces are joined together to form a vacuum-tight seal, said method comprising the steps of placing the tube parts in a gas-tight chamber, maintaining a nonoxidizing atmosphere in said chamber, heating said sealing surfaces while maintaining said nonoxidizing atmosphere, and forcing said sealing surfaces together with a pressure substantially above the pressure obtainable by evacuating the interior of the tube and exposing the exterior to the atmosphere, the temperature to which said sealing surfaces are heated being less than the melting temperature of the surfaces, one of said sealing surfaces being copper, and the adjacent sealing surface in contact with the copper being a metal which is harder than copper.

10. A method of making electron tubes of the type having an envelope in which metal sealing surfaces are joined together to form a vacuum-tight seal, said method comprising the steps of placing the tube parts in a gas-tight chamber, maintaining a nonoxidizing atmosphere in said chamber, heating said sealing surfaces to about 750° C. while maintaining said nonoxidizing atmosphere, and forcing said sealing surfaces together with a pressure on the sealing surfaces of at least 11,000 pounds per square inch, the temperature to which said sealing surfaces are heated being less than the melting temperature of the surfaces, and at least one of said sealing surfaces being copper.

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CERTIFICATE OF CORRECTION

Patent No. 2,996,347 August 15, 1961

Jack A. McCullough et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, line 50, for "for" read -- the --.

Signed and sealed this 9th day of January 1962.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

DAVID L. LADD
Commissioner of Patents