



LB-894

CERAMIC - METAL SEALS

OF THE TUNGSTEN-IRON TYPE

RADIO CORPORATION OF AMERICA  
RCA LABORATORIES DIVISION  
INDUSTRY SERVICE LABORATORY

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## Ceramic-Metal Seals of the Tungsten-Iron Type

### Introduction

The advantages of higher permissible temperatures and better dielectric properties have made ceramic materials attractive for use in high-power high-frequency vacuum tube construction and have been an incentive to the development of successful methods of sealing ceramic to metal.

This bulletin describes a new method of preparing metal-ceramic seals which is relatively simple and non-critical in processing. The area to be sealed is brush-coated with a thin film of mixed tungsten and iron powders and fired to a suitable temperature in a diluted reducing atmosphere. A homogeneous and dense thin metal film is produced which is strongly adherent to the ceramic. Tests indicate that the bond may be stronger than the ceramic body itself. For most applications this seal is superior to previously-used types.

Included in this bulletin are a short review of a few other ceramic-metal seal processes, a general discussion of ceramics and sealing metals, and comprehensive tables of pertinent data on ceramics and metals.

### General Discussion

The coating of ceramics for ornamental purposes goes back to ancient times. However, there is but little similarity between the ornamental metal coating on a ceramic and the type of coating required for a vacuum-tight electron tube envelope. Historically, the development of hermetic seals between ceramic bodies and metals for electron tube use began some fifteen years ago.

The prerequisite for the production of a metal-ceramic tube envelope is the formation of a permanent soldered joint between ceramic and metal. The ceramic used must be impervious and strong, and its physical properties and chemical composition must be such that it can combine adherently with the metal coating applied to

it. This metal coating should be of such character that brazing can be accomplished without the coating-to-ceramic bond being affected.

Because of the amount of work done on ceramic-to-metal seals, a full reference list would be extensive. It may be in order, however, to refer briefly to a few of the more interesting methods employed. All of these methods have been given experimental consideration at RCA Laboratories. All but three or four had sufficient deficiencies to eliminate them, but certain processing details of some are of distinct interest.

The short descriptions that follow indicate the nature of some of the seals that were studied.

## 1. *Metallic Oxide Seal*

When certain metallic oxides, notably that of copper, are applied to a ceramic and fired, a diffusion occurs to form a physical-chemical union. By subjecting this impregnated surface to the action of a reducing atmosphere in a furnace, a pure metal film is left which, although very thin, is very adherent.

## 2. *Pressed Powder Seal*

The pressed powder method of combining a ceramic and a metal consists in applying under pressure a powdered layer of nickel, iron, molybdenum, etc., to a suitable ceramic raw material and sintering to solidification. A dense compact is possible if the raw material is of a type to permit bonding, and if the expansion properties are compatible. Differences of thermal expansion may be matched somewhat by using adjusted layers of metal-ceramic mixture.

## 3. *The High Pressure Seal*

A bond can be formed between certain metals and ceramics by the application of pressure of the order of 3000 lbs/in.<sup>2</sup>, at a temperature of around 1000 degrees C, in vacuum or pure nitrogen.

## 4. *Hydride of an Active Metal Seal*

The hydrides of such metals as zirconium, thorium, tantalum, columbium and titanium have been successfully used to form ceramic-to-metal seals. A suitable solder must be present so that the bond is formed simultaneously with brazing. This method has been extended experimentally to include materials other than ceramics. It has also been made more practical by processing in pure inert gases, such as helium or argon, in addition to the usual processing in vacuum.

## 5. *Active Metal Seal*

The presence of hydrogen, as in a hydride, is not necessary in the formation of a seal. An active metal, such as titanium, zirconium, etc., preferably alloyed with silver, will wet and bond ceramics, or bond a ceramic to a metal.

## 6. *Ceramic Glaze Seal*

Much time and work have been devoted to sealing ceramics to ceramics, and ceramics to metals with glaze materials. A seal between ceramic parts is simple and effective. A glaze seal between a ceramic and a metal is by no means as easy to make or as certain, but it is a useful, often-used method.

## 7. *Glaze and Metal Powder Seals*

Firing a mixture of glaze and a metal powder, such as 80 per cent of nickel

and 20 per cent of a suitable glaze, by weight, in a reducing atmosphere provides a metal layer on the ceramic that can be electroplated and/or silver brazed. Such a seal is not as strong as the hydride or sintered type, but it has useful applications.

## 8. *Sintered Seals*

Seals of the sintered type, made with the refractory metals in powder form, are most important. Molybdenum, rhenium and tungsten have been used, generally with additions such as nickel, iron, or cobalt, to improve the properties of the seal. The tungsten-iron seal, the subject of this bulletin, is a seal of this type, an important feature of which is that a rigid schedule of processing is not required to produce a successful seal. Considerable variations in metal powder composition, firing rate, temperature and atmosphere can be tolerated.

## Ceramic-to-Metal Seals

Forming a bond between a ceramic and a metal involves two fundamentally different materials. The chemical and physical as well as the thermal and mechanical natures of such materials must be considered in attempting to join them together in the intimate relationship necessary for a strong, permanent, and gas-tight seal. If silver or copper is heated until molten on a ceramic surface and kept in that condition for a few minutes before cooling, spheres of metal form like droplets of mercury. These spheres neither wet nor stick to the ceramic. If the spheres are kept molten for a much longer period of time, say an hour or more, the spherical shape remains but the spheres adhere to the ceramic. This phenomenon may be explained by the fact that the molten metal slowly reacts with the ceramic at the point of contact to form an interface which facilitates bonding.

Several theories have been advanced to explain why a firmly adhering layer of metal on a ceramic can be obtained. The reactions that occur are complex, and it is believed that none of the explanations is complete enough to satisfy the several conditions encountered.

One plausible, but not very revealing, assumption is that, in the case of a refractory

Metal powder, the bond consists of metal and ceramic particles which, by a chemical action have caused the formation of a bonding material at the interface. Another hypothesis holds that the metal diffuses into the ceramic, and possibly by a peculiar arrangement or rearrangement of the crystals at the interface a bond is created. Still another belief is that certain constituents in the ceramic promote crystallization and prevent the separation of a glass phase, and that, by a type of slag formation, the metal is firmly and intimately joined to the ceramic. It is also believed that solid reactions take place because of loosening of the atomic bonds by thermal agitation, permitting mutual diffusion of the different atoms into adjacent parts of the structure. In this case it is possible that large crystals grow from smaller ones, or a new type of crystal grows from two dissimilar ones. Some knowledge of the formation of the interface, its composition and its properties, is important to an understanding of the bonding processes between ceramics and metals.

### Machining Ceramics

The ceramic parts used in metal-to-ceramic seals must often be altered in size or shape by machining. In production work, standard machines equipped with diamond drills and cutting and grinding wheels are used. Where such equipment is not available, acceptable machining can be done on shop tools. For example, holes have been drilled through ceramic parts on a drill press using carbide tipped drills, operating wet or dry, preferably wet. The very hard high-alumina porcelains are difficult to drill in this manner but many forsterite parts were successfully drilled. The use of a copper tube in a drill press chuck, with 180 to 220 grit silicon carbide with water, is more satisfactory. All types of ceramics were drilled fairly accurately and as rapidly as would be expected.

Some preliminary experimental work on drilling holes in ceramics involves the use of an air blast with an aluminum oxide abrasive. This equipment was recently introduced for dental use, and is somewhat similar to that

used in sand blasting. There is an important difference, however, in that a special nozzle is used.

Cutting of ceramics is accomplished on a glass cut-off machine. The abrasive wheel is an Allison cutting disc, usually 120 grit, used with water.

Grinding and shaping of ceramic parts have been accomplished, for the most part, on standard grinding machines, grinding either wet or dry, with silicon carbide wheels. Dry grinding has been used only where the machines were not adapted to wet grinding.

### Cleaning Ceramics

To form an adherent layer of metal, such as tungsten and iron, on a ceramic surface, the ceramic must be free of any contaminating material. Since the contaminants are generally unknown, a single, simple cleaning procedure cannot be specified. Usually, suitable cleaning may be obtained by firing the ceramic to 800-1000 degrees C in air. A less time-consuming operation is to degrease the ceramic in a suitable alkaline cleaner and then wash it thoroughly in water. It is then immersed in dilute nitric acid for not over 5 minutes, followed by water rinse and drying; alternatively the usual glass cleaning operation will often be satisfactory.

### The Metal Powder Mixture

Assuming that the tungsten powder has a particle size of the order of 1 to 4 microns and that the iron has a similar particle size, they are combined in the ratio of 90 per cent tungsten and 10 per cent iron by weight. This ratio appears to be suitable but is not at all critical, and in actual practice seals have been made to forsterite with tungsten or iron alone. The mixture is the choice for superior seals, however, and when so used the mixing should be thorough.

If the tungsten or iron powder is suspected of consisting of mixed fine grains and coarse

grains, the fine grains can be separated from the coarse. They should be mixed thoroughly in alcohol, approximately 10 grams of metal powder in 50 cc of alcohol, then allowed to stand about 4 or 5 minutes. The coarse particles settle to the bottom and the fine particle powder is decanted off with the liquid. After standing 1 to 3 hours, the alcohol is poured off and the deposited fine powder is dried at about 150 degrees C.

### Application of Powder to Ceramic

The mixed powders are made into a thin paste or paint by stirring them into collodion diluted with ethyl acetate. An excess of collodion will produce a somewhat less fluid paint that is slower drying. This is desirable since more time can elapse without thinning and a smoother coating can be applied to the ceramic. This may be done with a camel hair brush. A thickness of about  $1\frac{1}{2}$  mils has been found satisfactory, although not critical. A gram of powder should cover 10 to 15 square centimeters of ceramic, depending on the ceramic surface and the manner of application.

For spray gun use, this mixture is suitably diluted. The adjustment of the gun nozzle, the pressure, and best distance between nozzle and the work will be determined by experiment. The several ceramic types suitable for metalizing are coated with the metal powders in a similar way, assuming proper surface conditions. Grinding the surface of the ceramic where the metal is to be applied is desirable not only to secure accurate dimensions but to provide a smooth surface for metalizing and brazing. Many of the ceramics used were not ground, however, and in practice very rough surfaces have been successfully treated.

### Sintering

The operation of firing metal powder coated ceramic bodies requires a hydrogen furnace that will run at 1350-1400 degrees C. Considerable latitude can be exercised in the

design of such a furnace. Experimentally, three furnaces, globar heated, but otherwise radically different in construction, have been successfully used.

Thin or fragile ceramic parts, even of forsterite, require suitable support in the furnace to avoid the possibility of warping out of shape. Two materials that have served very well to support the powder coated ceramics are molybdenum and the porous type of alumina used for power-tube insulators. A cylindrical ceramic part, metal powder coated on both ends, may be kept in a vertical position by supporting it upon three or more tapered pieces of the alumina. These pieces are positioned so that little or none of the coating touches the alumina. The whole rests on a molybdenum plate.

Since unusual things can happen at temperatures above 1000 degrees, care must be exercised in the loading of the furnace, the selection of materials, and the placement of the parts to be fired.

The time and temperature must be adjusted for optimum sintering for the particular ceramic. There appears to be a range of temperatures suitable for firing the various ceramics, but in general, it can be said that the alumina and porcelain bodies require, for good sintering, temperature and time beyond those for forsterites and steatites.

In experimental metalizing the usual practice has been to load the furnace cold and then to increase the temperature slowly, the rate of increase being limited by the possible rate of heating the furnace rather than by the thermal properties of the work being fired and sintered. Cooling is slow also, the limit being the rate of heat loss by the furnace. If power were turned off at the time maximum temperature is reached, the work would be subjected to the maximum temperature for a period of possibly 5 minutes, depending on the furnace. This together with the period at near maximum temperature, has been found to be sufficient in several tests, although a maximum of ten minutes or more for the porcelains or alumina should give improved adherence.

Suggested approximate sintering temperatures for the most used ceramics are:

Steatites	1240-1250 degrees C
Forsterite	1350-1360

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Zircon	1350-1360
Alumina	1390-1420

More specifically:

B.N. 2532 (steatite)	1250 degrees C
Alsimag 243 (forsterite)	1360
RCA-102351-2 (forsterite)	1360
Alsimag 475 (zircon)	1360
Almanox 4462 (high alumina)	1420

As a precaution, no metal other than the metal powder layer and the molybdenum supports should be permitted to touch the ceramic in the sintering operation. Most particularly, none should touch the metal powder layer, except such metal as may be applied intentionally to serve as a solder. As an example of what might occur, an alumel-chromel thermocouple accidentally came in contact with an iron-tungsten-on-ceramic piece in sintering. A eutectic of unknown composition was formed and flowed over part of the metal coating as though it were a solder. An indication of the durability of the bond to the ceramic was that no loss of adherence occurred.

### Sintering Atmospheres

The atmosphere in which sintering occurs has an influence on the quality of the bond. Protection against excessive oxidation is necessary, but there is evidence indicating that a small percentage of oxygen improves the bond. This small amount of oxygen is probably present in tank nitrogen as an impurity, hence in average use this consideration does not arise.

Fortunately, the type of sintering under discussion is not critically dependent on an exact atmosphere composition. Sintering has been carried out in tank hydrogen, but the oxides in ceramics are often subject to injurious reduction in pure hydrogen. Hydrogen and nitrogen mixtures ("forming gas") have been found to cause superior bonding in the sintering operation. Furthermore, the danger of explosion is much reduced by the use of forming gas. Thirty per cent forming gas (30% hydrogen, 70% nitrogen) has been successfully used, and even 10 per cent forming gas permits sintering.

Nitrogen is not a necessary component of the atmosphere; other inert gases, such as helium or argon, are acceptable but more expensive.

The volume of gas flowing into the furnace cannot be specified unless all the conditions involved in the firing operation are known. It is believed that no more than enough to carry off the contaminating gases or vapors from the heated work at a suitable rate is necessary for adherent bonding of the metal to the ceramic.

Depending on the conditions of sintering, the metal surface may be found to be discolored, or it may be clean and ready for brazing. It has been found that a 1 per cent to 5 per cent addition of fine nickel powder to the mixed tungsten and iron may give a surface that requires but little cleaning. The nickel, however, has no bonding action, and may even retard it slightly. In any event, the metal layer may be cleaned with a fine wire brush and lightly plated with nickel to promote soldering.

Experience with many metal coated ceramic pieces shows that oxidation or discoloration of the metal will occur if it is exposed to the air over a period of time. An important use of the nickel plate mentioned previously is the protection afforded against contamination. Another use, as in soldering, will be mentioned later.

While not necessary, a very thin plate of bright copper, which is readily cleaned, may be used with or without the nickel. A more important use of a thin copper plate on the tungsten-iron layer is that it may disclose, by inspection, small defects in the metal layer on the ceramic which, otherwise, are difficult to detect.

### Soldering

A metal part is joined to a metalized ceramic by soldering. The "solder" refers to any metal used to complete an assembly, and may include suitable pure metals or alloys for brazing as well as soft solders. Wherever a solder may be present inside an electron tube, it should have no high vapor pressure constituents.



Table I

Properties of Solders				
Solder	Composition	Melt °C	Flow °C	Furnace brazing, °C, about
Pure tin	Sn 100	230	-	-
"BT" silver solder	Ag 72 Cu 28	779	779	800
Coin silver	Ag 90 Cu 10	890	890	905
Pure silver	Ag 100	960	960	990
Gold solder No. 1376 (brittle)	Au 37.5 Cu 62.5	998	1020	1025
Pure gold	Au 100	1063	1063	1070 (?)
Copper	Cu 100	1083	1083	1100
Coin Nickel	Cu 75 Ni 25	1205	1205	1225 (?)
Nickel-moly	Ni 51 Mo 49	1305	-	-

The properties of some solders that may find useful applications in ceramic-to-metal radio tube structures are summarized in Table I.

Furnace brazing is usually done in tank hydrogen. It can generally be done in vacuum, helium, or forming gas (30% H<sub>2</sub>, 70% N<sub>2</sub>) if the metal parts are sufficiently clean. Chromium-bearing alloys cannot be brazed satisfactorily unless dry hydrogen is used. The chromium trioxide that forms on chromium alloys in "line" hydrogen firing is generally so adherent that it is removed only with difficulty. To make possible the brazing of such metals in tank hydrogen, a protecting plate of nickel is used. The protection afforded is a function of the firing time, temperature, dew-point of the hydrogen, and the composition of the metal. To "BT" braze such alloys, a nickel plate some 0.2 to 0.3 mil thick is useful. To copper braze a chromium-bearing metal, a much heavier nickel plate is ordinarily necessary.

A thin-edge copper seal to a ceramic part is readily obtained if certain precautions are observed. Copper so readily alloys with silver solders that failure to complete a proper seal will occur unless time and temperature are carefully controlled. A light nickel plate on the thin-edge of copper, together with furnace control, will assure good seals. It has been found possible to braze to the tungsten-iron layer on ceramic at high temperature. Copper has been used as a brazing metal. It is possible to do sintering and brazing simultaneously, since all that is required is the correct metal part and a suitable solder.

In all brazing operations the ceramic parts should be preheated to avoid stresses, the heating rate depending on the thermal shock properties of the particular ceramic body.

Metals of various thicknesses have been brazed to ceramics. Depending on the metal and the type of seal, a thickness of 5 to 10 mils may be most safely soldered, but heavier metals have on occasion given good seals. The metal part should snugly fit the ceramic to which it is to be brazed. If the expansion match is not good and the metal at the intended sealing area expands too fast, a gap may develop so that at the melting of the solder some of it may run out, or too much of it collect there. An excess of solder may cause failure of the bond by fracture of the ceramic or stripping. Too little solder may cause a weak joint, and a leaky one. Too high a temperature in brazing may cause loss of solder, or alloying, or intergranular penetration, depending on the metals involved, since certain metals are particularly susceptible to attack by silver and its alloys.

Seals between ceramics and metals and between ceramics and ceramics may take many shapes. Some are simple cylindrical seals, some are disc or butt seals, while others may be so involved that they are limited not so much by metalizing techniques as by the jigs required in brazing.

The features of a more or less typical ceramic and metal composite structure will be easily understood from the drawing of Fig. 1.

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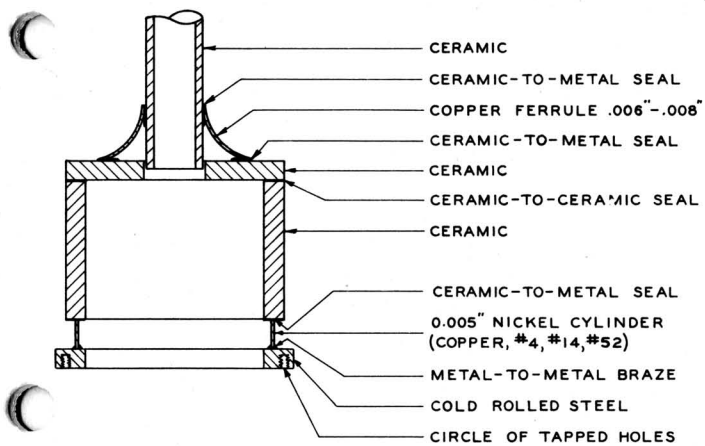


Fig. 1 - View of a ceramic and metal assembly.

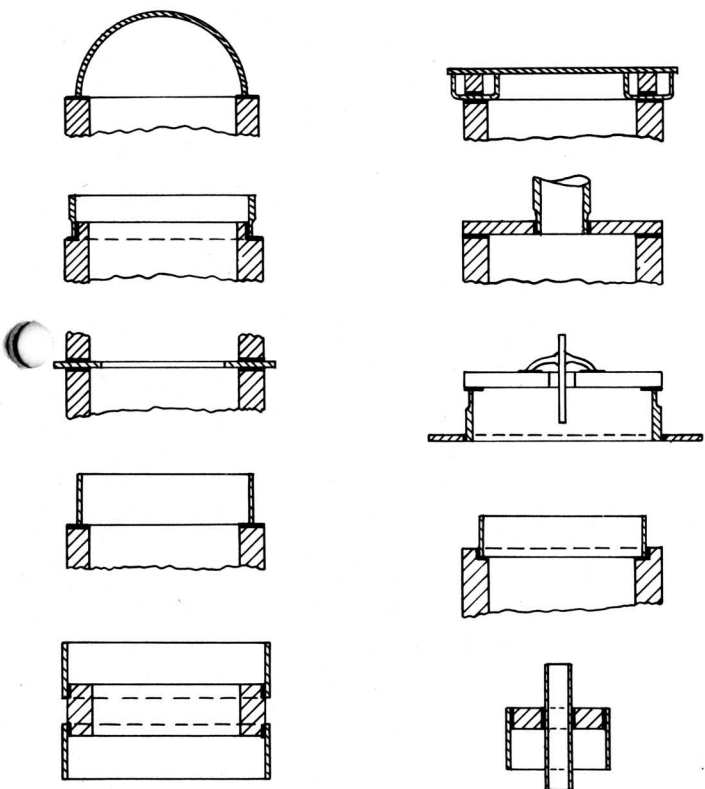


Fig. 2 - Cross section views of several ceramic-metal assemblies. The metalized and brazed regions are shown by the heavy lines.

It is a cross-sectional view of part of an assembly consisting of three parts having five tungsten-and-iron coated, one ceramic-to-ceramic brazed seal, and three ceramic-to-

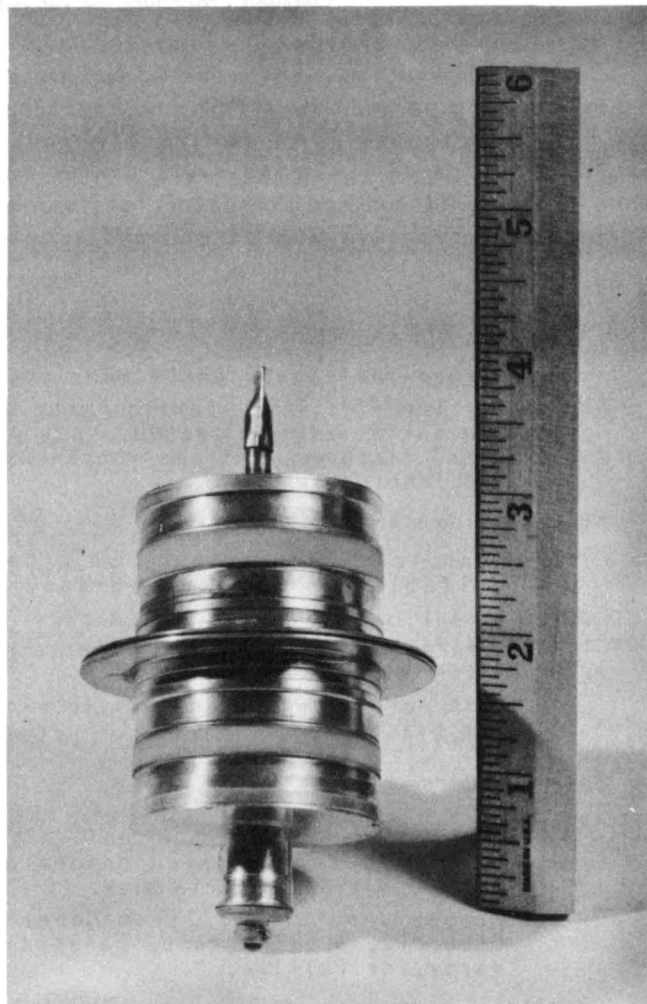


Fig. 3 - Ceramic-metal triode.

metal brazed seals. All the brazing is done in one operation.

The lower section of the assembly is a cold rolled steel annulus, having a circle of tapped holes which, with a similar stem section, forms a copper ring type compression seal. A short, 5-mil thick nickel cylinder joins the annulus to the ceramic cylinder.

Several forms that ceramic-metal seals may take are illustrated in Fig. 2.

Fig. 3 is a photograph of a ceramic-and-metal triode, in which there are six metal-to-ceramic seals and one gold diffusion seal.

## Detailed Procedure for Tungsten-Iron Method of Metalizing Ceramics

The following guide to the steps to be undertaken to give good metalizing was designed specifically to apply to forsterite and a particular furnace. It is, however, useful for other ceramics if due consideration is given to sintering temperature and other conditions.

## I. Ceramic

## A. Inspection

1. For overall shape and dimensions.
2. For imperfections, particularly of the surface to be coated, such as pits, fissures, extreme roughness, and fractures.

## B. Cleaning

1. Wash in clean acetone, or other suitable solvent or degreaser.
2. Wash in clean water.
3. Immerse for 2 minutes in 25 per cent nitric acid.
4. Wash well in water and dry in warm air blast.

## II. Metal Powders

## A. Tungsten

1. Use pure, dry tungsten powder of about 2 micron particle size.
2. Probably obtainable from General Electric, Westinghouse, Fansteel, Hardy, or Philips.

## B. Iron

1. Use pure dry iron powder of about 2 micron particle size.
2. Carbonyl iron powder may be obtained from the General Aniline and Film Corp., Charles Hardy, etc.

## C. Note:

Metal powders of an exact particle size are not available. Those listed as about 1-4 micron particle size are considered useful.

## D. Mixture of metal powders

1. By weight, 9 parts of tungsten and 1 part of iron.
2. Mix the powders thoroughly.
3. Mix only enough powders for the job on hand.

## E. Note:

Fine particle size metal powders have a tendency to agglomerate, hence thorough mixing is desirable for uniformity in material and to reduce likelihood of lumps in the coating operation.

## III. Coating Ceramic

## A. By brush

1. Mix metal powders with ethyl acetate and nitrocellulose binder, using the binder in excess to cause slow drying and to promote adherence to the ceramic.
2. Stir the mixture exceedingly well to break up the clusters of powders to get a smooth-flowing paint. Roll if convenient.
3. Rotate the ceramic part, if possible and apply the paint with a camel hair brush of such size that one dip will complete coating.

## B. By spray gun

1. For quantity production of metalized ceramic parts and for special parts where some form of masking may be employed, the use of a spray gun to apply the metal powders may have advantages.
2. The same composition as used for brush coating the ceramic with metal powders would be used for spray gun use, except thinning to a suitable consistency would be required.
3. Explicit instructions for a spraying method cannot be given without knowing and specifying all the conditions. Coating by spray gun depends on the peculiarities of each application with respect to such considerations as the gun type, the nozzle and its adjustments for volume and spray pattern, the distance between gun and work, the shape of the part to be sprayed, whether or not the work must be rotated or given some other motion and if masking is necessary.
4. A suitable technique can be readily worked out based chiefly on tests.

## C. Note:

If suitably mixed, applied, and dried, the coating will be durable enough to stand reasonable handling. If the paint is of proper consistency, and maintained in that condition by adding ethyl acetate, a smooth coating about 0.002 inch thick can be obtained.

## IV. Firing

## A. Placement of ceramic pieces

1. Place parts in a molybdenum boat or on porous alumina plates so that there is no contact between metal powder coating and the boat or plates. Place them so there is separation of parts.

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2. Place in muffle in furnace.

### B. Firing on metal film

1. Raise temperature in furnace to 1360 degrees C during a period of 40 to 60 minutes. Hold temperature to about 1360 degrees for 5 minutes, then reduce power to about 50 per cent for 10 minutes. Turn off power.
2. Depending on size or type of furnace and muffle, maintain a flow of forming gas (70% N + 30% H<sub>2</sub>) of about 1½ liters per minute.
3. *Note:* The above schedule applies to a certain globar furnace with heavy alumina muffle of about 4 liters capacity. Any suitable furnace arrangement with sufficient supply of gas will serve equally well, with the heating and cooling cycle suited to the furnace.

### V. Treatment of Metal Surface

#### A. Polishing and cleaning

1. Polish the metal film with a fine wire brush (Dixon No. C3434 or equivalent).
2. Immerse in acetone for about ½ minute.
3. Immerse in pennsalt for about ½ minute. (Pennsalt is a proprietary

cleaning or degreasing agent). Any equivalent cleaner may be used.

4. Wash well in water.

5. Electroclean the metal surface in a saturated solution of sodium carbonate at about 3 to 5 volts for not over 5 seconds. Connection to be one (work negative) that gives most reaction.

6. Wash in water.

#### B. Electroplating

1. Pickle in 15 per cent HCl for not over 3 to 5 seconds.

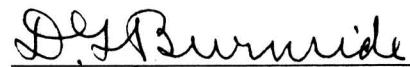
2. Wash in water.

3. Nickel strike at 2½ to 3 volts for 5 seconds.

4. Nickel plate to about 0.0001 inch - 0.0002 inch.

5. Wash and dry.

6. *Note:* Ordinarily, the tungsten-iron surface appears dark to bluish when removed from the furnace. Brushing with a moderately stiff steel wire brush (wires 0.003" - 0.004", and about ½" long) leaves a fairly bright metal surface. The brush should be new and clean and used for no other purpose.



D. G. Burnside

## Appendix I

### Ceramic Materials

Several ceramic materials produced by numerous manufacturers are available for use in electron tube construction. The most important properties of ceramics for tube envelope applications are porosity or vacuum tightness and thermal expansion. Other important considerations are physical strength, thermal conduction, thermal shock resistance, softening temperature, and radio-frequency losses. For the creation of a strong bond between a ceramic and a metal, the chemical composition and physical structure of the ceramic body must also receive consideration. The properties of ceramic bodies are entirely functions of the materials used and their processing into ceramics. Very often relatively small variations in either composition or processing at any stage of the ceramic making may cause undesirable characteristics.

For tube envelope use, dense, impervious bodies are required to assure vacuum tightness, which must be retained at temperatures up to 600 degrees C or more. In ceramic tables, porosity is usually classified in terms of moisture absorption wherein an impervious ceramic rated at 0 to 0.02 per cent is considered vacuum tight.

Strong and stable ceramic compositions have approximately straight thermal expansion curves. The expansion characteristics of both metal and ceramic should match sufficiently well to prevent excessive strain at the interfaces or in one of the components. It is also desirable to have a solder or brazing material whose expansion does not vary too greatly from that of the ceramic body, since an excess of a high expansion solder sets up strains in the seal. Unfortunately, suitable low expansion solders are not obtainable. Care is therefore required in choosing the amount of solder for a seal. Exceptions to the requirement for close matching of expansion between metals and ceramics are mentioned in Appendix II.

Tensile and compressive strength of ceramics are important since the ceramic can be subjected to considerable strain if the ceramic-metal bond is strong. Some forsterite

and zircon bodies have failed when put under stress by the metal on cooling because the metal-ceramic bond was stronger than the body of the ceramic. Some zircon bodies have been rated equal to or higher than forsterite in physical strength, but the experience at RCA Laboratories, using practical tests, seems to indicate the contrary, as far as seals are concerned. Mechanical strength of ceramics is most usefully indicated by the modulus of rupture, a measure of cross breaking. This test simulates the type of stress the ceramics in tube structures receive in service. Both in processing and as a completed tube in service, the ceramic may be subjected to high thermal stresses. The ceramics that have low expansion properties have high thermal shock resistance and, conversely, the high expansion ceramics have, in general, poor thermal shock properties. High mechanical strength and good thermal conductivity may, however, act as compensating factors to improve the resistance to thermal shock of some ceramics.

The softening temperature of ceramics is of importance only in certain processing techniques used in metalizing. The methods of applying adherent layers of tungsten, molybdenum, manganese, iron, cobalt, vanadium, etc., to ceramic bodies employ relatively high temperatures. Some criticism has been leveled at such methods because of the possibility of causing deformation of ceramics. Some cases of distortion have occurred which may justify the criticism, but often such failures were due to improper use of the technique.

The rated safe temperatures for ceramic bodies are very conservative and are based on operation at continuous heat, which is always much below the ceramic firing temperatures and in some cases below the recommended metalizing temperatures. However, the temperatures required to sinter metal to ceramic are maintained for relatively short periods of time, and in consequence no damage should occur to the ceramics. It should be remembered, however, that the properties of a given ceramic type made by one manufacturer may vary greatly from

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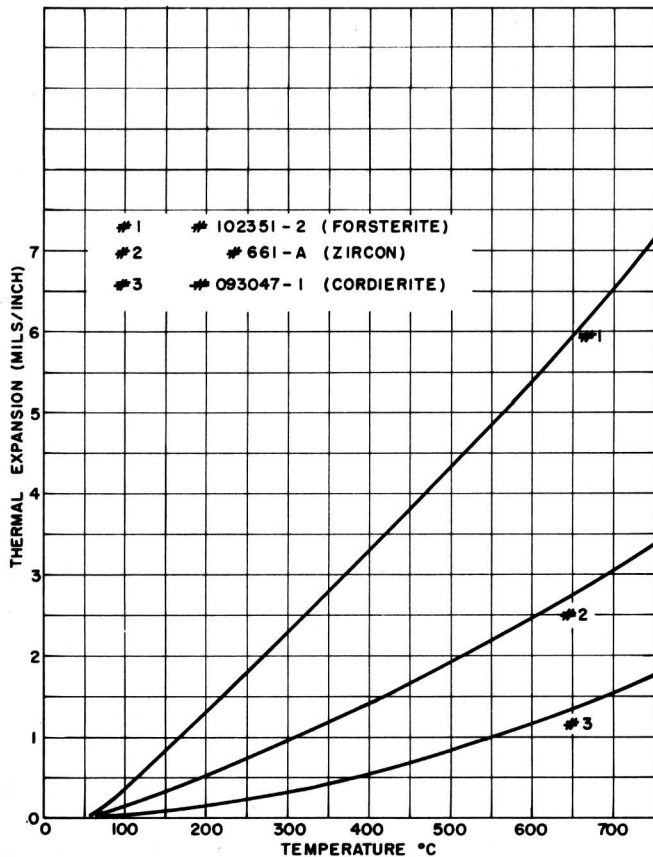


Fig. 4 - Thermal expansion curves of RCA ceramic bodies.

that type made by another. For example, one steatite sample withstood the metalizing temperature employed for forsterite whereas another steatite became plastic enough to flow.

That the properties of ceramic parts are often difficult to control is indicated by the fact that in the process of firing ceramic products a complete equilibrium, according to the phase diagram, is seldom, if ever, obtained. Usually certain crystal formations, traceable to the raw materials, remain unchanged in the fired article and have a pronounced effect on the properties and crystal structure of the fired product. Chemically pure raw materials are not used in commercial ceramic production; hence, the impurities may affect the color, and act as fluxes to lower the firing temperature of the ceramic material. It is understandable, then, that ceramic bodies of a similar type but made by different manufacturers have dissimilar properties.

Data on the physical and electrical properties, as supplied by the manufacturers, of a number of ceramic products are given in Table

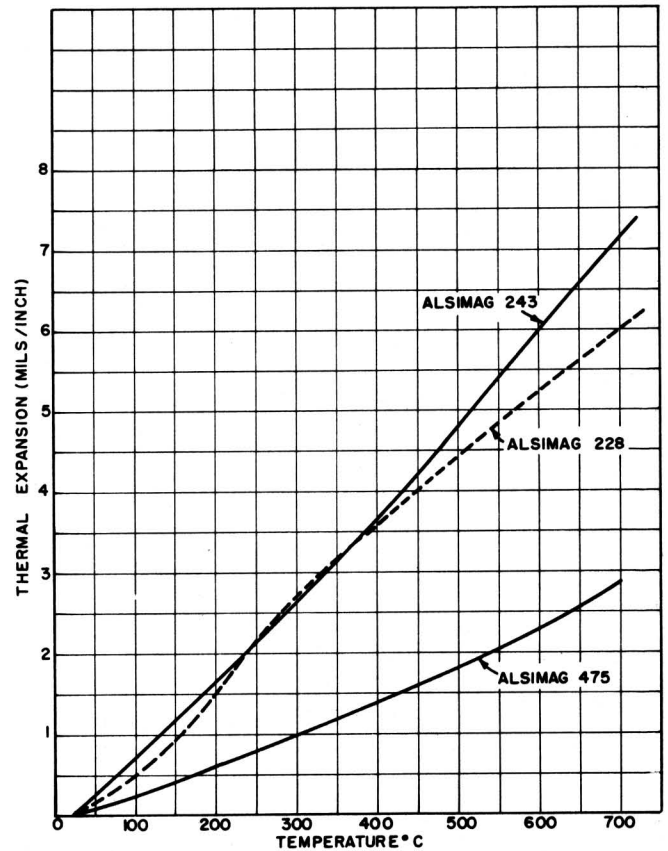


Fig. 5 - Thermal expansion curves of American Lava Co. ceramics.

II. These ceramic bodies are selected as some that might be most useful, from the standpoint of being gas tight and capable of being metalized for metal-to-ceramic seals. This list can be lengthened, of course, by investigating the products of other manufacturers. In Figs. 4 and 5 the expansion characteristics of a few ceramics are shown. The RCA ceramics listed in the table are experimental bodies and all of their properties have not been determined.

The electrical properties of ceramic bodies are of extreme importance for use in electron tubes, as well as in circuit components. This is particularly true in tubes where temperatures might rise in operation to such an extent that losses at radio frequencies become excessive. It is well known that glasses become very lossy at only moderately high temperatures and that tube failures can, and do, occur. On the other hand, certain ceramic bodies can be operated at near red heat and still have perhaps acceptable electrical losses.

The electrical characteristics of ceramics shown in Table II give  $T_e$  values. (The  $T_e$  value

Table II

Summary of Properties of Some Ceramic Bodies						
Ceramic Body Type No.	Steatite 302	Cordierite 400	Zirconite 452	Steatite BN2532	Steatite BN3030	Zircon M81
Manufacturer	Centralab	Centralab	Centralab	Gen. Cer. Co.	Gen. Cer. Co.	Gen. Cer. Co.
Specific gravity	-	-	-	2.7	2.8	3.1
Porosity %	0-0.005	0-0.007	0-0.005	0-0.05	0-0.05	0-0.05
Tensile strength psi	-	-	-	9500	9000	-
Compressive strength psi	-	-	-	81500	80000	91000
Modulus of rupture psi	20500	11600	17300	19000	20000	26500
Hardness Mohs scale	7-7.5	7-7.5	7.5	7.5	8	7
Thermal conductivity cgs units	-	-	-	0.006	0.006	-
Coefficient of expansion x 10 <sup>-6</sup>	6.9	1.9	3.3	6.5	6.0	2.95
20-100°C	8.5	-	-	-	-	-
20-300	-	-	-	7.8	7.3	5.15
20-400	-	-	-	-	-	-
20-600	-	3.1	4.0	-	-	-
20-1000	-	-	-	-	-	5.6
Thermal shock resistance	good	good	good	-	-	-
Softening temperature °C	-	-	-	-	-	-
Safe temperature °C	-	-	-	980	980	1196
T <sub>e</sub> value °C	-	-	-	700	700	700
Dielectric strength V/mil	260	250	215	240	200	250
Dielectric constant	5.82	5.4	8.65	5.85	6.3	7.1
Power factor	0.0011	0.0054	0.00165	0.0012	0.00065	0.0008
Volume resistivity	-	-	-	-	10 <sup>14</sup>	10 <sup>14</sup>
20°C	-	-	-	2x10 <sup>9</sup>	1.8x10 <sup>10</sup>	1.2x10 <sup>9</sup>
500°C	-	-	-	17x10 <sup>9</sup>	16x10 <sup>8</sup>	-
700°C	-	-	-	-	-	-

Table II

Summary of Properties of Some Ceramic Bodies				
Ceramic Body Type No.	Steatite SI-5	Steatite S-300	Zircon Z-200	
Manufacturer	DM Steward	DM Steward	DM Steward	
Specific gravity	2.5	2.75	3.0	
Porosity %	0-0.05	0-0.05	0-0.05	
Tensile strength psi	6500	8000	7500	
Compressive strength psi	77000	80000	90000	
Modulus of rupture psi	20000	21500	23000	
Hardness Mohs scale	-	-	-	
Thermal conductivity cgs units	-	-	-	
Coefficient of expansion $\times 10^{-6}$	6.5	6.0	4.5	
	20-100°C	7.0	5.5	
	20-400°C			
Thermal shock resistance	-	-	good	
Softening temperature °C	-	-	-	
Safe temperature °C	1285	1260	1232	
$\tau_e$ value °C	700	700	700	
Dielectric strength V/mil	210	250	235	
Dielectric constant	6.25	6.3	7.5	
Power Factor	0.0012	0.00065	0.0008	
Volume resistivity	$10^{19}$	$10^{14}$	$10^{14}$	
	$8 \times 10^{10}$	$3.1 \times 10^{12}$	$10^{11}$	
	$1.2 \times 10^7$	$1.64 \times 10^9$	$2.6 \times 10^7$	



Table II

Summary of Properties of Some Ceramic Bodies					
Ceramic Bodies Type No.	Alumina AI-200	Alumina AB-2	Zircon ZI-4	Sillimanite SI-1	
Manufacturer	Coors	Coors	Coors	Coors	
Specific gravity	3.63	-	2.85	2.78	
Porosity %	0.0	-	0.0	0.0	
Tensile strength psi	27000	20000	13000	12000	
Compressive strength psi	290000	225000	75000	80000	
Modulus of rupture psi	49000	45000	26000	27000	
Hardness Mohs scale	9	-	8	7.5	
Thermal conductivity cgs units	-	-	-	-	
Coefficient of expansion $\times 10^{-6}$					
25-200°C	6.67	-	3.36	4.5	
25-1000	9.14	-	5.78	5.9	
400-600	8.88	-	5.35	5.9	
600-800	10.33	-	7.7	6.6	
Thermal shock resistance	-	-	good	good	
Softening temperature °C	-	-	-	-	
Working temperature °C	1700	-	1400	-	
$T_e$ value °C	1070	-	515	-	
Dielectric strength V/mil			280-320	-	
175°C	-	-	-	-	
320	280-320	-	-	-	
500	100-120	-	30-35	-	
Dielectric constant					
100Kc 25°C	7.15	-	6.82	-	
1000Mc 25°C	8.16	-	6.16	-	
Power factor 2Kc	0.00065-0.00079	-	-	-	
Volume resistivity					
100°C	$4 \times 10^8$	-	$7.6 \times 10^8$	-	
250°C	$5 \times 10^7$	-	$4 \times 10^6$	-	

Table II

Summary of Properties of Some Ceramic Bodies						
Ceramic Body Type No.	Steatite 13889	Zircon-mullite 2570	Zircon 3569	Alumina-mullite 7873	Alumina 4462	Alumina 6096
Manufacturer	Frenchtown	Frenchtown	Frenchtown	Frenchtown	Frenchtown	Frenchtown
Specific gravity	2.68	2.84	3.08	2.97	3.52	3.44
Porosity %	0.0	0.0	0.0	0.0	0.0	0.0
Tensile strength psi	7500	4830	6980	10650	15500	13230
Compressive strength psi	74700	77600	62400	120000	187000	144400
Modulus of rupture psi	17080	19960	18000	28300	36070	29200
Hardness Mohs scale	-	-	-	-	9	-
Thermal conductivity cgs units	0.0057	0.0062	0.0072	0.0095	0.018	0.0144
Coefficient of expansion x 10 <sup>-6</sup>	5.47	2.0	2.94	4.4	-	5.33
25-100°C	6.58	3.36	4.05	5.72	6.11	6.85
25-400	7.28	3.82	4.49	6.42	7.29	7.42
25-700	-	3.9	-	7.4	-	7.7
25-871	-	-	-	-	-	-
Thermal shock resistance	-	good	good	good	good	good
Softening temperature °C	1388	1649	1549	1649	1930	1971
Safe temperature °C	-	-	-	-	-	-
$\alpha$ value °C	632	527	674	710	799	749
Dielectric strength V/mil	198	252	210	200	202	202
Dielectric constant	5.9	5.95	7.08	7.02	9.19	8.40
Power factor	0.0019	0.0032	0.00173	0.0014	0.00035	0.00086
	-	-	-	-	0.00055	-
Volume resistivity ohms/cm	-	-	-	-	-	-
200°C	1.4x10 <sup>8</sup>	12.8x10 <sup>6</sup>	14x10 <sup>7</sup>	13.3x10 <sup>6</sup>	1.95x10 <sup>8</sup>	2.2x10 <sup>8</sup>
400	1.23x10 <sup>7</sup>	4x10 <sup>6</sup>	3x10 <sup>6</sup>	4.7x10 <sup>6</sup>	1.44x10 <sup>7</sup>	7x10 <sup>6</sup>
600	-	-	-	0.4x10 <sup>6</sup>	1.3x10 <sup>6</sup>	0.6x10 <sup>6</sup>
800	-	-	-	-	-	-

Table II

Summary of Properties of Some Ceramic Bodies						
Ceramic Body Type No.	Steatite 196	Steatite 228	Forsterite 243	TiO <sub>2</sub> 192	Zircon 475	Alumina 491
Manufacturer	American Lava	American Lava	American Lava	American Lava	American Lava	American Lava
Specific gravity	2.6	2.7	2.8	4.0	3.7	3.5
Porosity %	0-0.02	0-0.02	0-0.02	0-0.02	0-0.02	0-0.02
Tensile strength psi	10000	10000	10000	7500	12000	-
Compressive strength psi	85000	85000	85000	80000	90000	100000
Modulus of rupture psi	20000	20000	20000	20000	22000	45000
Hardness Mohs scale	7.5	7.5	7.5	8.0	8.0	9.0
Thermal conductivity cgs units	0.006	0.006	0.008	0.009	0.012	0.02
Coefficient of expansion x 10 <sup>-6</sup> 25-100°C	7.3	6.4	9.1	7.3	3.2	6.2
25-700	8.6	8.9	10.6	8.7	4.1	7.7
Thermal shock resistance	-	-	-	-	good	-
Softening temperature °C	1440	1440	1440	1450	1440	1750
Safe temperature °C	1000	1000	1000	1000	1100	1400
T <sub>e</sub> value °C	750	820	1000	520	870	670
Dielectric strength V/mil	240	240	240	100	250	250
Dielectric constant	5.8	6.1	6.2	85	-	-
100 Mc	5.6	6.0	6.1	85	-	-
Power factor	0.0021	0.0013	0.0004	0.0005	0.0008	0.002
100 Mc	0.0014	0.001	0.0003	-	-	-
Volume resistivity ohms/cm <sup>2</sup> 25°C	10 <sup>14</sup>	10 <sup>14</sup>	10 <sup>14</sup>	10 <sup>12</sup>	10 <sup>14</sup>	10 <sup>14</sup>
100	1x10 <sup>13</sup>	10 <sup>14</sup>	5x10 <sup>13</sup>	9.8x10 <sup>11</sup>	2x10 <sup>13</sup>	10 <sup>14</sup>
300	6.5x10 <sup>9</sup>	8x10 <sup>10</sup>	7x10 <sup>11</sup>	1x10 <sup>9</sup>	5.5x10 <sup>11</sup>	1.7x10 <sup>11</sup>
700	1.8x10 <sup>6</sup>	5x10 <sup>6</sup>	1x10 <sup>6</sup>	2.5x10 <sup>4</sup>	1.4x10 <sup>7</sup>	6.2x10 <sup>6</sup>

Table II

Summary of Properties of Some Ceramic Bodies					
Ceramic Bodies Type No.	Steatite F-66	Zircon	Forsterite 102351-2	Zircon 661A	Zircon
Manufacturer	Bell Labs	Westinghouse	RCA	RCA	RCA
Specific gravity	-	3.68	-	-	-
Porosity	0.1	0.0	0.0	-	-
Tensile strength	-	12700	-	-	-
Compressive strength	-	90000	-	-	-
Modulus of rupture	-	-	-	-	-
Hardness	-	8.0	-	-	-
Thermal conductivity	$5 \times 10^{-8}$	0.0117	-	-	-
Coefficient of expansion $\times 10^{-6}$	-	4.9	9.3	4.3	4.3
		-	11.2	-	-
Thermal shock resistance	-	good	-	good	good
Softening temperature	1275	-	-	-	-
Safe temperature	1000	1050	-	-	-
$\alpha$ value	-	700	-	-	-
Dielectric strength	-	290	-	-	-
Dielectric constant	6.3	9.2	6.47	-	-
Power factor	0.0005	0.001	-	-	-
	0.00055	-	-	-	-
Volume resistivity	-	$10^{13}$	-	-	-

## Ceramic-Metal Seals of the Tungsten-Iron Type

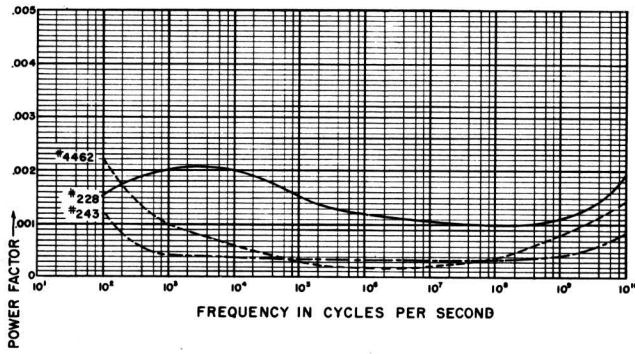


Fig. 6 - Power factor curves of ceramics: No. 4462 (Frenchtown) at 25°C; No. 228 (Alsimag) at 25°C; No. 243 (Alsimag) at 22°C.

of a ceramic is the temperature at which the volume resistivity is one megohm.) Usually this is not of great importance. What may be of more importance in a radio tube is that in the processing operation evaporated metal may deposit on the ceramic surface and so lower the surface resistivity. In the tungsten-iron method of metalizing, evaporation is not troublesome. In subsequent brazing operations, particularly with silver or its alloys, there is greater possibility of surface contamination, although care in brazing will minimize this trouble. Should contamination occur, it can be

avoided for the most part by painting or spraying a light layer of alumina on the ceramic before brazing. Later this alumina can be removed easily.

Operation of tubes in high-frequency circuits involves dielectric losses, as well as losses due to conduction by the metal parts that carry currents. The latter includes areas of contact (ceramic-to-metal seals) between insulator and metal. Losses in seals are of particular concern, but a satisfactory method for making measurements is not so far available.

The power factor values shown in the table indicate what may be expected of a ceramic that is exposed to high-frequency electric fields. Unfortunately, the data do not include power factors of ceramics at elevated temperatures.

Curves showing the power factor of three ceramic bodies over a range of 100 cycles to 10<sup>10</sup> cycles are shown by Fig. 6. Measurements on dielectric loss for ceramics Alsimag 243, and Alsimag 228, as shown by Fig. 6, are from "Tables of Dielectric Materials", issued by the Laboratory for Insulation Research, Massachusetts Institute of Technology. Data for the curve for ceramic No. 4462 were prepared by M.I.T. and supplied by the Frenchtown Porcelain Co.

Appendix II

Metals for Ceramic Seals

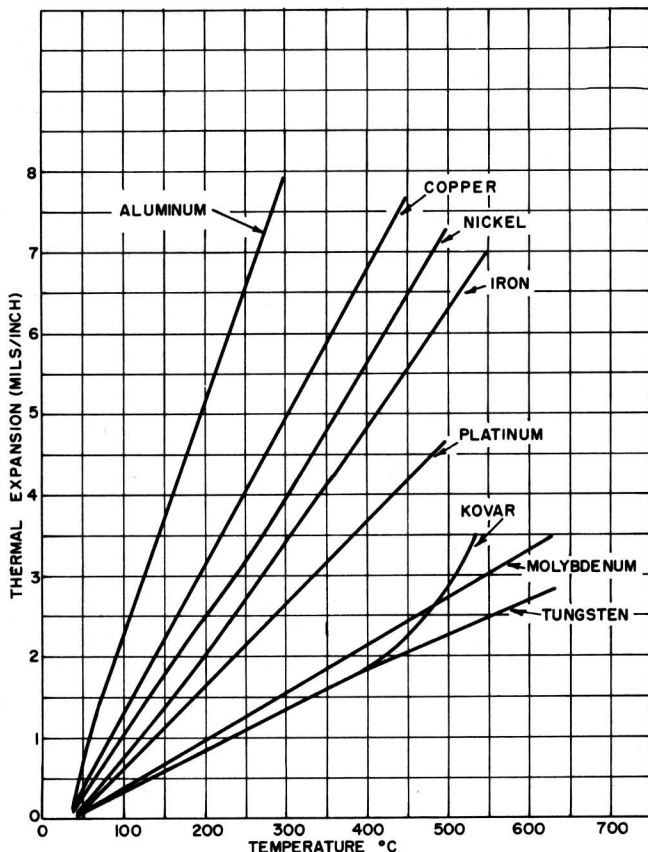


Fig. 7 - Linear thermal expansion curves of some metals.

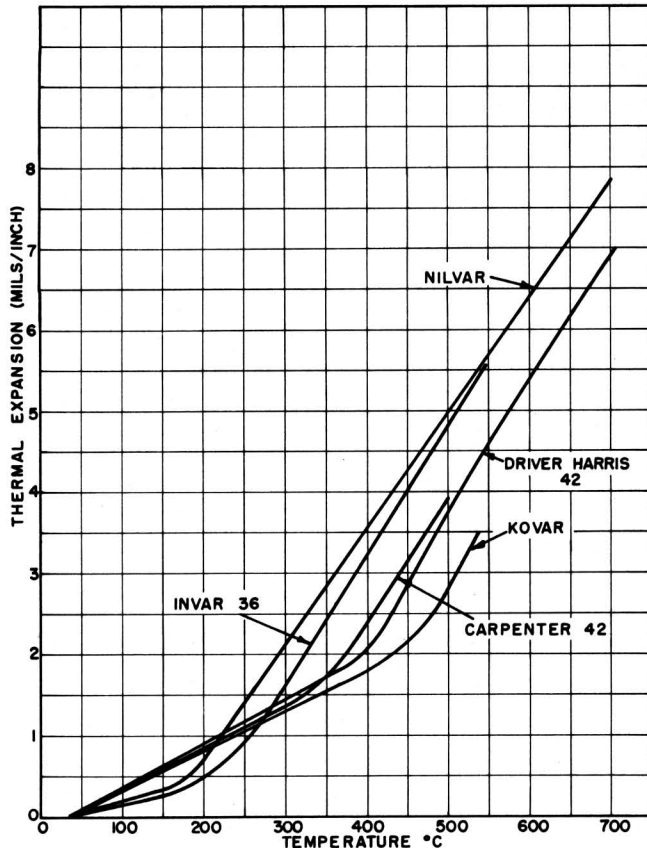


Fig. 8 - Expansion-temperature curves of some alloys having pronounced inflection temperature regions.

Where two materials of widely different properties are rigidly attached to each other it is evident that one or the other or both must be ductile, or have "give" enough to avoid stress that would cause failure. Ceramics are by their nature relatively unyielding materials. Hence, should a permanent bond between a ceramic and a metal be desired, it is necessary that the metal be capable of yielding to any dimensional changes imposed by the ceramic.

There are but few metals to match the range of expansion coefficients of the few ceramic bodies useful in tube structures. None of the pure metals has practical value for sealing to a ceramic unless they have high ductility, through heat treatment, and unless thin edges are formed on them to which a seal is adapted. Copper and nickel are valuable in

this respect. Tungsten, titanium, molybdenum, and a few other metals have expansion properties not far removed from those of some ceramics, but have drawbacks, chiefly that of not being subject to satisfactory annealing. Platinum and palladium have more ideal properties, but there is the obvious objection of cost to their use.

Expansion curves of several pure metals and of kovar are shown by Fig. 7.

Several alloys specially developed for sealing purposes are available. None has perfect properties for ceramic seals but some are within practical limits. Nearly all of these are iron-nickel base alloys, the dilation behavior of which is a function of the nickel-to-iron content, although some of these are modified by additions such as cobalt, chromium

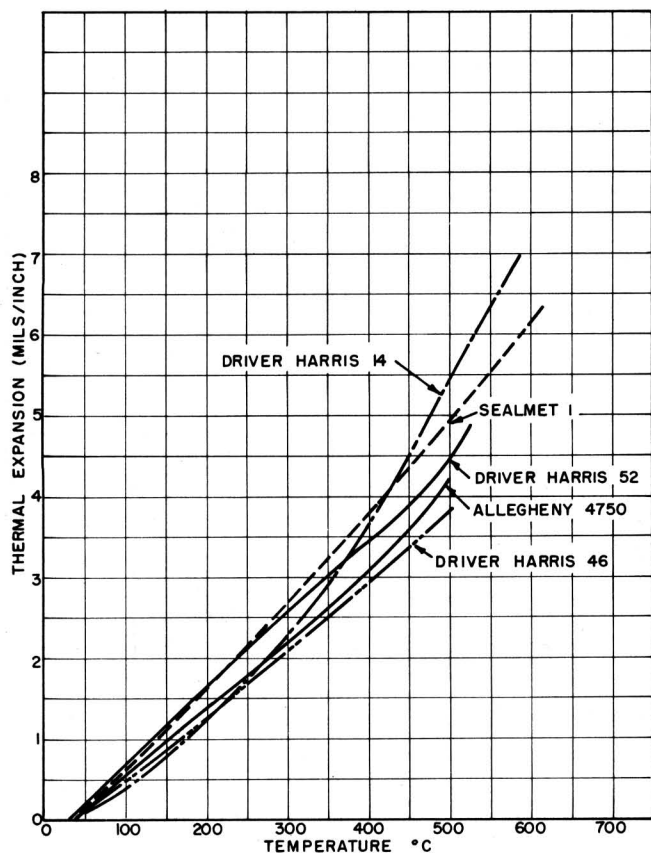


Fig. 9 - Linear thermal expansion curves of some sealing alloys.

and manganese. Beginning at 36 per cent nickel in an iron-nickel alloy (invar), the expansion is low and fairly constant up to a moderate temperature (200°C). In this region a magnetic inversion or Curie temperature occurs and a change to a higher expansion coefficient begins. Sealing alloys having inflection points are shown by Fig. 8. This occurrence should be recognized in applying these alloys.

The properties of metals are given in Table III and additional curves of expansion are shown in Figs. 9 and 10.

A metal for an "outside seal" is one that has a slightly higher expansion than that of the ceramic. When the metal part embraces the ceramic part, the joint remains under compression and dangerous tensile stresses are avoided. Thin metal, of the order of 5, 10, or 15 mils thickness, at or near the seal, depending on several factors, should be used whenever possible. The thin metal parts should be sufficiently elastic so that the tensions caused by rapid temperature changes do not damage the seals.

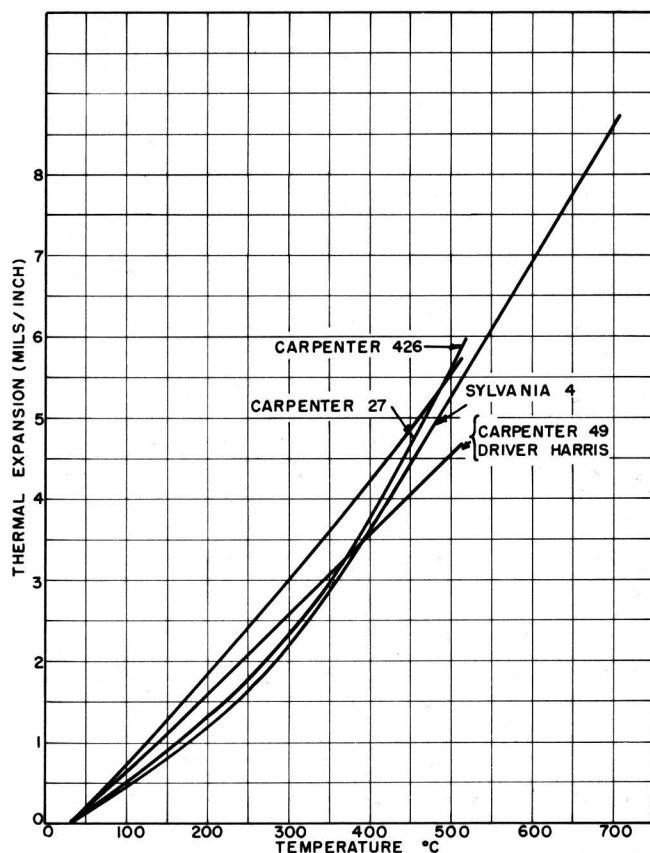


Fig. 10 - Linear thermal expansion curves of some sealing alloys.

Fig. 11 compares alloys D.H. 46 and D.H. 42 with the ceramic No. 4462. The match in expansion is not as good as desired, but the graph indicates the variations that must be considered. Fig. 12 compares No. 4 and No. 49 alloys with forsterite No. 102351-2, and also kovar with zircon. In connection with the properties of pure metals and alloys, the data require interpretation and consideration. Variations in composition, structure, and manufacturing practices produce corresponding variations in the properties of the metals.

As stated elsewhere, not only reasonable expansion match between the metal and ceramic, but also ductility of the metal, is required to produce a safe seal. Ductility comes partially from annealing. In the "as supplied" condition, metals are generally hard. The plastic deformation that results from cold working alters the properties of a metal by hardening. Relying on an average condition, the heat-treatment temperatures given in the table are based on experience.

## Ceramic-Metal Seals of the Tungsten-Iron Type

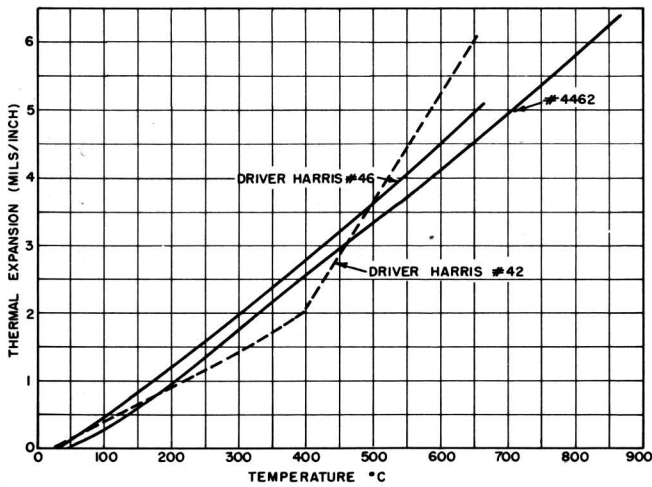


Fig. 11 - Linear thermal expansion curves of No. 4462 Porcelain; Driver Harris alloy No. 46; Driver Harris alloy No. 42.

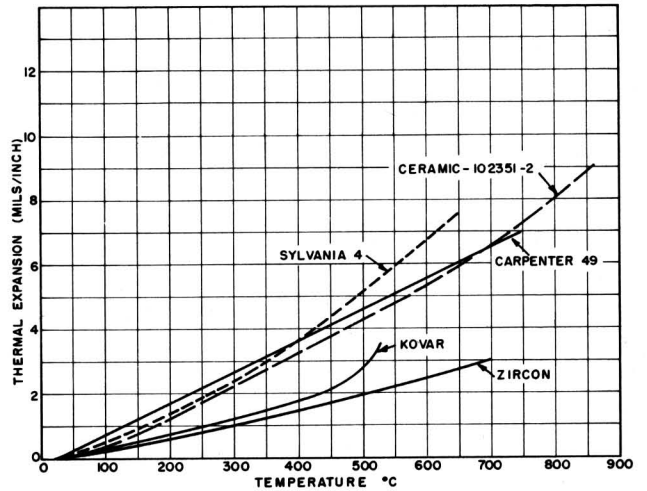


Fig. 12 - Thermal expansion curves to indicate match between No. 4 alloy and Forsterite; No. 49 alloy and Forsterite; Kovar and Zircon.

Data on materials are often given in different units, there being no universal system. In a single technical report one may find more than one system of units used. As a matter of convenience these conversion factors are here given:

$$\text{Cal}/(\text{sec})(\text{cm}^2)(^\circ\text{C}/\text{cm}) = 4.183 \text{ watts}/\text{cm}^2(^\circ\text{C}/\text{cm})$$

$$\text{Btu}/(\text{hr})(\text{ft}^2)(^\circ\text{F}/\text{in}) = 3.445 \times 10^{-4} \text{ cal}/(\text{sec})(\text{cm}^2)(^\circ\text{C}/\text{cm})$$

$$\text{Expansion: mil}/\text{in}/^\circ\text{C} = 1.8 \text{ mil}/\text{in}/^\circ\text{F}$$

$$\text{Electrical resistivity: ohms}/\text{cir mil}/\text{ft} = 6.015 \text{ microhm-cm}$$



Ceramic-Metal Seals of the Tungsten-Iron Type

Table III

PROPERTIES OF METALS							
Metal Type or No.	Tungsten	Molybdenum "D"	Platinum	Nickel "A"	Copper O.F.H.C.	Iron 1010	
Supplier	Fansteel Mallory Phillips Westinghouse	Fansteel Mallory Phillips Westinghouse	Baker and Co. Amer. Plat. Sigmund Cohn J. Bishop and Co.	Driver Harris Whitehead Co. I. N. Co. -	- - - -	- - - -	
Composition	W. 99.9% - - - -	Mo 99.9% - - - -	Pure Pt - - - -	Ni 99% Cu 0.2% Fe 0.3% Mn 0.35% C 0.2% Si 0.008	Pure Cu - - - -	C 0.10% Mn 0.4% P 0.04% S 0.05% Fe bal. -	
Melting point °C	3400	2625	1773	1450	1083	1535	
Coefficient of expansion x 10 <sup>-6</sup> 20°C	4	5.45	-	12.8	16.6	11.7	
20-450	-	-	9.4	-	17.5	-	
20-500	-	-	-	15	-	-	
Thermal conductivity cas units 20°C	0.399	0.349	0.167	0.14	0.928	0.161	
Heat treatment °C	1000. 20-30min	1000. 3min	600. 5min	900. 10min	900. 10-20min	900. 10-20 min	
Anneal in atmosphere	He or vac.	H <sub>2</sub>	H <sub>2</sub> or air	H <sub>2</sub>	H <sub>2</sub>	H <sub>2</sub> or dry H <sub>2</sub>	
Specific resistance microhm/cm 20°C	5.48	5.17	10.8	10	1.724	10	
Magnetic	No	No	No	Yes	No	Yes	

Table III

PROPERTIES OF METALS						
Metal Type or No.	Kovar	Fernico	Sylvania	Invar "36"	Titanium	
Supplier	Stupakoff	Gen. Elec.	Sylvania	Carpenter Steel Co.	E.I., du Pont Remington Arms Allegheny Ludlum	
Composition	Ni 29% Co 17% Fe 53.7% Mn 0.3%	Ni 28% Co 18% Fe 54%	Ni 42% Cr 5.6% Fe 52.35%	Ni 36% Fe 64% Mn 0.5%	Ti 99.5%	
Melting point	1450	1450	-	1495	1725	
Coefficient of expansion x 10 <sup>-6</sup>	30-100°C	-	-	0.8	-	
	25-200	-	-	-	9.1	
	30-300	4.4-5.7	-	-	-	
	30-400	-	9.6-10.2	-	8.5	
	20-500	5.7-6.2	-	-	-	
	30-800	-	-	-	9.9	
Thermal conductivity	0.046	-	0.032	-	-	
Heat treatment	1050, 15min	-	1050, 15min	-	-	
Annéal in atmosphere	H <sub>2</sub>	H <sub>2</sub>	dry H <sub>2</sub>	H <sub>2</sub>	He, A or vac.	
Specific resistance	49	-	34	-	61	
Magnetic	Yes	Yes	Yes	Yes	Para	

Table III

Properties of Metals						
Metal Type or No.	No. 14 Alloy No. 14	No. 42 Alloy No. 42	No. 46 Alloy No. 46	No. 52 Alloy No. 52	Nilvar	
Supplier	Driver Harris	Driver Harris	Driver Harris	Driver Harris	Driver Harris	Driver Harris
Composition	Ni 42% Cr 55% Fe 52.5%	Ni 42% Fe 58%	Ni 46% Fe 54%	Ni 51% Fe 49%	Ni 36% Fe bal	
Melting point	1425	1425	1425	1425	1425	
Coefficient of expansion $\times 10^{-6}$	-	-	-	-	1.0	
	-	-	-	-	-	
	-	5.3	-	-	-	
	10.8	-	8.0	-	-	
	-	-	-	9.5	-	
Thermal conductivity	0.032	0.038	0.0365	0.04	0.0264	
Heat treatment	1050. 15min dry H <sub>2</sub>	1050. 15min H <sub>2</sub>	1050. 15min H <sub>2</sub>	1050. 15 min H <sub>2</sub>	- H <sub>2</sub>	
Anneal in atmosphere						
Specific resistance	93	66.5	45.7	43.2	80.5	
Magnetic	Yes	Yes	Yes	Yes	Yes	

**Ceramic-Metal Seals of the Tungsten-Iron Type**

**Table III**

Properties of Metals						
Metal Type or No.	Carpenter No. 27	Carpenter No. 42	Carpenter No. 49	Carpenter No. 426	Chrome Iron No. 430	Copper-clad chrome-iron No. 430
Supplier	Carpenter Steel Co. - -	Carpenter Steel Co. - -	Carpenter Steel Co. - -	Carpenter Steel Co. - -	Latrobe Steel Co. Allegheny Ludlum	- - - -
Composition	Cr 27% C 0.15% Fe bal -	Ni 41% C 0.1% Fe 58.4% -	Ni 49% C 0.1% Fe 50.9% -	Ni 42.5% Cr 5.75% C 0.1% Fe 51.65% -	Cr 16-18% Mn 1.0 max Si 1.0 max Ni 0.5 max Fe bal	- - - -
Melting point °C	-	-	-	-	1480	-
Coefficient of expansion $\times 10^{-6}$	20-300	-	9.0	-	9.5	-
	20-350	-	-	9.2	-	-
	20-400	5.3	-	-	-	-
	20-500	-	-	-	11.2	-
	20-815	-	-	-	11.8	-
Thermal conductivity cgs units	0.06	0.038	0.04	0.032	0.054	-
Heat treatment °C	1050 20min	1050 20min	1050 15min	1050 20min	1000 20min	-
Anneal in atmosphere	dry H <sub>2</sub>	H <sub>2</sub>	H <sub>2</sub>	dry H <sub>2</sub>	dry H <sub>2</sub>	dry H <sub>2</sub>
Specific resistance microhms/cm	72	71	-	34	60	-
Magnetic	Yes	Yes	Yes	Yes	Yes	-

Ceramic-Metal Seals of the Tungsten-Iron Type

Table III

Properties of Metals						
Metal Type or No.	Alleghehy No. 28 Stainless 446	Alleghehy No. 42	Alleghehy No. 4750	Sealmet No. 1 No. 1	Sealmet No. 4 No. 4	
Supplier	Alleghehy Ludlum	Alleghehy Ludlum	Alleghehy Ludlum	Alleghehy Ludlum	Alleghehy Ludlum	
Composition	Cr 23-27 Mn 1.5% Ni 1.0% C 0.35% Si 0.75% Fe bal	Ni 42% Fe 58%	Ni 48% Fe 52%	Cr 28% Fe bal	Ni 42% Cr 6% Fe bal	
Melting point °C	1490	-	-	-	-	
Coefficient of expansion x 10 <sup>-6</sup>	20-100 °C 20-200 20-400 20-500 20-600 20-1000	4.6 4.7 5.6 7.8 9.3	8.4 8.8 9.1 9.8 10.8 13.5	9.8 9.9 10.8 11.0 11.4	7.3 7.4 9.8 11.1 11.9	
Thermal conductivity cgs units 20 °C	0.05	0.026	0.037	0.059	0.029	
Heat treatment °C	1000, 20min dry H <sub>2</sub>	1050, 20min H <sub>2</sub>	1050, 20min H <sub>2</sub>	1000, 15min dry H <sub>2</sub>	1050, 20min dry H <sub>2</sub>	
Anneal in atmosphere	67 Yes	66 Yes	50 Yes	72 Yes	94 Yes	
Specific resistance microhms/cm 20 °C						
Magnetic	Yes	Yes	Yes	Yes	Yes	