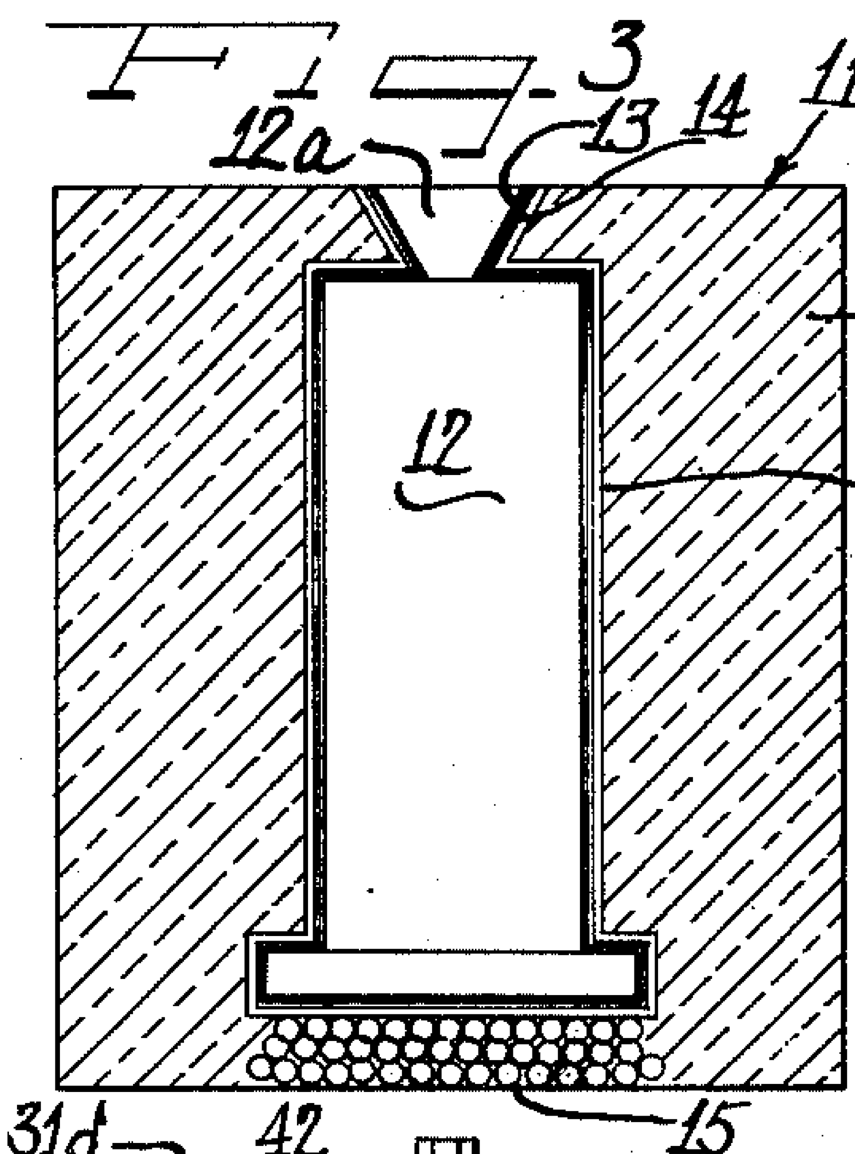
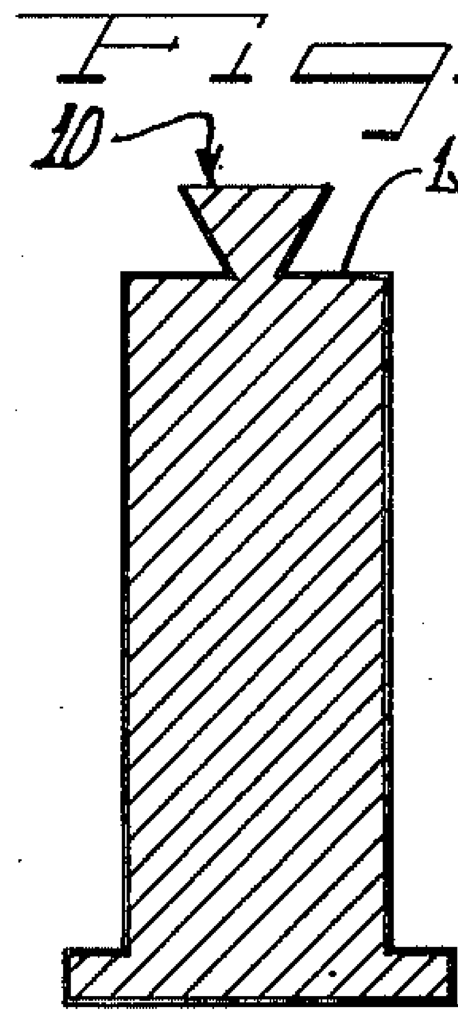
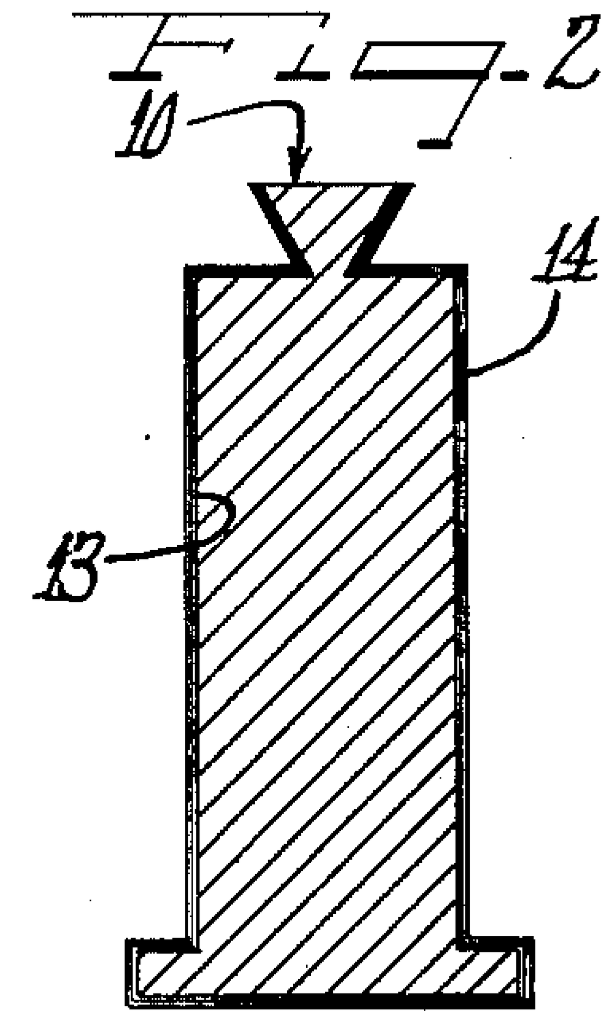
Sept. 17, 1957 T. OPERHALL 2,806,271

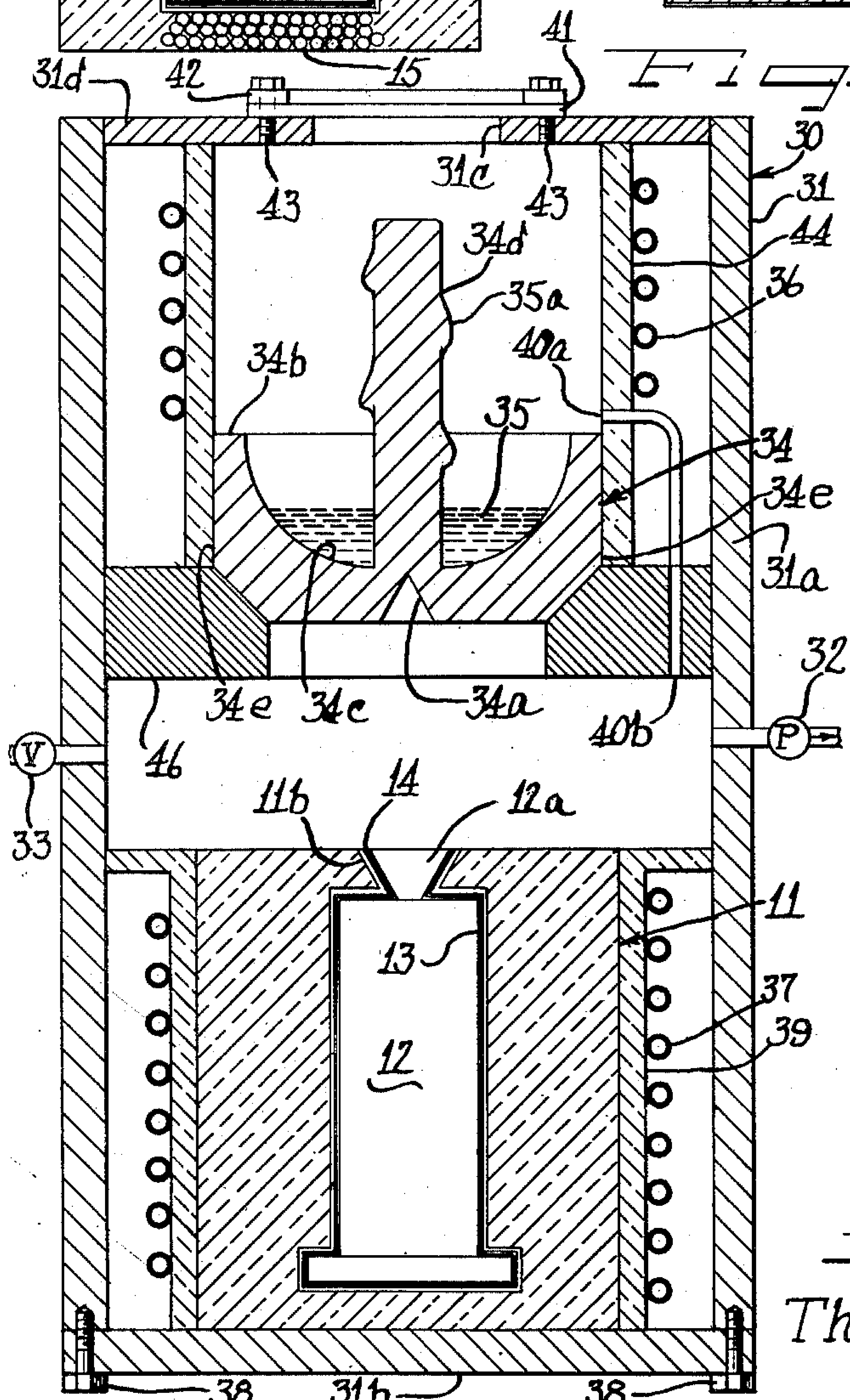
PROCESS OF CASTING TITANIUM AND RELATED METAL AND ALLOYS

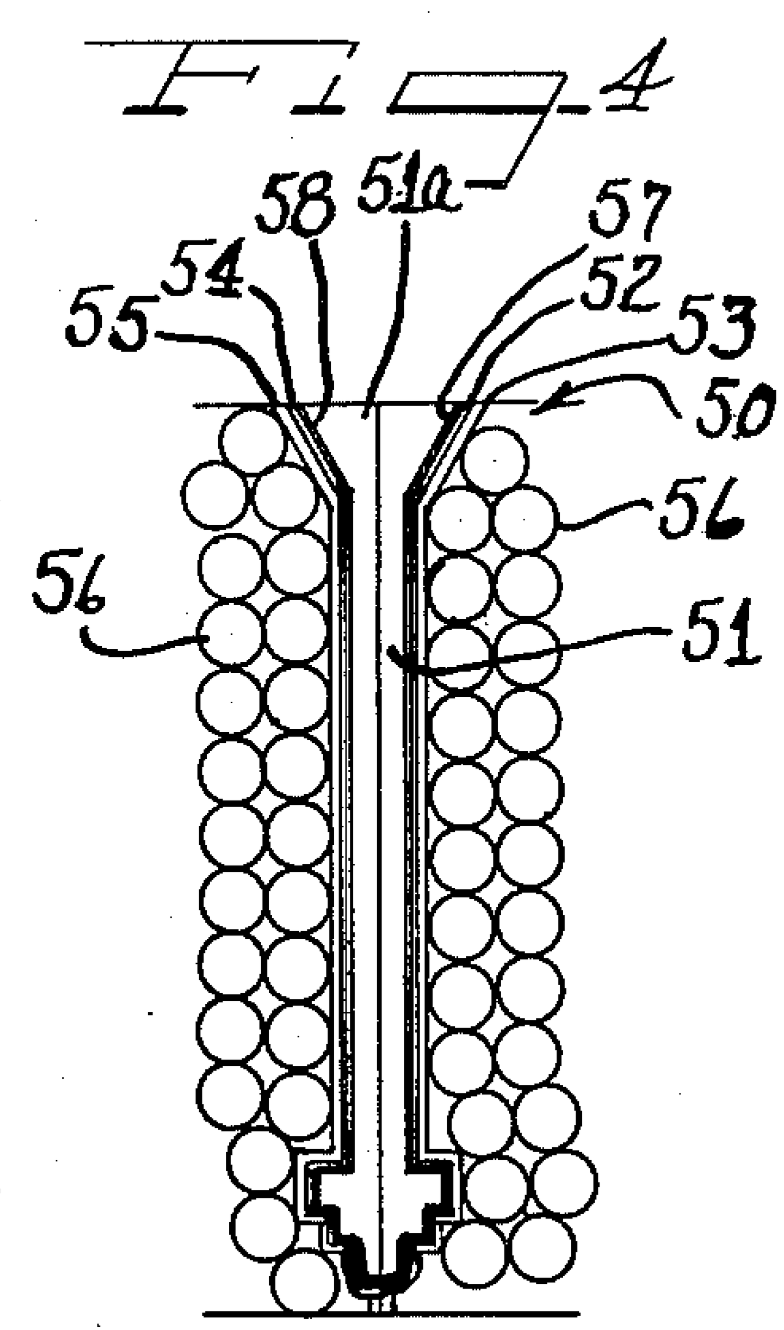
Filed April 5, 1956 2 Sheets-Sheet 1











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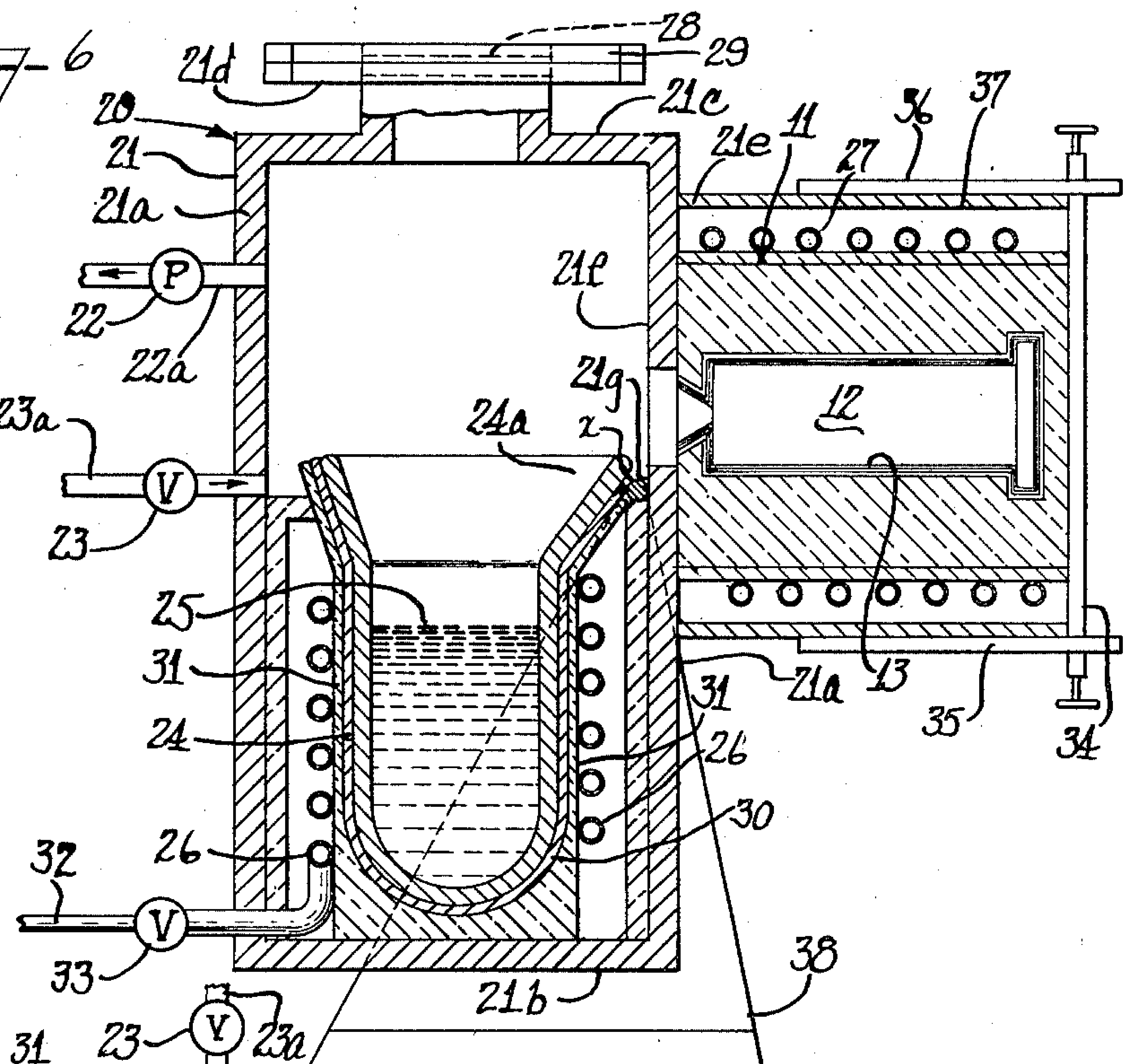
PROCESS OF CASTING TITANIUM AND RELATED METAL AND ALLOYS

Filed April 5, 1956 2 Sheets-Sheet 2

Fig-6



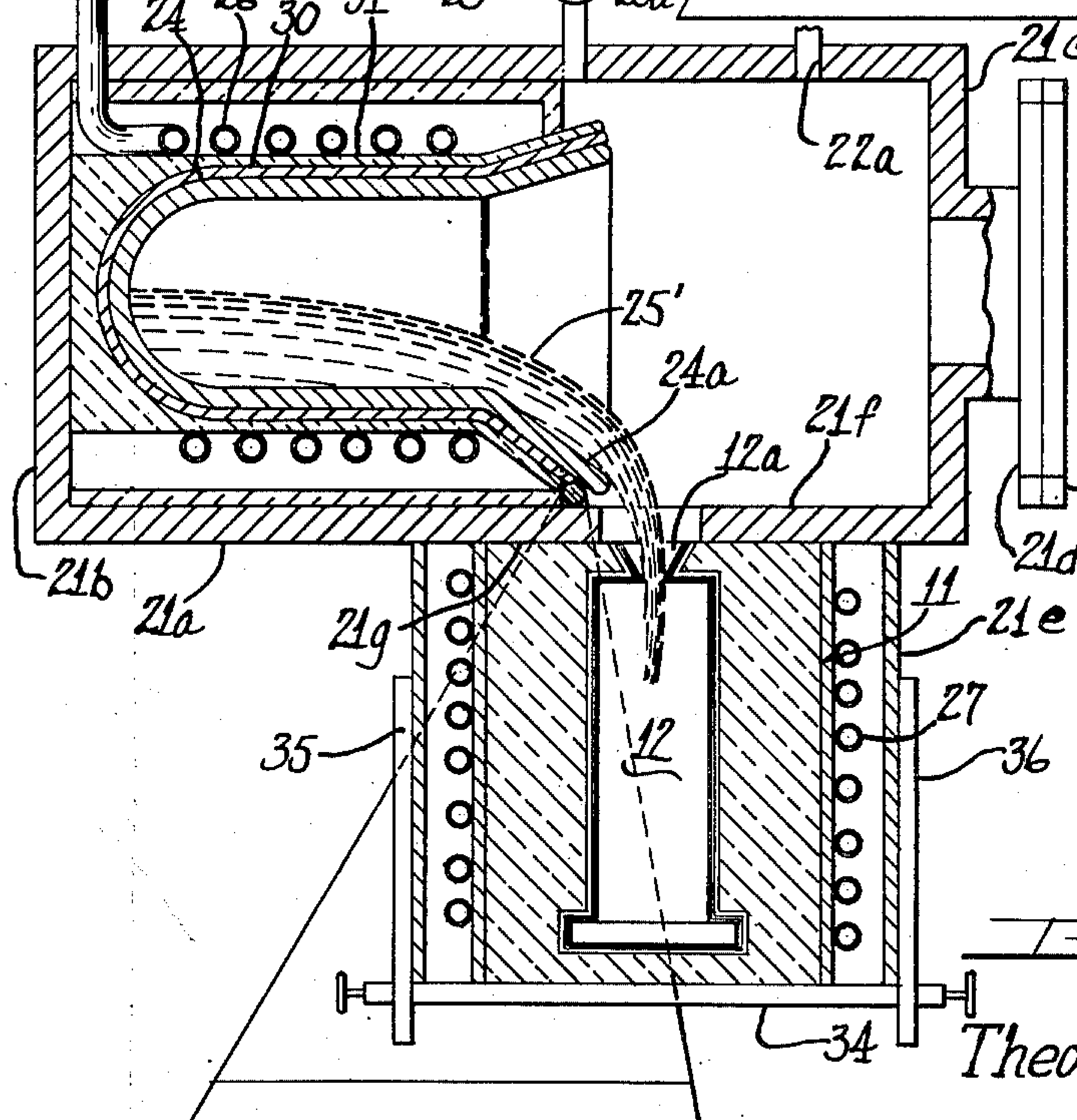


Fig-7

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2,806,271

PROCESS OF CASTING TITANIUM AND RELATED METAL AND ALLOYS

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Application April 5, 1956, Serial No. 576,311

5 Claims. (Cl. 22—200)

This invention relates to a method for casting metals of the group IV–A in the periodic system, as represented by the metals titanium, zirconium and hafnium, and it relates more particularly to the process of casting titanium in sand molds, such as in the process of shell or investment casting.

This application is a continuation-in-part of application Ser. No. 419,814, filed March 30, 1954, entitled "Process of Casting Titanium and Related Metals and Alloys and Apparatus Therefor" now abandoned.

As is well known in the art, titanium is a highly reactive material while in the molten state. As a result, certain precautions are taken in the melting of titanium and in the processing thereof to avoid exposure to oxygen, hydrogen, nitrogen, carbon and compounds thereof. These same conditions arise in the processing of molten titanium and alloys thereof in the production of castings. The high solubility rate of the titanium for the various gases, other than the inert gases, and the high affinity of the molten metal for various metals and metal oxides, such as the oxides of silicon and the like which are employed extensively in shell and in investment casting processes, makes it difficult to produce a casting of acceptable quality of titanium. The behavior of zirconium and hafnium is substantially comparable to that of titanium in most of these respects and, for these reasons, the problems involved in the casting of zirconium and hafnium and alloys thereof are substantially similar.

It is an object of this invention to provide a new and improved method and means for use in the production of castings of the group IV–A metals and alloys thereof.

Another object is to provide a method and means for use in the investment and shell mold casting of the metals of the group IV–A and alloys thereof and it is a related object to provide a method of the type described to produce an acceptable casting of titanium and alloys thereof.

A further object is to provide a furnace for use in casting such metals as titanium, zirconium and hafnium wherein use is made of a closed housing, evacuating means for drawing a vacuum in the housing, inlet means for introducing an inert gas into the housing, a crucible in said housing for retaining the metal in molten form therein, a first heating means for the crucible, a mold member in the housing positioned to receive molten metal from an outlet on the crucible, a solid lining of said metal defining a cavity in the mold member, and a second heating means mounted in the housing for the mold.

These and other objects and advantages of this invention will hereinafter appear and for purposes of illustration, but not of limitation, an embodiment of the invention is shown in the following drawings in which—

Figure 1 is an elevational view of an expendable investment casting pattern prepared in accordance with the teaching of this invention;

Figure 2 is a view in elevation of the expendable investment casting similar to that of Figure 1 but illustrating a preferred practice of this invention;

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Figure 3 is a view in elevation of an investment casting mold formed by the use of the expendable patterns shown in Figures 1 and 2;

Figure 4 is a sectional elevational view of a shell mold prepared in accordance with the teaching of this invention;

Figure 5 is a sectional elevational view of a furnace embodying the features of this invention;

Figure 6 is a sectional elevational view of a modification of a furnace which may be employed in the practice of this invention; and

Figure 7 is a sectional view of the furnace shown in Figure 6 in a different operating position.

While invention herein relates to all of the metals of the group IV–A of the periodic system, as represented by titanium, zirconium and hafnium, and to alloys thereof, description hereinafter will be made using titanium as representative and the preferred metal of said group.

It has been found, in accordance with the practice of this invention, that reaction with the molten titanium at the surface portion of the casting can be alleviated and substantially completely avoided so as to produce an acceptable casting of titanium, zirconium, hafnium or of the alloys thereof when the mold cavity into which the molten metal is cast is lined in advance with a continuous film of the metal to be cast and which is sufficient to function as a barrier between the molten metal and the remainder of the body of the mold. The barrier film can be formed on the walls of the mold cavity in green sand casting or in molds such as shells used in shell molding and the barrier film can be provided as a lining about the mold cavity by first applying the film to an expendable pattern, followed by investment of the expendable pattern and subsequent removal, as by burning out the pattern or by solution, to leave the barrier as a film lining the mold cavity. In the same sense, the investment casting procedure can be advantageously carried out in accordance with the teaching of the invention by the application of the barrier film as a coating to a cluster formed of expendable wax patterns suitably mounted with expendable gates and runner attachments.

While a barrier film of infinitesimal thickness is usually sufficient to prevent reaction, such for example as between the cast molten titanium and the silicon oxide particles and other reactive ingredients present in the body of the mold, by reason of substantially instantaneous cooling and solidification of an outer integral surface layer of the material cast, thereby immediately to build up the thickness of the barrier, it is the preferred practice of this invention to make use of a metal coating on the outer surface of the barrier film wherein the coating is formed of a metal characterized by high heat conductivity, such for example as copper. In the use of an outer layer of a metal of high heat conductivity, the heat is conducted away rapidly from the surface of the metal cast to produce a rapid and almost immediate hardening of surface portions of the casting thereby to prevent break-through of the barrier film even though the latter is almost of immeasurable thickness. Under such circumstances, it is only necessary to make use of a barrier film of titanium which is continuous but which could ordinarily be incapable of self-sufficiency but which serves as a completely non-reactive barrier and as a base for the application of the heat conductive layer of copper and the like.

The barrier film of titanium becomes integrated with the casting to become a part thereof but calculations for its thickness will be unnecessary in mold design because its thickness would, in general, be less than the tolerances available for such casting and its use would tend to hold the casting more accurately to the tolerances required. When a heat conductive coating of another metal, such as copper, is provided on the barrier film of titanium, removal from the casting is usually necessary thereby to produce a product having a protective surface. Such removal can be effected by electrolytic means or by solution in chemicals and the like.

To the best of my knowledge, no one before has made use of a film formed of titanium about the surface portion of the mold cavity to protect the titanium cast into the mold against deterioration by reactions or by contaminations with the oxides or oxygen compounds and other materials present in the body of the mold. To the best of my knowledge, no one before has made use of a layer of a metal having a high heat conductivity as an outer layer about the barrier film of titanium for the purpose of conducting heat away from the film sufficiently rapidly to prevent break-down of the film upon engagement by the large mass of molten titanium cast into the mold.

Bodger, in Patent No. 2,510,735, teaches the use of a metallic layer for lining the mold cavity in the manufacture of turbine vanes but its use and the purposes therefor differ from the invention described and claimed herein to the extent that Bodger offers no suggestions for overcoming the problems involved in the casting of molten titanium in sand molds or shells and the system described by Bodger cannot be employed in the practice of this invention.

More specifically, Bodger is concerned with the problem of achieving a good surface finish on a casting of turbine vanes. For this purpose, he makes use of a pattern of wax upon which he forms a shell of the metal which differs from the material to be cast to form the turbine blades or vanes and which is of sufficient thickness to remain intact and form the surface on the cast blade so that the finish of the metal on the expendable pattern will represent the finish in the cast product. Thus the thickness of the shell of Bodger is sufficient to maintain its shape and integrity under the conditions existing in molding and it becomes integrated with the cast metal to provide the smooth surface portion integrally bonded to form a part of the vane.

The invention herein differs materially from that which is described in the Bodger patent, not only from the standpoint of the differences in the problems faced but in the solutions thereof since the Bodger patent fails to teach a method for casting titanium by providing a film of the same metal about the mold cavity to protect the molten material against contact for reaction with the oxygen or oxides and which becomes integrated with the cast titanium to form a mono-metallic system having a surface free of corrosion or attack.

In the Couse Patent No. 1,912,889, a teaching exists with respect to the use of copper as a film applied to a metal layer but the amount of copper is insufficient to achieve the desired chilling action secured by the combination of the copper layer on the barrier film of titanium in the system described herein and no one in the prior art, it is believed, has ever employed the combination of steps which includes applying the copper to form a heat conductive layer on the titanium barrier film followed by removal from the final product after casting titanium in the mold cavity thereby to produce a mono-metallic casting of titanium.

Having described the concepts of this invention, reference will now be made to the drawings for a specific description of the invention.

In Figures 1 and 2, the reference numeral **10** indicates generally the expendable relatively low melting pattern which is formed as an initial step in the investment casting art. Actually, in the investment casting procedure, it is necessary to start with a master pattern (not shown) which has the configuration of the article ultimately to be formed and which is designed to compensate for process shrinkage of the expendable (e. g. wax) pattern and the metal to be cast. This master pattern is preferably made of brass and it is then cast in, for example, a tin-bismuth alloy to produce an injection mold (not shown), which in turn is employed to cast the relatively low melting expendable pattern **10**.

In a preferred process, the expendable pattern is made of a wax composition having been injection molded in the tin-bismuth alloy at 155° F. with pressures of 500 to 1000 pounds per square inch. Other expendable materials may be used, however, such as various plastic materials, preferably the thermoplastic synthetic resin materials, and various low melting metal alloys which are known to be used in this art.

After the wax pattern **10** has been injection molded, with suitable gates and runners attached thereto, the usual procedure calls for the mounting of a plurality of the wax patterns **10** on supporting members so as to assemble a "cluster" which provides through its supporting members (also made of wax) the necessary expendable pattern members for the subsequent formation of gates and runners in the investment mold. In the customary procedure, this step is followed by the various dipping and "investment" steps whereby the wax pattern is ultimately mounted in a monolithic mold, which is then heated so as to melt out the wax pattern and provide a cavity therein of the required configuration.

In the instant invention, however, the procedure just mentioned is changed, for the reason that a normal monolithic mold ordinarily obtained in the investment casting process presents refractory oxide cavity walls which are readily attacked by molten titanium or zirconium. The net result would be a very substantial contamination of the casting, so as substantially to destroy its desirable commercial properties. In the investment casting procedure embodying the instant invention, the mold (indicated generally at **11** in Figure 3) is provided with a cavity therein, at **12**, for defining the article to be cast and having a lining **13** in the form of a thin layer of the metal or metals of group IV–A to be cast therein. This lining **13** forms a barrier between the molten metal which is cast in the cavity **12** and the refractory oxides which form the matrix **11***a* of the mold **11**.

Unfortunately titanium and the other metals of group IV–A are very peculiar in their behavior in many respects. Aside from the very great difficulty in handling these metals in molten form, they are also incapable of being electroplated or chemically deposited from solution to form the desired barrier film. As a result, it has been necessary to devise means for providing the described film about the mold cavity. It has been found, however, that a film of sufficient dimension can be formed of these materials on a given surface by the technique of sputtering or deposition by condensation in a vacuum when carried out on the expendable pattern **10**, before subsequent investment casting steps are carried out. Vacuum deposition of the metal involves the steps of vaporizing the metal by the use of heat under vacuum conditions in the presence of the pattern **10** so as to deposit a film **13** of the metal on the surface of the pattern **10**.

Vacuum deposition is carried out in a vacuum chamber wherein high efficiency diffusion pumps create vacuums of about 0.1–1 micron (0.0001–0.001 mm. of Hg absolute). Preferably, the articles to be coated, which may be the patterns **10** or (more preferably) is a cluster of such patterns with gate and runner pattern members attached, are mounted (on individual rotating means) on the inside of a revolving cylindrical wall within the chamber and a heating element such as a tungsten or molybdenum electrical resistance element is centrally located. The metal of group IV–A (Ti of M. P. 3300° F.) and/or alloys thereof or with other metals (of comparable volatility) in the form of strips, wraps, powder, etc. are positioned in close proximity to or in contact with the heating element. Under these conditions heating of the metal is carried out to the extent necessary to volatilize (sublime) the metal (without going through a noticeable liquid phase). The vacuum deposition process thus involves subjecting the metal to conditions of reduced vacuum (i. e. about 0.1–1 micron) and elevated temperatures (i. e. about 3000–4000° F.) which are drastic enough to effect direct volatilization of the (solid) metal as in sublimation. The thickness of the film of metal that is vacuum deposited may range from something in the neighborhood of one millionth of an inch to as much as three ten thousandths of an inch (using repeated applications), and coatings of about five millionths of an inch are satisfactory. In view of the extremely small amount of coating thus applied (which ultimately may be incorporated in the cast article) it is not absolutely necessary to employ, for example, the titanium alloy which has the exact composition of the titanium alloy which is ultimately cast in the mold. Also, all of the titanium alloys will not necessarily perform in the same manner during vacuum deposition, because of reduced volatility in the case of some of the metallic components in the alloy. This offers no problem in the practice of the instant invention, however, because the pure metal of group IV–A may be deposited in the vacuum deposition process, without effecting any appreciable alteration in the composition of the alloy of this metal which is to be cast. If the pure metal is to be cast, of course, the vacuum deposited coating can be also formed of the pure metal. This vacuum deposit coating, even though it is extremely thin in character, does provide a solid metal barrier which must first be completely fused by the heat of the casting, before it possesses the dissolving power or chemical reactivity to attack the mold matrix, and then the metal in this layer must have a certain amount of time in order to effectively accomplish the attack on the mold matrix. Because of the time element here involved, the metal lining or barrier is particularly effective in preventing any appreciable contamination of the casting.

Another important aspect of the instant invention resides in an improvement in the effectiveness of the metal lining or barrier, by depositing a second metal coating thereto. The second metal coating deposited, which is designated in Figures 2 and 3 by the reference numeral **14** may be deposited by any of the well known metal deposition processes, which would include another vacuum deposition process, as well as electroplating and chemical deposition from solution. The initial vacuum deposited layer **13** is, of course, a conductive metal layer which permits electroplating and thus provides a preferred type of metal deposition. In the electroplating process, copper or nickel may be plated onto the vacuum deposited film by standard plating procedures (which are well known in the art and need not be further described herein) so as to obtain plating thicknesses of an average of about 0.001–0.005 (and preferably 0.003) inch. Chromium plating may also be used; and any other type of metal including iron, cobalt, etc. may be deposited onto the initial vacuum deposited coating by any suitable conventional method.

A number of advantages are provided by the deposition of the second layer of metal. For example, the metal provides an additional "chilling" effect by conducting heat away from the vacuum deposited film at a rate sufficient to minimize or prevent fusion of this film through the heat of the casting. Substantially complete protection against the oxides of the mold matrix is provided by the second metal deposit.

A distinct and appreciable amount of contamination of the casting is prevented solely by the use of the initial vacuum deposited film **13**. The advantages afforded by the second deposited layer of metal **14** include the "cooling" effect upon the initial film **13** plus reinforcing and supporting functions which the heavier second coating **14** may provide, plus additional protection against the oxides of the mold matrix **11*a***. If still additional chilling or cooling effect is desired, the second metal deposit may be backed up or supported by additional heat conductors, as for example, buckshot, shown in light lines at **15** in the bottom of the mold **11**. The buckshot may be poured into the form (not shown) at the time that the investment procedure is being carried out, so as to be embedded in the matrix **11*a***, if the cooling effect thereof is desired. In general, it will be noted that the amount of heat which must escape from the poured molten metal through the metal linings depends to an appreciable extend upon the mass of molten material which is to be poured directly adjacent a given area of lining. If extremely thin castings are to be made, the metal linings **13** and **14** may very effectively handle the heat transfer without breaking down. On the other hand, if a relatively thick section is to be cast, it may be necessary to include the buckshot **15** or some other conductive means in the mold matrix **11*a*** in order to prevent complete fusion of the barriers or linings **13** and/or **14**. Still another feature of the instant invention involves the use of a barrier or lining which consists of a metal that is to be plated upon the surface of the cast article by this procedure.

As the various metal coatings may be altered, or the thicknesses thereof changed to suit certain conditions, it may also be necessary to make rearrangements in the venting design of the instant mold **11** because of variations in the gas permeability of the cavity liners. In general, the instant liners will materially reduce the gas permeability of the cavity walls, but the generation of gases along the cavity walls usually is not a material consideration except in "shell" molding proceses and even then the ceramic shell contains the greater bulk of materials which will volatilize or form gases during the casting operation, and the instant liners actually separate the shell from the casting itself (as will be explained hereinafter).

After the metal coatings (such as the coatings **13** and **14**) have been applied to the pattern **10**, the investment casting procedure may be continued along the customary lines. The metal coated pattern **10**, or a suitable metal coated cluster of patterns **10**, is then invested in the monolithic mold. Preferably, an initial dip coating operation is carried out wherein the cluster is dipped in a slurry of fine (less than 325 mesh) silica flour suspended in a colloidal silica binder and withdrawn and "dusted" with dry silica flour. In such operation, the silica flour and colloidal silica (30% silica in aqueous medium) are admixed to give a fluid stable suspension of the silica flour.

The above mentioned precoat is customarily employed using only a plain wax pattern, so as to provide an extremely fine silica particle size at the surface of the cavity, for the purpose of improving the surface characteristics of the cast article. In the instant process, however, this is not necessary because of the metal linings here provided, and it is possible to carry out the mounting of the coated patterns **10** in a suitable mold member merely by the final investing step. In this case, the patterns, mounted in a cluster, are suitably positioned within a shell (with or without the silica precoating above described thereon) and the form is filled with a wet blend of 30–45 parts of silica (of substantially equal proportions of silica flour and sand), 55–70% ground grog, and the remainder ethyl silicate on the basis of 100 ccs. of ethyl silicate per pound of solids. This wet blend surrounds completely the pattern **10**, with the metal coatings **13** and **14** thereon, and sets to form the mold matrix **11*a***. The next procedure involves that of completing the setting of the matrix **11*a*** and also the removal of the expendable mold pattern **10**. This would ordinarily be accomplished by slowly heating the mold member **11** (with the sprue **12*a*** facing downwardly) from about 375° F. to the desired temperature for casting, so as to effect substantially complete removal of the expandable pattern **10** from the cavity **12** and also substantially complete removal of all organic or other volatile material in the mold matrix **11*a***.

In the practice of the instant invention, however, the metal lining 13 must be treated in a different manner. First of all, the metal lining 13 (coupled with the reinforcing layer 14) will effectively reduce if not completely prevent the flow of wax into the mold matrix 11*a*, rather than out the spruce 12*a*. For this reason, the melting out of the pattern 10 may be followed by repeated solvent washings, or other cleansing steps in order to effectively remove all of the expendable pattern 10. In addition, the titanium lining 13 becomes quite reactive at temperatures above 900° F., and it is thus desirable to carry out any heating above these temperatures in an inert atmosphere. This may be accomplished in an argon (or other noble gas) atmosphere in a muffle furnace. In any such procedure, the mold member 11, with the pattern 10 therein, is heated at least to the melting temperature of the pattern 10 and not in excess of about 900° F. in order to remove the pattern. This procedure may be carried out in an inert atmosphere or it may be carried out in ordinary atmosphere, because the titanium lining is not particularly reactive at temperatures below 900° F. Heating in excess of 900° F. to approximately the desired temperature of the mold for casting, which is about 1500–2000° F., should, however, be carried out in an inert or noble gas atmosphere in order to prevent contamination of the titanium (or other metal of group IV–A) lining 13. Instead, an inert gas may be introduced into the mold cavity during heating, as by various means, such as by the venting of an inert gas into the area or by the use of materials which release an inert gas upon volatilization at elevated temperatures.

Another aspect of the instant invention involves the provision of a furnace (such as the furnace shown in Figures 6 and 7) designated generally by the reference numeral 20 for casting a metal of group IV–A or an alloy based thereon, which comprises a closed housing 21, evacuating means 22 for drawing a vacuum in the housing 21, inlet means 23 for introducing an inert or noble gas into said housing 21, a crucible 24 in the housing 21 for retaining the metal 25 in molten form therein, first heating means as the induction coil 26 for the crucible 25, the mold member 11 in the housing 21 positioned to receive the molten metal 25 from an outlet 24*a* on the crucible 24, a solid lining 13 of the metal defining a cavity 12 in the mold member 11 and second heating means such as the induction coil 27 mounted in the housing 21 for the mold 11.

Referring to Figure 6, it will be noted that the housing 21 has generally cylindrical side walls 21*a*, a flat bottom 21*b*, an annular top 21*c* equipped with a flange 21*d* to which is clamped or bolted (by means not shown) a sight glass 28 aligned for visual observation of the molten metal 25. The sight glass 28 is sealingly clamped to the flange member 21*d* by means of a ring 29.

The crucible 24, which may be made of titanium, but which is preferably made of an extremely refractory metal that is substantially inert with respect to the molten titanium, such as tungsten, is seated in a graphite crucible 30 which completely surrounds the crucible 24 (and which has a sufficient cooling effect upon the outside walls of the crucible 24 to maintain a solid phase of titanium thereat, in the event that titanium is used as the crucible material). A secondary crucible 31 made of a refractory electrical insulator material such as "magnesite" receives the graphite crucible 30 and supports the crucible assembly in the housing 21. A suitable induction coil 26 or similar heating equipment is positioned within the walls of the secondary crucible 30 and also surroundingly of the crucible 24 in order to effectively heat the molten metal contents thereof. The induction coil 26 is a (hollow) copper tube which accommodates the flow of cooling materials to prevent overheating. The induction coil 26 is indicated as being connected to a line containing cooling liquid at 32 controlled by valve 33, in primarily a diagrammatic showing since cooling systems for an induction type furnace are well understood by those skilled in the art.

The evacuating means 22 used for the instant purpose must be capable of creating an extremely low vacuum and diffusion pumps or similar equipment, well known to those skilled in the art, may be used for this purpose. The evacuating pump 22 is here shown communicating with the interior of the chamber 21 through the line 22*a*, in substantially a diagrammatic showing. Also, a line source of argon or other noble gas is shown diagrammatically at 23*a* which communicates with the interior of the housing 21 through the valve 23. In operating the instant furnace, the evacuating means 22 is employed to draw a vacuum of approximately 1 micron in the housing 21, and the argon gas is then fed through the valve 23 so as to substantially completely replace the atmosphere in the furnace with the noble gas. It is ordinarily preferable to introduce an appreciable amount of argon gas into the furnace, in fact, up to 1 atmosphere, in order to effectively prevent leaking of atmospheric air into the furnace 21 during the operation thereof. Also, it will be appreciated that the amount of argon introduced into the interior of the housing 21 is an amount sufficient to prevent a reaction such as vacuum deposition of the titanium when the same is heated to the molten state.

The instant furnace 20 provides an additional advantage in that it has means which will removably accommodate an individual mold member 11, so that the mold member 11 may also be heated to molding temperature in the presence of an inert atmosphere. As previously mentioned, the mold member 11 should preferably be heated to a temperature of about 1800–2000° F. for the casting operation, but the titanium lining 13 should not be heated above 900° F. in anything but an inert atmosphere, if contamination of the lining 13 is to be avoided. Accordingly, the furnace 20 is provided with a housing portion 21*e*, which is preferably cylindrical shaped to substantially the exact size of the normally cylindrical mold 11, and which is mounted on the side wall 21*a* of the housing 21 so as to extend perpendicularly of the main axis of the housing 21 (and perpendicularly of the main axis of the crucible 24). The housing 21*e* removably receives the mold 11 and the wall portions 21*f* and 21*g* of the side walls 21 provide a restricted entrance into the housing portion 21*e* and also provide backing members for urging the mold 11 into fixed position. A clamping bar 34 removably engages the bottom of the mold 11 and is in turn engaged by side bars 35 and 36 mounted on the housing portion 21*e* so as to rigidly clamp the mold 11 in position in the housing 21*e*. In assembling the instant device, the mold 11 is slipped axially into the housing 21*e* and the clamping bar 34 is applied to retain the same therein. The mold 11 may be preheated up to 900° F., and preferably is preheated up to approximately this temperature in order to remove as much as possible of the pattern 10 therefrom, before the mold 11 is inserted into the housing portion 21*e*. Just prior to putting the mold 11 in position, the charge of titanium or other metal which is to form the molten metal 25 is placed in the crucible 24, the mold 11 then being slipped into position as shown in Figure 6, and the clamp 34 applied. Then the vacuum can be drawn through the means 22 and the argon gas introduced through the means 23, and heating may be commenced. The heating of the molten metal 25 is, of course, carried out in the crucible 24 so as to obtain the desired casting fluidity for the molten metal 25. The housing 21*e* is also provided with heating means 27 in the form of the induction coil shown, and this induction coil 27 is used to accomplish heating of the mold 11 up to the casting temperature of at least about 1500° F., and preferably about 1800–2000° F., such heating being carried out in the inert atmosphere that is also employed for melting the molten metal 25.

It will be noted that the entire furnace 20 is swingably mounted about the pivot point X on swingable mounting means shown diagrammatically at **38**. After the mold **11** has been heated to the casting temperature desired and the molten metal **25** has obtained the desired fluidity for casting, the casting operation is obtained simply by tilting the mold **20** clockwise 90° to obtain the position shown in Figure 7. As shown in Figure 7, all of the elements described in Figure 6 are the same, except that the molten metal **25'** is now flowing through the spout **24***a* and into the sprue **12***a* for the cavity **12** in the mold **11**.

Referring to Figure 5, which shows a different furnace arrangement **30** embodying the instant invention, the furnace **30** of Figure 5 comprises a closed housing **31**, evacuating means **32** for drawing a vacuum in the housing **31**, inlet means **33** for introducing an inert gas into the housing **31**, a crucible **34** in the housing **31** for retaining metal (titanium) **35** in molten form therein, first heating means in the form of the coil **36** (for induction heating) for the crucible **34**, a mold member **11** (which again has the same structure as that shown in Figure 3 and in Figures 6 and 7), the mold member **11** being positioned in the housing **31** to receive molten metal from an outlet at **34***a* on the crucible **34** and having a solid lining **13** of the metal (titanium) defining a cavity **12** in the mold member **11**, and second heating means in the form of the induction coil **37** mounted in the housing **31** for the mold member **11**.

In the furnace **30** of Figure 5, the crucible **34** and the mold member **11** are coaxially aligned within the generally cylindrical housing side walls **31***a*; and the mold **11** is maintained in upright position on a removable bottom plate **31***b* suitably affixed to the cylindrical side walls by bolts **38** so as to removably mount the mold **11** in the housing **31**. The induction coil **37**, suitably mounted within a refractory insulator matrix **39**, surrounds the mold **11** and provides means for induction heating of the mold **11** to the desired pouring temperature of about 1800–2000° F. Resistance heating means (not shown) may also be used for this purpose.

The vacuum creating means **32** and the noble gas inlet means **33** function in the same manner that the corresponding means **22** and **23** function in connection with the furnace **20** in Figures 6 and 7, so as to create the necessary vacuum conditions within the housing **31** (above the crucible **34** also via the vents **40***a* and **40***b*) and then to afford a noble gas atmosphere. Means (not shown) for creating a pressure differential across the crucible **34** may also be used to assist in forcing the break-through of molten metal at the crucible outlet **34***a*.

A viewing window **41** is also clamped over the top aperture **31***c* in the housing **31** by means of an annular ring **42** and bolts **43**, **43**, so that the melting of the metal **35** may be observed. The heating coil **36** for the crucible **34** is positioned just above the upper peripheral edges of the crucible **34** (at **34***b*) and the coil **36** is disposed within an annual matrix **44** made of refractory insulating material.

The crucible **34** comprises a dish-shaped portion **34***c* which rests upon an annular support **46** suitably mounted on the housing wall **31***a*. The dish-shaped portion **34***c* has what amounts to a plug member or (integrated) portion in the region of the opening **34***a*, which portion ultimately is melted by the molten metal **35** and gives way so as to drop molten metal directly downwardly into the sprue **12***a* for the mold **11**. Directly above the opening **34***a* in the crucible **34** there is mounted an upwardly extending finger portion **34***d* which extends upwardly above the outer or peripheral edge **34***b* so as to be surrounded by the induction coil **36**. The crucible **34** shown in Figure 5 is substantially in the form in which the crucible is first placed in the housing **31** (through the removable top **31***d*). During operation, the coil **36** is energized and induction heating of the projecting finger **34***d* is commenced. This results in the melting of the finger **34***d* so as to cause molten metal droplets as at **35***a* to flow down the sides of the finger **34***d* and form a pool of molten metal in the bottom of the dished portion **34***c* of the crucible **34**. This pool of molten metal **35** increases in size with further melting of the finger **34***d* and also causes melting at the base of the finger **34***d* and thus in the region of the opening **34***a*. As previously mentioned, an increased (argon) gas pressure above the crucible **34** may assist in forcing the opening **34***a*. The opening **34***a* is provided initially merely as a notched portion in the bottom of the crucible **34** to provide a thin section which will serve as a "plug" for the bottom of the crucible **34**. When the thin section just above **34***a* has melted away (and the size of this section may be carefully gauged so as to provide for the melting of the correct total amount of molten metal in the pool **35**), the molten metal **35** flows through the opening **34***a* and into the sprue **12***a* for the mold **11**. The annular support member **46** is preferably made of a suitably conductive material such as copper which may be maintained at a controlled temperature so that the outer edges **34***e* of the crucible **34** may be maintained in the solid state sufficiently unreactive to avoid contamination by the matrix **44** as well as the copper annulus **46**.

It will thus be seen that the furnace **30** of Figure 5 provides an arrangement that is comparable in certain respects to that employed by furnaces using the principle of "levitation," whereby the material to be melted is suspended in a magnetic field. In such instance, the finger **34***d* would be suspended by the use of suitable magnetic fields, and the remainder of the crucible **34** would not be employed. The finger **34***d* would thus be heated until it is transformed into a molten state and when adequately melted, the molten finger **34***d* would be released from the magnetic field and dropped into the sprue **12***a*. In the instant case, the size and thickness of the plug portion at the opening **34***a* is used to control and time the dropping of the molten metal **35** into the sprue **12***a*.

Referring now to Figure 4, which shows in an essentially diagrammatic view a somewhat different mold arrangement **50**. The mold **50** is primarily a conventional shell mold, which is formed by the well known "shell molding" process. In the shell molding process, a hot platen having substantially the shape of one-half of the cavity **51** here shown is covered with a mixture of fine sand and thermosetting resin. The heat of the platen fuses the thermosetting resin and ultimately causes the same to set so as to provide an initial thin shell here indicated at **52**. This operation is usually followed by a comparable operation using coarser sand so as to provide a reinforcing or backing shell here designated **53**. The shell assembly **52**, **53** is then removed from the heated platen and assembled with a mating shell assembly **54**, **55** as shown in Figure 4 so as to define the mold cavity **51**. The shell members **52**, **53** and **54**, **55** are usually backed up in the mold flask with shot, here shown at **56** (although it will be appreciated that the shot actually used is substantially smaller in comparison to that here shown). The shell mold **50** is thus assembled and ready to receive the molten metal through the sprue **51***a*. In the instant invention, before the shell assemblies **52**, **53** and **54**, **55** are put together, they are exposed to the vacuum deposition conditions hereinbefore described so as to deposit on the cavity defining faces thereof a thin metal film of a metal of group IV–A, such as titanium. The films **57** and **58** are thus used to define the surfaces or walls of the cavity **51** and the sprue **51***a*, in substantially the same manner that the lining **13** defines the cavity **12** in the mold **11**; and the function of the lining members **57** and **58** is the same as that hereinbefore described in connection with the lining **13**. Again, the shell mold **50** is also preferably employed in place of the mold **11** in the furnaces **20** and **30**, using suitable mounting means to retain the shot **56**, etc. as those skilled in the art will readily appreciate.

Throughout the instant disclosure, reference is made generally to a metal of group IV–A, which includes titanium, zirconium and hafnium; although it will be appreciated that alloys based on these metals may be used in place of the pure metals. Actually, the problems involved in the handling of the pure metals are also present in the handling of alloys which contain as little as 5% by weight of these particular metals. As a practical matter, the handling problems become particularly acute if the proportion of such metals is at least 25%, although the commercial alloys based on these metals, such as the "titanium base alloys" contain at least about 90% titanium and the alloying metals which comprise the remainder include copper, tin, iron, aluminum, chromium, cobalt, molybdenum, tungsten, columbium, thorium, tantalum and nickel. Because of the extremely small amount percentagewise of metal added to the casting by the instant vacuum deposited film, it is not necessary to use the particular alloy (if an alloy is being cast) in the vacuum deposition process and the pure base metal (such as titanium or zirconium) may be vapor deposited.

Although the instant invention has been described primarily in connection with titanium casting (which is currently of great interest industrially), the procedures employed for the casting of each of the metals of group IV–A are substantially identical to those used with titanium because of the similarity of the physical properties such as melting points, etc. Also, the casting procedures for titanium, zirconium and hafnium alloys are substantially the same, with the exception that the actual pour temperature of alloys may differ somewhat (this being within the knowledge of the art).

As also mentioned, the casting may be controlled by the relative thicknesses of the vacuum deposited film **13** of the metal of group IV–A and one or more electrodeposited layers **14**. In some instances alloy formation may be allowed to take place between the metal layer and the film to form a part of the product but it is preferred, as described, that the extra metal layers **14** may be subsequently removed from the casting by acid etching, machining, deplating, etc.

It will be understood that modifications and variations may be effected without departing from the scope of the novel concepts of the present invention.

I claim:

1. In the method of casting with a metal of group IV–A, the steps of forming an expendable pattern of the article to be molded, depositing a metal corresponding to the metal to be cast as a continuous thin barrier film having a thickness of less than .0003 of an inch on the surface of the expendable pattern, depositing another metal having high heat conductivity as an outer layer on the barrier film in an amount to provide a thickness sufficient to conduct heat away from the surface portion of the molten metal cast into the mold to prevent reduction of the barrier film to molten conditions, investing the expend-

able pattern in a mold body, removing the expendable pattern at a temperature below the melting point temperature for the metals whereby the barrier film remains as a lining about the mold cavity, casting the molten metal into the mold cavity whereby the barrier film prevents reaction between the molten metal and the materials in the body of the mold, removing the casting after the metal has set with the barrier film integrated to form a part thereof and removing the outer layer of metal of high heat conductivity from the casting.

2. The method as claimed in claim 1 in which the barrier film has a thickness within the range of 0.0000001 to 0.0003 of an inch and in which the coating of the metal having high heat conductivity is within the range of 0.001 to 0.005 of an inch.

3. The method as claimed in claim 1 in which the outer layer deposited on the film of titanium on the expendable pattern comprises copper.

4. The method as claimed in claim 1 which includes the additional step of heating the mold member to about 1500–200° F. in a noble gas atmosphere and casting the molten metal into the mold cavity while the mold is retained at said temperature and in said atmosphere.

5. In the method of casting titanium, the steps of forming an expendable pattern of the article to be molded, depositing titanium as a thin film of less than .0003 of an inch on the surface of the expendable pattern, depositing another metal having a high heat conductivity as an outer layer on the titanium film in an amount providing a thickness sufficient to conduct heat away from the surface portion of the molten titanium cast into the mold to prevent reduction of the titanium film to molten condition, investing the expendable pattern in a mold body, removing the expendable pattern leaving the titanium film as a lining about the mold cavity, casting the molten titanium into the mold cavity whereby the titanium film prevents reaction between the molten titanium and materials in the body of the mold, removing the casting after the metal has set, and then removing the outer layer of metal of high heat conductivity from the casting.

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