

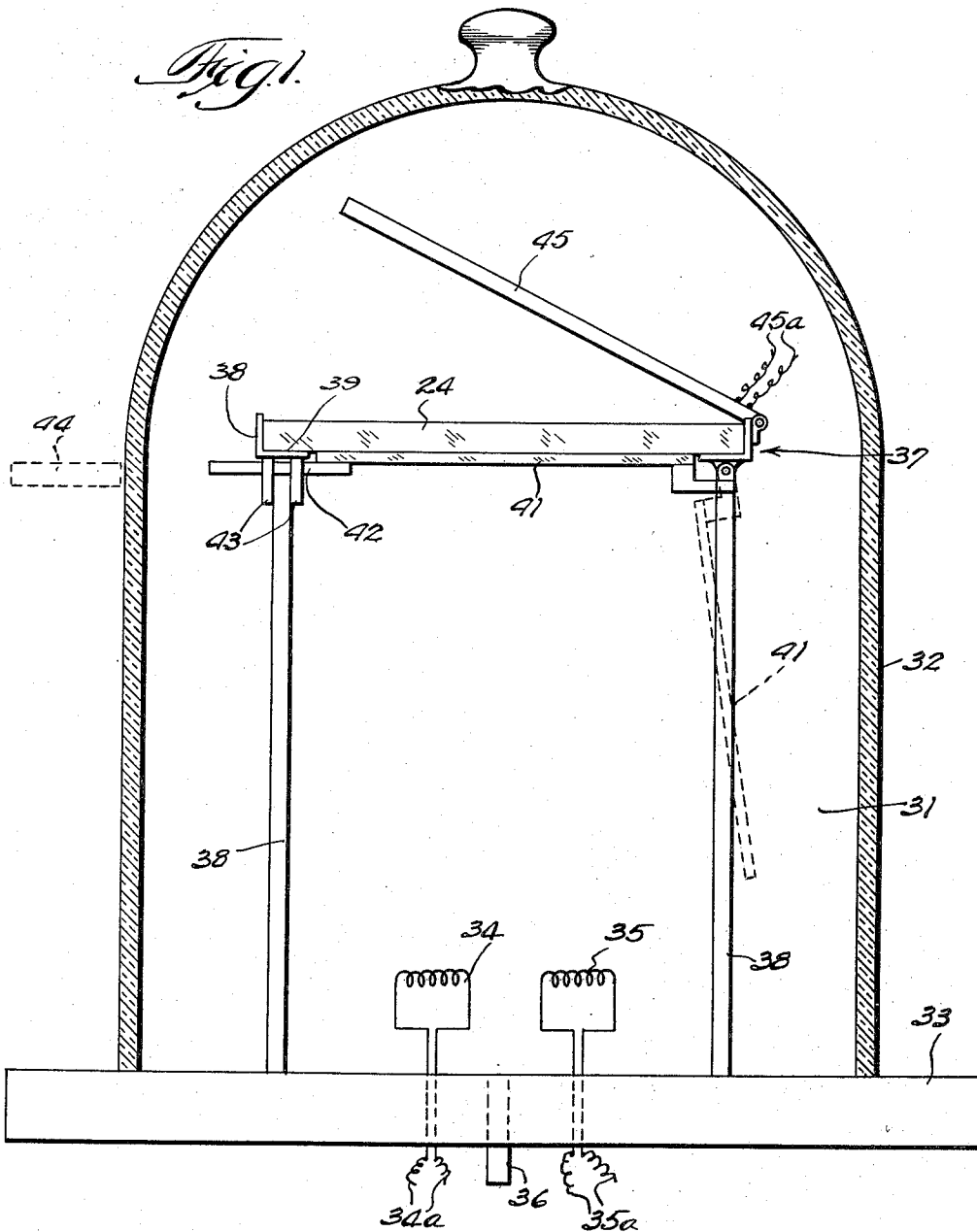
Aug. 26, 1958

N. PRITIKIN
ELECTRICAL RESISTOR AND METHOD AND APPARATUS
FOR PRODUCING RESISTORS

2,849,583

Filed July 19, 1952

5 Sheets-Sheet 1



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Aug. 26, 1958

N. PRITIKIN
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5 Sheets-Sheet 2

Fig. 2.

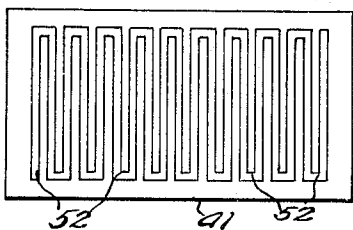


Fig. 3.

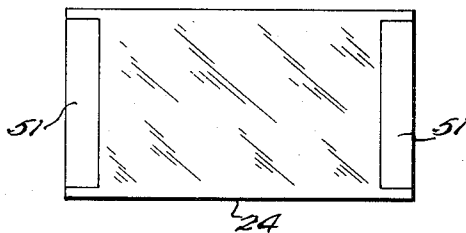


Fig. 4.

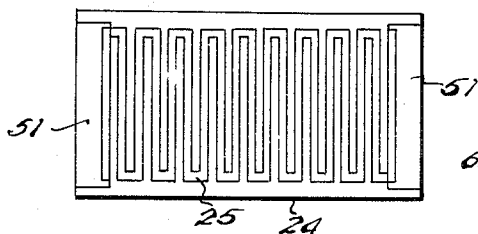


Fig. 5.

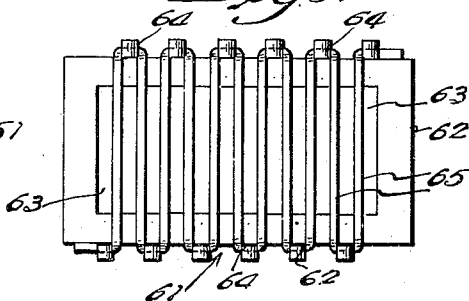


Fig. 6.

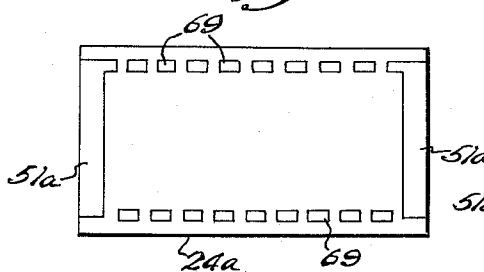


Fig. 7.

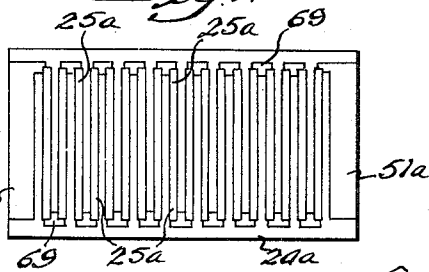


Fig. 8.

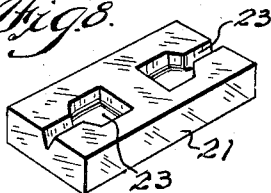


Fig. 9.

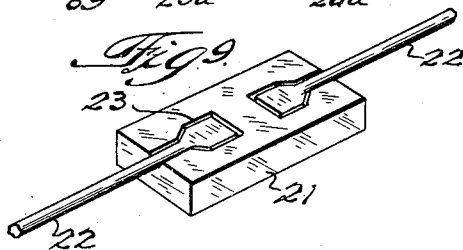
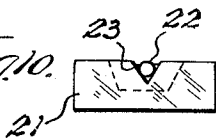


Fig. 10.



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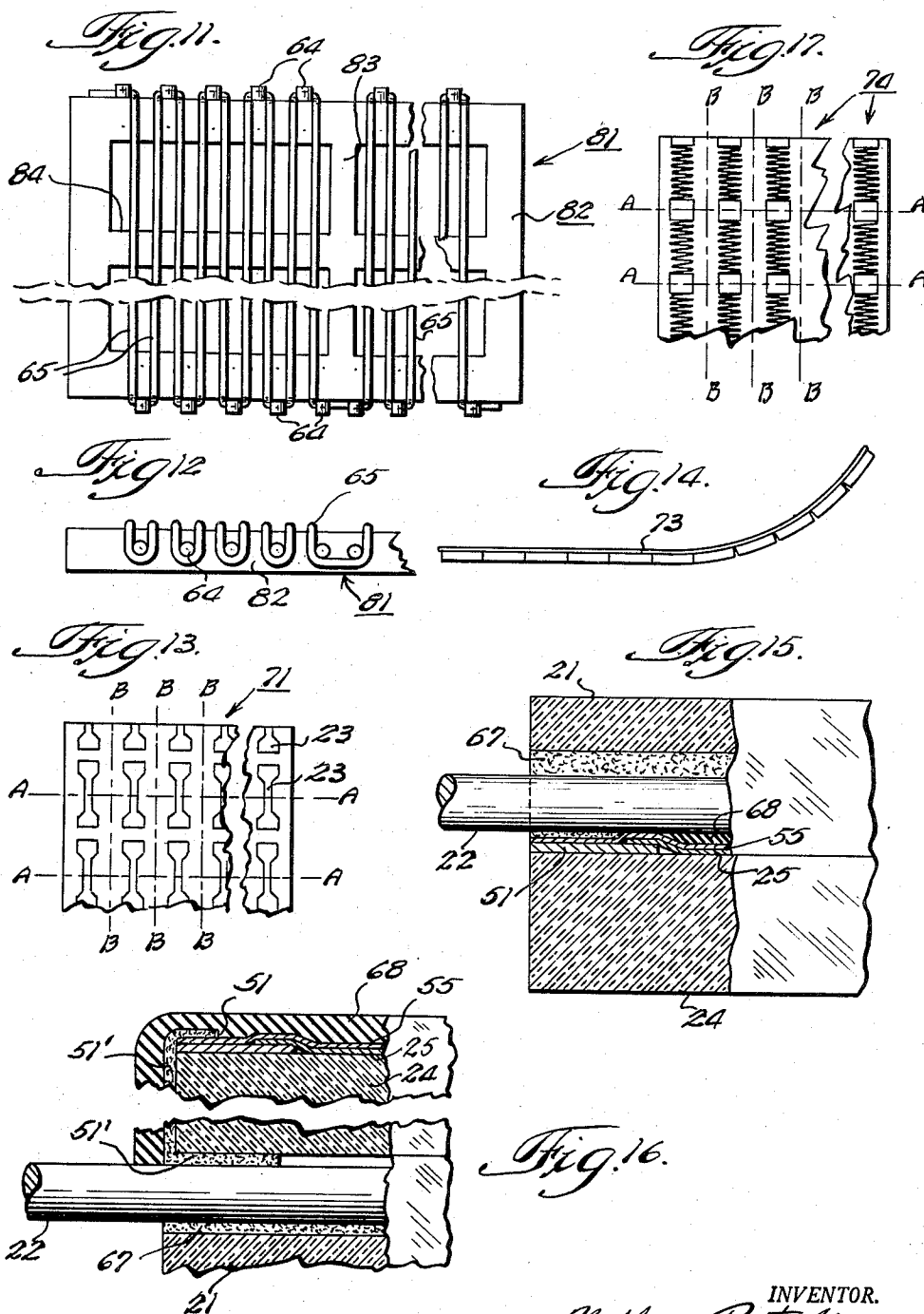
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5 Sheets-Sheet 3



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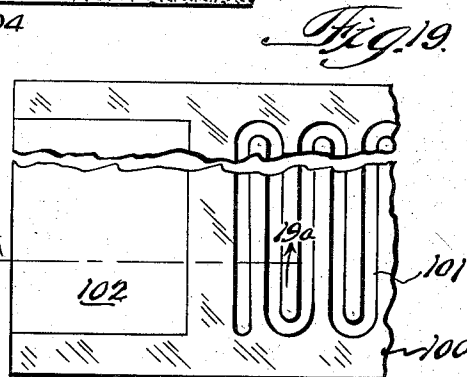
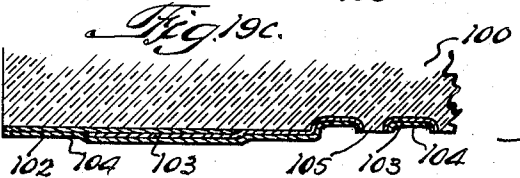
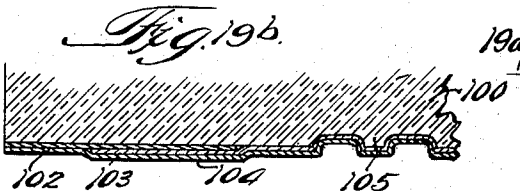
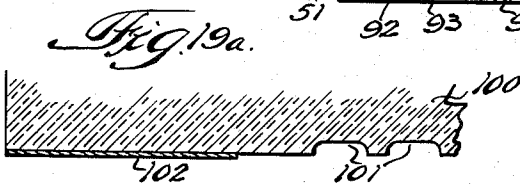
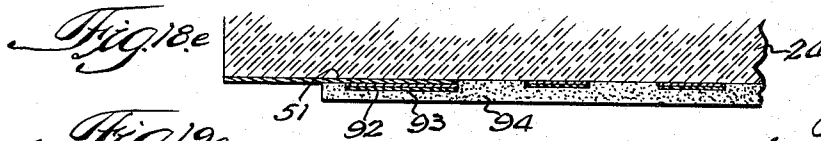
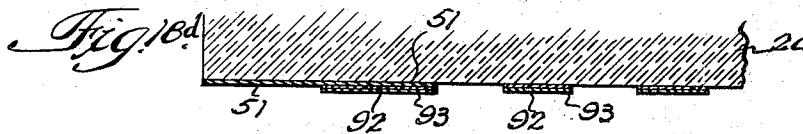
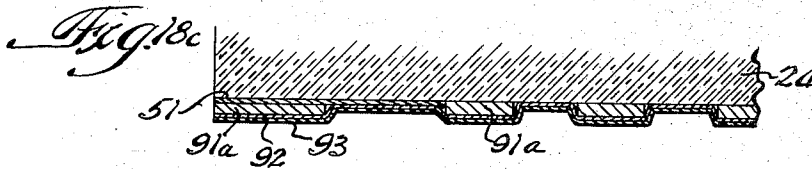
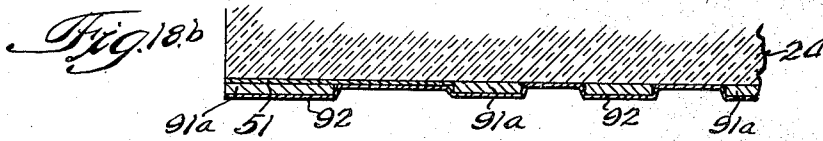
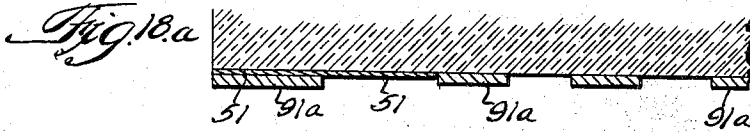
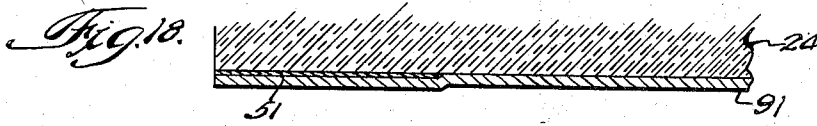
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2,849,583

5 Sheets-Sheet 4



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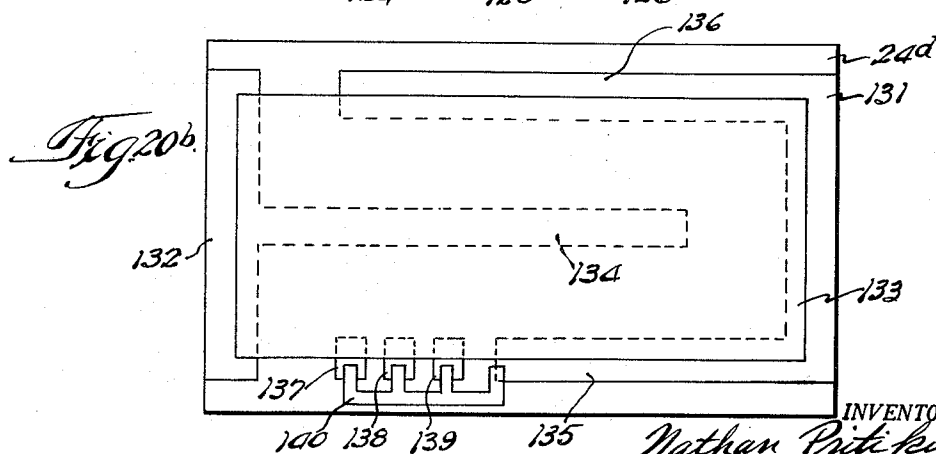
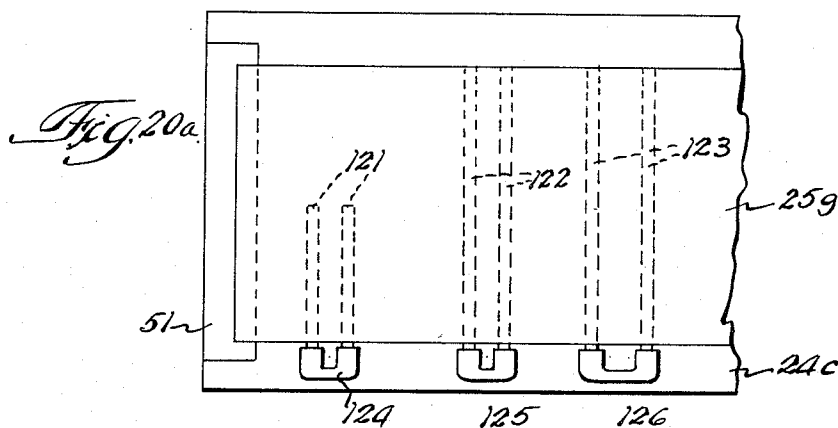
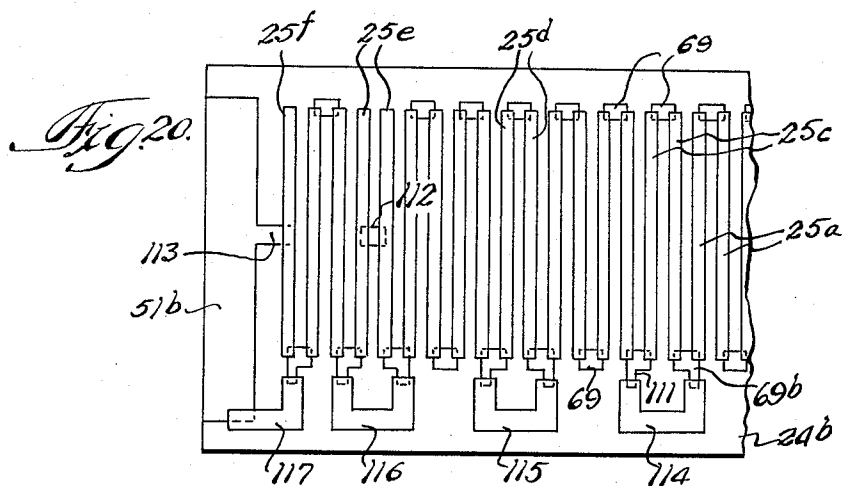
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FOR PRODUCING RESISTORS

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Filed July 19, 1952

5 Sheets-Sheet 5



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ELECTRICAL RESISTOR AND METHOD AND APPARATUS FOR PRODUCING RESISTORS

Nathan Pritikin, Chicago, Ill.

Application July 19, 1952, Serial No. 299,797

6 Claims. (Cl. 201—73)

This invention relates to an electrical resistor and to a method and apparatus for making resistors. It is an object of the invention to provide an improved electrical resistor and an improved method and apparatus for making resistors.

Conventional low priced electrical resistors, such as carbon resistors, are unsatisfactory in regard to various characteristics, whereby such resistors are seriously limited as to their utility in many applications. Among these characteristics are temperature coefficient of resistance, noise level, maximum permissible ambient temperature, stability, and change due to humidity. In a conventional low price resistor, the temperature coefficient of resistance generally lies between .02 and .1% per degree centigrade. In a resistor constructed in accordance with the invention, the temperature coefficient may readily be maintained between plus and minus .003% per degree centigrade. The noise level in conventional low priced resistors generally is on the order of .6 to 1.5 microvolts per volt, whereas in a resistor constructed in accordance with the invention the noise level may be readily maintained at less than .1 microvolt per volt.

Conventional low priced resistors, and even many relatively expensive resistors, are capable of operating at an ambient of not more than 120° C., whereas a resistor constructed in accordance with the invention may operate at over 200° C. Conventional resistors normally have a humidity change ranging from 3 to 5%, based on JAN R-11 amendment 4 test specifications, whereas the effect of humidity upon a resistor constructed in accordance with the invention is negligible. Furthermore, a resistor constructed in accordance with the invention can readily be made to have predetermined resistance value and has been found to be equal or superior to conventional resistors in regard to other tests to which resistors are frequently subjected, such as load life tests, hot spot temperatures, short time overload, high frequency characteristics, shelf life, salt water immersion, solder test, insulation strength, high altitude flash over, security of terminals, and vibration.

It has been determined also that a resistor constructed in accordance with the invention, in addition to thus surpassing carbon and other low cost resistors in all important characteristics, and in addition to surpassing so-called precision resistors in many important characteristics, may be manufactured substantially as cheaply as conventional low cost resistors, such as carbon type resistors.

Accordingly, it is another object of the invention to provide a resistor having resistor characteristics at least equal to and generally superior to those of so-called precision resistors while at the same time being very inexpensive to produce.

One reason that a resistor constructed in accordance with the invention may be inexpensively manufactured is that it may readily be manufactured on a mass production basis, substantially as described and claimed in application Serial No. 225,382, now Patent No. 2,796,504, entitled "Electrical Resistor and Method of Making Re-

sistors en Masse," filed May 9, 1951, by Nathan Pritikin and Harold Weinstein, of which applicant is the sole owner by virtue of assignment of any interest by Harold Weinstein to applicant.

Accordingly, it is another object of the invention to provide an improved resistor and method and apparatus for making the same, which lend themselves to mass production.

This invention, together with further objects and advantages thereof, will best be understood by reference to the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

In the drawings, in which like parts are designated by like reference numerals,

Fig. 1 is an elevational view, partially broken away, of apparatus used, in accordance with one embodiment of the invention, in the production of resistors;

Fig. 2 is a plan view of a mask useable in the apparatus shown in Fig. 1;

Fig. 3 is a plan view of a resistor part illustrating its condition at one stage during the manufacture thereof;

Fig. 4 is a plan view of the same resistor part at a later stage in the manufacture thereof;

Fig. 5 is a plan view of a different form of mask useable for the same purpose as the mask illustrated in Fig. 2;

Fig. 6 is a plan view of a resistor part illustrating its condition at one stage in the manufacture thereof, this resistor part being used in conjunction with the mask of Fig. 5;

Fig. 7 is a plan view of the resistor part illustrated in Fig. 6 but at a later stage in the manufacture thereof;

Fig. 8 is a perspective view of a resistor part which may cooperate with the resistor part illustrated in Figs. 3 and 4 or the resistor part illustrated in Figs. 6 and 7;

Fig. 9 is a perspective view similar to Fig. 8 but showing resistor terminals assembled therewith;

Fig. 10 is an end view of the assembly illustrated in Fig. 11;

Fig. 11 is a plan view of a mask similar to that illustrated in Fig. 5 but designed for simultaneous masking of a plurality of resistor parts;

Fig. 12 is an edge view of the mask shown in Fig. 11;

Fig. 13 is a plan view of a large sheet from which may be formed a plurality of the resistor parts illustrated in Fig. 8;

Fig. 14 is a side view of a strip of the same resistor parts;

Fig. 15 is a central longitudinal partial cross-sectional view of a resistor constructed in accordance with one embodiment of the invention;

Fig. 16 is a view similar to Fig. 13 but illustrating another embodiment of the invention;

Fig. 17 is a plan view of a large sheet from which may be formed a plurality of the resistor parts illustrated in Figs. 4 or 7;

Fig. 18 is a partial cross-sectional view of a resistor part similar to that illustrated in Fig. 4 or Fig. 7 but illustrating a different embodiment of the invention;

Figs. 18a-18e are views similar to Fig. 18 but illustrating the resistor part thereof in various stages of manufacture;

Fig. 19 is a plan view of a resistor part constructed in accordance with another embodiment of the invention;

Figs. 19a, 19b, and 19c are partial cross-sectional views of the resistor part of Fig. 19, shown in successive stages of manufacture;

Fig. 20 is a plan view of a resistor part similar to that illustrated in Fig. 7 but illustrating a feature of the invention whereby the resistance of the resistor element may readily be adjusted to a predetermined value; and

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Figs. 20a and 20b are views similar to Fig. 19 but illustrating the application of the resistance-adjusting feature of the invention to different forms of resistor elements.

A resistor constructed in accordance with the preferred embodiment of the invention includes a sheet of glass 21, seen in Fig. 8, a pair of leads 22 set into grooves 23 in the sheet 21, a second sheet of glass 24, seen in Fig. 3, and a resistance element 25 adhering thereto, said resistance element being formed by condensation of evaporated metal. Various other materials and components enter into the final resistor which will be described in detail subsequently.

The resistance element 25 is applied to the glass sheet 24 by an evaporation process and in Fig. 1 there is illustrated a preferred embodiment of apparatus to be utilized in this process. A vacuum chamber 31 is shown formed by a bell jar 32 and a base 33. Contained within the chamber 31 are filaments 34 and 35 having leads 34a and 35a, respectively, extending through the base 33 for connection to suitable sources of electrical power for heating the filaments. A suitable connection 36 is provided in the base 33 through which the chamber 31 may be evacuated.

Also arranged in the chamber 31 is a framework 37 supported by suitable legs 38. The framework 37 includes an angular member 38 extending around a substantially rectangular area. The inwardly directed legs 39 of the member 38 provide a shelf or platform upon which the edges of the glass sheet 24 may be placed. For reasons which subsequently will become apparent, it is desirable that the angular member 38 be of such proportions as to accurately locate the sheet 24 when the latter is placed therein.

A mask 41, seen in Fig. 2 as well as in Fig. 1, is hingedly secured to the framework 37 such that it may swing between a downwardly depending position, illustrated by the dotted lines in Fig. 1, and a horizontal position, illustrated by the solid lines in Fig. 1. In the latter position the mask may be immediately adjacent or, preferably, actually in contact with the lower surface of the glass sheet 24.

At the left hand side of the framework 37 there is provided a pin 42 which is slidable in a pair of bushings 43. When the pin 42 is in its right-hand position, as illustrated in Fig. 1, it supports the mask 41 in its horizontal position. The pin 42 is of magnetic material whereby it may be drawn to the left in Fig. 1 by a magnet 44, shown in phantom in Fig. 1. When the pin 42 is drawn to the left, as by the magnet 44, the mask 41 is free to pivot downwardly to its vertical position illustrated by the dotted lines of Fig. 1.

Arranged above the position of the glass sheet 24 is a heating device 45 which is preferably connected hingedly to the framework 37. The heater 45 may be raised to the position shown in Fig. 1 to permit convenient insertion of the glass sheet 24 into the framework 37, after which the heating device may be lowered to a horizontal position in which it is closely adjacent or in actual contact with the glass sheet 24.

The purpose of the heater 45 is to maintain the glass sheet 24 at an elevated temperature during the evaporation process, it being well-known in the art that a more tenacious bond between the deposited film and the base is obtained where the base is at an elevated temperature. The heater is preferably a sheet of glass with a resistance film deposited thereon, this type of heater providing uniform heating of the entire area of the glass sheet 24. A pair of leads 45a are shown, these leads being connectable to a suitable source of electric power, preferably through the base 33.

The glass sheet 24 upon which the resistance element 25 is to be deposited is preferably provided with a pair of terminals 51 at two opposed edges thereof as illustrated in Fig. 3. These terminals are preferably metallic and may, for example, be applied as a mixture of 40%

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platinum particles, 35% silver particles and 25% glass particles in a carrier comprising 20% ethyl cellulose and 80% pine oil, mixed to suitable consistency for painting, rolling, or screening onto the sheet 24. After application of this particular mixture thereto, the sheet may be baked at a temperature in the range of 1000° F. to 1100° F. to evaporate the solvent, to burn off the ethyl cellulose, and to fire the glass and metal particles onto the glass sheet. Such procedure, and various suitable materials therefor, are well-known in art. After the sheet 24 has been thus prepared and has been thoroughly cleaned, it may be placed within the framework 37 for deposition of the resistance film thereon.

The mask 41, best illustrated in Fig. 2, is a thin glass sheet having a circuitous slot 52 etched therethrough, the sheet preferably being very thin in order that a fine pattern with sharp edges may be etched therethrough. Such etching may be accomplished through the use of hydrofluoric acid and by processes well understood in the art.

With the glass sheet 24 and the heater and the mask arranged in the vacuum chamber 31 as previously described, air is exhausted through the connection 36. The heater 45 may then be energized to heat glass sheet 24 to an elevated temperature, preferably at least 250° C. The heater is preferably so energized for a short period of time before the actual evaporation process is started and while evacuation is being carried on in order that any vaporizable matter present may be boiled off and removed from the vacuum chamber. When the apparatus has been so heated and when the pressure in the chamber has been reduced to approximately .0001 to .00001 millimeter of mercury the evaporation process may be started.

The metal to be evaporated is placed on the filament 34 prior, of course, to evacuation of the chamber 31 and in a manner well understood in the art. It has been found that chromium, molybdenum and tungsten are excellent metals to form the resistance film, for reasons which are described below. Since these three metals are in group VI-B of the periodic table it is believed that uranium, the remaining element of this group, may also be a good metal for the purpose. Of this group, chromium is recommended for the practical reason that its relatively low boiling point (in vacuo) permits the use of a tungsten filament 34, and in the ensuing description chromium is referred to, for convenience, as the metal used for this purpose.

Evaporation of the chromium is accomplished by energizing the leads 34a to raise the tungsten filament 34 to a temperature on the order of 1600° C. A portion of the chromium is thereby boiled off or evaporated and a quantity thereof passes through the circuitous slot 52 in the mask 41 and condenses on the glass sheet 24.

In Fig. 4 the glass sheet 24 is shown with the resistance film 25 deposited thereon. As is suggested by this Fig. 4, the terminals 51 are so spaced apart and so located with respect to the mask 41 that the outer ends of the deposited resistance film overlap and contact said terminals. The two terminals are thereby connected together by a current path of a selected resistance value.

Since the evaporation of metals and the condensation thereof on the surface of an object is a process which is well understood in the art, it will not be explained in detail herein. Certain precautions must be taken, of course, to produce a proper film deposit and to obtain a film of the proper thickness and purity. For example, the filament 34 must be maintained at a temperature which will cause reasonably rapid evaporation of the chromium but which will substantially avoid evaporation of tungsten from the filament. A sufficient quantity of chromium should be present that a deposited film of desired thickness may be obtained while still leaving a substantial quantity of chromium on the filament 34, since a coating of chromium on the filament tends to deter evaporation of tungsten from the filament. Deposition

of a film of the desired thickness may be obtained simply by controlling the temperature of the filament and the period of evaporation, or an auxiliary film may be deposited and continually tested during the evaporation process to determine when proper film thickness has been obtained, all as is well understood in the art.

In a resistor constructed in accordance with the invention, stability and continuity of the ultimate resistor may be obtained with a resistance film whose thickness is such as to provide a resistance per square of one thousand ohms, the absolute thickness varying substantially with differing conditions of evaporation but being on the order of one millionth of an inch. "Resistance per square" is a term believed to be well understood in the art, and indicates the resistance of a square area to current passing between opposed edges of such square, the size of the square being of no consequence since the width of the current path varies directly with the length of the current path, and is, in fact, equal thereto. This measure is employed in the present case because it provides a standard which is a function only of the resistivity of the material and the thickness thereof.

It is desirable, of course, to provide a film having a high resistance per square, while still providing stability, since this permits construction of a resistor with high resistance in a small size and with a given elongation of the resistance path. In one embodiment of the invention the surface of the glass sheet 24 upon which the resistance film is deposited measures $\frac{1}{4}$ " x $\frac{1}{2}$ ". In this area a circuitous path has been obtained by the glass mask 41 which provides a ratio of length-to-width in the order of ten thousand to one. This ratio in combination with the above-mentioned resistance per square of one thousand ohms indicates that a resistance of ten megohms may be obtained in the $\frac{1}{2}$ " x $\frac{1}{4}$ " area specified. Resistors of this magnitude have been manufactured by this process and have been found to have all of the superior characteristics referred to above.

Subsequent to the evaporation of the chromium and while a high degree of vacuum is still maintained in the chamber 31, a protective, and preferably insulating, film is deposited upon the surface of the resistance film, a quantity of material for producing such protective film having been placed on the filament 35 prior to evacuation of the chamber 31. The protective film may be seen in part in Figs. 15 and 16 wherein it is designated 55.

In order that the protective film may cover all surfaces of the resistance film including the edges thereof, the mask 41 is preferably removed prior to deposition of the protective film. This may be accomplished in accordance with the apparatus disclosed in Fig. 1 by using the magnet 44 to withdraw the pin 42 and to permit the mask to drop to the position indicated by the dotted lines in Fig. 1. The mask is thus removed without breaking the vacuum and therefore without exposing the resistance film to atmosphere.

In accordance with the preferred embodiment of the invention, the material placed upon the filament 35 and which forms the protective coating is silicon monoxide, the advantages of which are pointed out subsequently herein. The thickness of the protective coating is not at all critical and may readily be controlled merely by maintaining the filament 35 at a predetermined temperature and continuing evaporation for a predetermined period of time.

It will be noted the silicon monoxide will be deposited over the terminals 51 or 51a. Where the terminals have been formed in the manner described above, the deposition of silicon monoxide thereover has been found to present no difficulty in subsequent establishment of contact between these terminals and the resistor leads 22. The same is true where the protective coating is magnesium fluoride, all as discussed below.

Following the deposition of the protective coating, the glass sheet 24 is substantially ready for assembly in

the ultimate resistor and may be removed from the vacuum chamber.

An alternative form of mask is illustrated in Fig. 5, this mask 61 having an advantage over the mask 41, illustrated in Fig. 2, in that it is somewhat more rugged and in that it is mechanical in construction and does not call for expert glass etching. The mask 61 comprises a rigid framework 62 having a rectangular opening 63 therein. A series of pins 64 are secured to the framework 62 in staggered relationship as shown, and a filament 65, preferably in the form of stainless steel wire is wound about the pins 64 to form what is, in effect, a grating.

The pins 64 are preferably located on the edges of the frame 62, as shown in Fig. 5, or on the underside thereof in order that the wire itself may be brought into contact with the surface upon which the resistance film is to be deposited, since this produces a finer pattern than is otherwise possible.

Where this mask is employed it may readily be seen that a resistance film 25a will be formed on the glass sheet 24 in the form of a series of straight parallel lines. In this instance a glass sheet 24a is employed which has adhering thereto not only terminals 51a, similar to the terminals 51 deposited on the glass sheet 24, but two rows of spots 69 of conducting material. These spots 69 may be formed of the same material as and in the same manner as are the terminals 51 or 51a. The spots are staggered as shown and are so arranged that each spot connects the ends of two adjacent lines of the deposited resistance film. As may be seen in Fig. 7 the spots 69 in conjunction with the lines of resistance film 25a produce a continuous circuitous resistance path.

The resistivity of the spots 69 may be made very low relative to the resistivity of the lines of resistance film 25a whereby substantially all of the resistance of the circuitous resistance path is contained in the lines of resistance material. Any variation in the resistivity of the spots 69, therefore, has substantially no effect upon the resistance of the ultimate resistor.

It has been found that by employing in the mask 61 stainless steel wire whose diameter is .001" and by employing a center-to-center spacing of .003" to .004" a resistance path may be obtained whose ratio of length-to-width is approximately equal to that specified above in connection with the glass mask 41, with a glass sheet of the same size, namely, $\frac{1}{4}$ " x $\frac{1}{2}$ ".

With either type of mask it will be seen that a resistance element comprising an evaporated film of metal is made to adhere to one surface of the glass sheet 24 or 24a. Furthermore, the resistance element is covered by a protective film while still in a vacuum, whereby the atmosphere, and in particular, oxygen, is never allowed to contact any part of the resistance element.

The glass sheet 21 seen in Figs. 8, 9 and 10 serves primarily to anchor the leads 22 in the proper physical position with respect to the resistance element on the glass sheet 24 or 24a. The grooves 23 may be molded in the glass sheet 21, or may be produced by any one of several obvious methods including grinding, etching or sand blasting, any suitable form of mask being provided to protect the other portions of the glass sheet during such process. The grooves 23 should, of course, be of sufficient depth to receive the lead whereby the leads do not protrude substantially beyond the notched or grooved surface of the glass sheet 21.

The grooves 23 are preferably expanded, that is, widened, near the center portion of the sheet in order that they may receive swaged or flattened leads. The flattening of the ends of the leads serves two functions, one being to better anchor the leads and the other being to provide a broad surface of lead whereby heat may more readily be transferred from the resistance element to the leads. In this connection, it will be noted that the two leads, in combination, extend over the major portion of the length of the resistance unit whereby they

may be closely adjacent all portions of the resistance element, and therefore, may more readily remove the heat generated by the resistance element. This particular feature of the invention is disclosed and claimed in application Serial No. 225,382, referred to above.

It will further be noted by reference to Figs. 8 and 9 that the two grooves 23 are separated by a bridge of glass whereby the leads are well insulated from each other.

In Fig. 15 the two glass sheets 21 and 24 along with the leads 23 are shown in assembled position. Additional insulation 68 is shown covering the protective coating 55 with the exception of the area overlying the terminals, this being recommended because of the thinness of the coating 55. This additional insulation may, for example, be a plastic material such as Ciba bonding resin No. 100 to which has been added a solvent such as trichlorethylene to produce a consistency suitable for painting, rolling or screening. This insulation is preferably cured by baking at 300° F. for two hours after permitting evaporation of the solvent.

In order to assure good electrical contact between the leads 22 and the terminals 51, it is preferred that a conductive plastic material 67 be painted, rolled or screened on the terminals. The material employed for this purpose may be any suitable plastic material bearing metal particles and may be, for example, Du Pont No. 4929 conducting paste. It has been found that this paste readily penetrates the protective film 55 to form a firm electrical contact between the leads and the terminals. This occurs because the rough surface of the fused or fired terminals prevents formation of a solid, continuous film 55 of silicon monoxide or magnesium fluoride thereon. Utilization of these characteristics of the materials employed eliminates the necessity of shielding the terminals during evaporation of the protective coating.

A suitable cement may then be applied by painting, rolling or screening, preferably to the glass sheet 24 over the area thereof other than that covered by the conducting paste 67. After the solvent or solvents have been permitted to evaporate, the resistor may be assembled and subjected to a temperature of 300° F. for two hours to cure the cement and the conducting paste.

An alternative assembly is disclosed in Fig. 16, wherein the resistance film 25 is arranged on the outer surface of the glass sheet 24 as assembled. In this embodiment the preferred construction for providing electrical contact between the terminals 51 and the respective leads 22 involves a continuation 51' of each terminal 51 extending over the corresponding edges of the glass sheet 24 and onto the opposite surface thereof, as shown. Preferably, the terminal continuations are applied after the glass sheet 24 or 24a has the resistance element 25 or 25a already adhering thereto. In this case the terminal continuations may be any suitable organic metal filled, conducting paste. Du Pont No. 4929 conducting paste has been found good for this purpose, also.

It will be apparent that the lowermost portion of the terminal continuation 51' is in position to contact the corresponding lead 22. Other than the fact that the glass sheet 24 is reversed, the general assembly of the two glass sheets and the leads is substantially the same as in the embodiment illustrated in Fig. 13. More specifically, the leads 22 are laid into the grooves 23, a conductive paste 67 is arranged in contact with the leads and the corresponding terminal continuations 51', and the two glass sheets are cemented together with any suitable form of cement. Additional insulation 68 is preferably used, similar to that shown in Fig. 15, and may be extended over the edges of the sheet 24 as shown in Fig. 16.

A resistor constructed in accordance with the invention as so far described provides for a substantially pure metallic resistance element having a high resistance per square, the resistance film being protected on all sides by

inorganic materials in intimate contact therewith. More specifically, the resistance film is protected on one surface by a glass sheet and on all other surfaces by a film of silicon monoxide, the resistance metal never having been exposed to atmosphere. It is believed that the superior stability of this resistor may be attributed, at least in large part, to the purity of the metal forming the resistance film and the continued protection of that purity by the glass sheet and the silicon monoxide coating.

Experiment has indicated that even minute quantities of oxygen in contact with the resistance material result in the formation of an oxide which in turn affects the resistance of the current path. Experiment has also indicated that the resistivity of the metal is altered by the passage of current therethrough when the metal is, or has been, exposed to oxygen. In any event it has been established by repeated tests that the resistance of a resistor constructed in accordance with the embodiment of the invention so far described varies less than .5% during standard load life tests, more particularly those specified in JAN R-11 amendment 4 specifications. In this respect this resistor is at least equal to previously known precision resistors and is vastly superior to conventional low cost resistors such as carbon type resistors.

In previously known resistors employing deposited films, it has been the practice to coat a solid, continuous sheet of deposited metal film with a protective coating prior to exposing the deposited film to atmosphere. However, an elongation of the resistance path, more specifically the increasing of the length-to-width ratio of the conducting path, has been accomplished by scratching or otherwise mechanically removing portions of the resistance film. This of course results in the exposure of the edges of the ultimate resistance element to atmosphere. Even if this exposure is made very brief, for example, if the scratched or otherwise mechanically treated resistor is promptly covered by a protective coating the oxygen which associates itself with these edges of the resistance film is believed to be the cause of the change in resistance which inevitably occurs in fact.

In a resistor constructed in accordance with the illustrated embodiment of the invention, the resistance film is originally formed as a circuitous path and all surfaces thereof are permanently sealed against the atmosphere either by the glass sheet upon which the film is deposited or by the protective coating. Accordingly, there is never an opportunity for oxygen to contact the metallic film.

Furthermore, in the prior art the most popular form of protective coating is magnesium chloride. Experiment has shown that a protective coating of this material tends to deposit in minute "islands," continued deposition resulting in overlapping of these islands until a substantially complete protective coating is formed. In order to form a reasonably continuous film, it is necessary that this material be deposited to a thickness of approximately ten millionths of an inch. It has been found, however, that even this substantial coating is porous, with the result that oxygen may find its way through this coating and attack the resistance film thereunder. The result again is that the resistance value of the resistance film is gradually affected by a substantial percentage. A resistor constructed in accordance with the illustrated embodiment of the invention, and more specifically one wherein the protective film is formed of silicon monoxide, has a relatively negligible change in resistance even after prolonged use and considerable passage of time. This is true even though the protective film is of the same thickness as that recommended above for the magnesium fluoride, or even substantially less.

It is believed that the reason for the superiority of silicon monoxide is that this material has the characteristic of being oxygen absorbent whereby it absorbs oxygen which might otherwise penetrate the protective coating and reach the resistance film below. More particularly, in the presence of oxygen, the outer surface of

the coating converts to silicon dioxide thereby forming a very dense shell substantially impenetrable by oxygen. Under severe conditions, silicon dioxide may be formed to a depth of one or two millionths of an inch, leaving the major portion of the recommended thickness as further assurance against oxidation of the metal resistance film. The resistance film is thereby permanently protected against exposure even to molecular quantities of oxygen.

It has also been found that an evaporated metallic film selected from the group VI-B metals has an extremely low temperature coefficient. More specifically, the temperature coefficient of a thin evaporated film of these metals may readily be maintained between plus and minus .003% per degree centigrade. This has been found to be true in the case of thin evaporated films in spite of the fact that the same metals in their normal solid state have temperature coefficients as high as .45% per degree centigrade. It has been found then that a thin evaporated film of chromium, molybdenum or tungsten has a temperature coefficient substantially equal to that of Advance metal or Manganin in their normal solid states. According to the invention, then, these pure metals may be used in place of recognized low temperature coefficient alloys which are quite difficult to evaporate without obtaining fractional distillation.

The noise level of a resistor constructed in accordance with the invention, since the resistance element is entirely of metal, can be maintained at less than .1 microvolt per volt whereby it is equal to wire wound resistors, and on the order of one-tenth the noise level of carbon resistors.

One of the outstanding characteristics of the resistor constructed in accordance with the invention is its ability to operate at relatively high ambient temperatures. Such a resistor may operate with substantial load at temperatures as high as 200° C., whereas conventional carbon resistors are normally rated to zero load at 120° C., and even wire wound resistors cannot normally operate above temperatures of 150° C. This characteristic of the resistor is attributable to the stability of the metallic resistance film and to the stability of the insulating materials employed in the construction thereof. More specifically, neither the glass sheets forming the main body of the resistor nor the silicon monoxide protective film is appreciably affected by temperatures in the order of 200° C.

Still another characteristic in which the resistor is markedly superior to other known resistors is the constancy of its resistance when subjected to high frequency voltages. It is well recognized in the art that carbon resistors are greatly affected by high frequencies, the resistance changing as much as 50% or even more. Similarly, conventional wire wound resistors present a very high apparent resistance to high frequency voltage because of their high inductance. The resistance of even specially wire wound resistors, designed to substantially eliminate inductance, varies substantially with frequency change, at least as compared to a resistor constructed in accordance with the invention. The compensating reversals of current path in the resistor disclosed herein substantially eliminate inductance, and "skin effect" is substantially eliminated since current penetration even at ultra high frequencies is on the order of ten times the recommended resistance film thickness.

As previously indicated, this resistor while having these and other superior characteristic is relatively inexpensive to manufacture. The low cost of construction of this resistor springs primarily from the fact that a very large number of resistors or resistor components may be handled as a unit in all operations required in the manufacture of the resistor. For example, the glass sheet 21, shown in Fig. 8 and having the lead receiving grooves 23 therein, may be cut from a relatively large sheet of glass 71 in which the pattern

of the individual resistor part 21 is reproduced a large number of times, such sheet being shown in Fig. 13. Since each individual resistor part 21 has a surface measuring only $\frac{1}{4}$ " x $\frac{1}{2}$ ", a sheet of glass approximately one foot square can readily include one thousand of the individual sheets 21. After the grooves 23 have been formed in this large sheet, the latter may readily be cut and broken along the lines AA and the lines BB to form the individual resistor elements 21. Preferably the entire sheet 71 is cut along all lines AA and BB before breaking along any of these lines in order that the entire sheet may be cut as a unit.

In order to permit continued convenient handling of the individual resistor elements 21 after cutting and breaking, and for other important reasons subsequently to be explained, it is desirable that strips of tape be secured to the smooth surface of the large glass sheet prior, at least, to the breaking of individual strips. More specifically, the large sheet may be cut and broken along the lines AA, but prior, at least, to breaking along the lines BB a strip of tape 73 is preferably secured to the smooth side of the individual strips, as illustrated in Fig. 14.

The resistor parts 24 or 24a of Figs. 4 and 7 may also be produced en masse, that is in a large sheet such as sheet 74 of Fig. 17, which sheet might measure 12" square to match the sheet 71 shown in Fig. 13. The terminals 51 or 51a, and (where a wire mask is used) the conducting spots 69, may be screened onto or otherwise applied to the entire 12" square sheet in repetition of the patterns suggested in Figs. 3 and 6. Where a screening or rolling operation is employed the entire repeated pattern may be applied to the large sheet in a single operation. The entire sheet may then be placed in the vacuum chamber 31 for deposition of the evaporated films thereon.

A wire mask 81 is illustrated in Fig. 11 which is substantially identical to that of Fig. 5 except that the mask 81 may be employed to produce, simultaneously, the pattern of Fig. 7, repeated any reasonable number of times. A single evaporation step is therefore required in producing a large number of resistance films (for example, one thousand) on the large sheet of glass 74.

Referring to Figs. 11 and 12 it will be noted that the wire mask 81 has an outer frame 82 and cross members 83 and 84. These cross members serve to shield those portions of the glass sheet which ultimately form the edges of the individual resistor elements 41 and at the same time serve to brace the outer frame 82 of the mask. As in the case of the single mask of Fig. 5, the wire 65 extends over the edges of the frame and is looped around pins 64 whereby the wire may be in contact with the sheet 74 during evaporation.

It is believed to be apparent that a multiple mask such as that illustrated in Figs. 11 and 12 may readily be provided for masking a very large number of resistor elements during the evaporation step, such mask readily being made to cover a sheet of glass measuring 12" square as suggested above. It will be noted in Fig. 17 that terminals 51 or 51a of adjacent resistors are contiguous and may, as shown, be applied as a single rectangle of conducting material, previously described. After the resistance element and the protective coating have been applied, the sheet 74 may be removed from the vacuum chamber and the additional insulation 68 applied. This additional insulation may be screened or rolled onto the sheet 74 in a single step after which it is heat treated to harden it. When the resistor parts 24, contained in the large sheet of glass 74, are ready for assembly, the latter is preferably cut along the lines AA and BB of Fig. 17 and broken along lines AA to form strips matching the strips of resistor elements 21, in turn formed by breaking along the lines AA of Fig. 13, as previously explained.

The strips formed from the glass sheet shown in Fig. 17 are preferably taped as in the case of the strips formed

from the sheet of glass of Fig. 13. Both strips are then broken along the lines BB of both figures, both large sheets having been cut along these lines while still in sheet form. The strips can readily be broken then along the cuts but the individual resistor elements are retained in strips by the tape previously secured to the surfaces thereof which ultimately form the outer surfaces of the completed resistor.

Assembly of the two sheets of glass forming each resistor is then accomplished by placing the two strips of glass in alignment one against the other with the leads in place and with conducting paste and bonding cement applied as described above in connection with Figs. 15 and 16. It is at this step of the process that the taping of the strips of glass proves to be advantageous other than in regard to the convenience of handling the small sheets of glass making up each strip.

The taping together of the individual small sheets of glass causes the edges thereof to be held in closely abutting relationship. Because of this the cement used to bond the pairs of glass sheet together may not escape along the abutting edges of the sheets. It has been found that containing of the bonding cement results in several desirable characteristics in the ultimate resistor. One of these is that the contained cement has much less tendency to form bubbles therein than is the case when the cement is not contained. Such bubbles are undesirable in that they invite seepage of moisture between the glass plates.

Another advantage in containing the bonding cement is that when the resistors formed in a strip are ultimately separated, the cement breaks cleanly and presents a clean, smooth edge. As opposed to this, if the cement is not contained, a rough jagged edge will appear unless substantial precautions are taken to guard thereagainst. A smooth edge on the bonding cement rejects moisture and tends to remain clean whereas a rough jagged edge tends to hold dust and moisture and increases the possibility of current leakage between the resistor leads.

In this regard, it should be noted that the strips of resistor elements are so cut (along the lines AA of Figs. 13 and 17) that the general flow of current in the ultimate resistors is from one edge of the strips to the opposite edge thereof. Accordingly, it is the edges of the resistors running in the direction of current flow which are abutting during the cementing step and which therefore ultimately present a smooth bonding-cement edge. It is these edges, of course, which should be clean and dry to resist leakage current.

Finally it is well recognized in the art that contained or confined cement forms a better bond than the same cement where it is allowed to flow during the cementing operation.

The taping of the strips of glass therefore permits not only much more convenient handling of the material but results in a firmer mechanical bond along with substantially increased resistance to moisture penetration and leakage current.

An alternative embodiment of the invention in regard to the formation of the resistance unit, particularly in a fine circuitous pattern, is illustrated in Figs. 18-18e. In this embodiment of the invention, a glass sheet 24 may be used which is identical to the glass sheet 24 illustrated in Fig. 3, including the terminals 51 adhering to opposite edges thereof. A photosensitive coating 91 is first applied to the surface of the sheet 24 to which the resistance film is ultimately to be applied, as illustrated in cross section in Fig. 13. This may be, for example, a bichromated colloid such as fish glue. Such special emulsions are well-known in the art.

The emulsion is next exposed to activating radiations in a pattern which is the reverse or negative of the desired ultimate pattern of resistance material. The emulsion is then developed by washing in water (where the photosensitive material above referred to is employed), the

water washing away the nonactivated portions thereof. The developed coating 91a, seen in Fig. 18a, may be of a pattern identical to that of the glass mask illustrated in Fig. 2. The photographic coating 91a, in fact, serves substantially the same purpose as the masks illustrated in Figs. 2 and 5.

The glass sheet 24, with the photographic coating 91a of desired pattern adhering thereto, may, after proper cleaning, be placed in the vacuum chamber 31. A film 92 of chromium or other metal is then deposited over the entire surface of the glass sheet, producing the result illustrated schematically in Fig. 18b. A coating 93 of magnesium fluoride, or other suitable protective material, is then deposited on the metal resistance film 92, the glass sheet then appearing as illustrated schematically in Fig. 18c.

When the glass sheet has been removed from the vacuum chamber, it is next subjected to a solvent such as sodium hypochlorite which is relatively inactive with respect to the metallic film and the protective coating but which serves to dissolve the developed photographic coating 91a. It has been found that this solvent will readily penetrate both the magnesium fluoride coating and the metallic film to attack and dissolve the photographic coating. The reason for this penetration is not known certainly but it is believed that the relatively rough and porous surface of the photographic coating prevents the formation of a continuous thin film of metal or protective coating thereon. When the photographic coating is so dissolved and washed away it carries with it the overlying portions of the metallic film and protective coating. This leaves the glass sheet appearing as is schematically illustrated in Fig. 18d.

It will be apparent that with this method a metallic film is obtained which is protected at all times from exposure to atmosphere over the principal surfaces thereof by the glass sheet and by the protective coating. It will also be apparent, however, that the edges of the metallic film are exposed to atmosphere following the removal of the photographic emulsion. This results in some instability of the resistance film and, for this reason, this photographic method is considered inferior to the methods employing the masks of Figs. 2 and 5.

As soon as possible after the glass sheet has been brought to the condition illustrated in Fig. 22 and thoroughly cleaned, a coating 94 is preferably applied further to protect the resistance film as well as to provide further electrical insulation and mechanical protection thereof. The coating 94 may be identical to the coating 68 applied in the previously illustrated embodiments of the invention and serves substantially the same purposes. The glass sheet 24 then appears as schematically illustrated in Fig. 18e and is ready for assembly with the glass sheet 21 and leads 22 in the manner illustrated in Fig. 15 or Fig. 16 and described above.

It will be apparent that this photographic method lends itself to production of resistors en masse. This method is, in fact, another embodiment of the invention whereby the large sheet 74 of Fig. 17 may be produced, and in each step of the method the large sheet 74 may be handled just as readily as a single resistor part 24.

Still another embodiment of the invention is disclosed in Figs. 19 and 19a, b and c. In this embodiment of the invention a glass sheet 100 is first etched to produce a circuitous groove 101 having a depth preferably on the order of .0002", a groove of this depth readily being etched in a very fine pattern. Preferably, but not necessarily, the groove terminates substantially inwardly of the ends of the glass sheet 100 as indicated in Fig. 19.

A terminal 102 is then applied at each end of the sheet 100 in a manner identical to that described above in connection with the terminals 51. The sheet 100 is then in the condition illustrated schematically in Figs. 19 and 19a.

After the sheet has been properly cleaned it is ready for deposition of a metallic film 103 and a protective coat-

ing 104 over the grooved surface of the sheet to produce a construction such as is illustrated in Fig. 19b.

In this figure, as in many other figures in this application, the thickness of the metallic and protective films is greatly exaggerated in order that they may be given finite thickness without resorting to such a large scale of drawing that all perspective is lost. In the embodiment of the invention as actually produced, the depth of the groove 101 is approximately .0002" as previously indicated, while the thickness of the metallic and protective film in combination is on the order of ten millionths of an inch, or approximately one-twentieth of the depth of the groove.

The sheet 100 may then be removed from the vacuum chamber 31 and subjected to polishing by a fine grain abrasive such as rouge or Barresite, such abrasive preferably being arranged on a narrow and relatively resilient wheel. The abrasive may, for example, be embedded in a soft copper band mounted on a soft, resilient wheel. The abrasive operates to remove those portions of the metallic and protective films which are deposited upon the ridges 105 between the grooves 101, and only in that area of the glass sheet 100 lying appreciably inwardly of the terminals 101. In Fig. 19c it will be noted that the metallic film 103 has been completely removed from the ridges 105 whereby a continuous current path is found only along the circuitous groove 101. It will also be noted in Fig. 19c that the metallic film 103 and the overlying protective coating 104 remain unbroken over the surface of the glass sheet 100 between the inner edge of the terminals 102 and at least some portion of the first leg of the groove 101, this being necessary in order to establish electrical connection between the terminals and the resistive film deposited in the groove 101.

The embodiment of the invention disclosed in Figs. 19-19c has the advantage that no mask is required and that the groove 101 is readily formed in the glass sheet 100 in a very fine pattern because of its shallowness. However, this embodiment has the disadvantage of the embodiment illustrated in Figs. 18-18e, namely, that the edges of the resistance film are exposed to atmosphere at least for a short interval between the polishing operation and a subsequent application of additional insulation and/or an additional protective coating. Even though this time interval may be made very small, nevertheless some oxidation occurs, with the undesirable results explained in detail above. For this reason the embodiment of the invention disclosed in Figs. 19-19c is considered less desirable from the standpoint of producing a suitable resistor than the preferred embodiments described above in connection with Figs. 1-17.

This embodiment of the invention, like all embodiments of the invention described above lends itself readily to mass production of resistors. More specifically, each of the glass sheets 100 forming the base of a resistance element may be and, in fact, preferably is, a small segment of a much larger sheet of glass, such large sheet being, for example, 12" square and readily containing or comprising one thousand of the glass sheets 100.

As has previously been indicated, it is possible to produce a resistor by the foregoing methods having a resistance value very close to any desired predetermined value. More specifically, a predetermined value can be obtained within ± 3 to 5%, and substantial experience in the production of such resistors may result in controlling the resistance value much more closely. In any event still more precise resistance values may be obtained by a method illustrated in Figs. 20, 20a and 20b.

In Fig. 20 there is illustrated a resistor which, by way of example, is similar to that illustrated in Fig. 7. The glass sheet 24b employed in this embodiment of the invention is identical to the glass sheet 24a of Figs. 6 and 7 with the exceptions that certain ones 69b of the conducting spots 69 include outwardly extending legs 111,

an additional conducting spot 112 is arranged near the center line of the resistor element, and a conducting bridge 113 connects the terminal 51b to the resistance element 25a near the center line thereof. The outwardly extending legs 111, the conducting spot 112 and the bridge 113 are the same material as that recommended above for the terminals and for the conducting spots 69.

After the resistance element 25a and the protective coating have been deposited on the glass sheet 24b by evaporation and after the glass sheet has been removed from the vacuum chamber 31, conducting paste, such as that recommended above for assuring connection between the leads 22 and the terminals 51, is painted, rolled or screened onto the surface of the glass sheet 24b to form connecting links 114, 115, 116 and 117 between adjacent ones of the conducting spots 69b and between one such spot and the terminal 51b, as shown in Fig. 20. Contact between these connecting links and the associated conducting spots 69b or the terminal 51b is obtained by virtue of the fact that the silicon monoxide or magnesium fluoride protective coating apparently fails to form a continuous film over the rough surfaces of these conducting spots and the terminal. In any event, and whatever the true explanation may be, it has been found that the connecting links 114-117 make firm electrical contact with the conducting spots and the terminal even though the latter have been subjected to the deposition of evaporated silicon monoxide or magnesium fluoride.

It will be apparent upon reference to Fig. 20 that the connecting link 114 short-circuits the two legs or bars of the resistor element 25a which are designated 25c in Fig. 19. Similarly the connecting link 115 short-circuits the bars 25d. Still further the conducting spot 112 short-circuits the upper half of each of the bars 25e while the connecting link 116 short-circuits the remaining or lower half of these bars. Finally, the connecting link 117 short-circuits the lower half of the bar 25f.

If the resistance of the resistor element with the connecting links 114-117 connected as shown, is of the proper or desired value, the resistor may be assembled as described above without adjustment. Where the adjustment features illustrated in Fig. 20 are employed, however, it is recommended that the resistance value be made slightly lower than the desired value. In such case the actual resistance is measured and if found, in fact, to be too low, selected ones of the connecting links 114-117 may be broken merely by wiping or cutting the same, whereby the short-circuiting of various bars or portions thereof is eliminated. In this regard it should be noted that the connecting links are of relatively soft conducting paste which can readily be broken or even substantially removed.

Let it be assumed that the resistor element 25a in Fig. 20 includes fifty individual bars. Each bar then represents 2% of the total resistance value. If it is found that the resistance value is approximately 4% too low, the connecting link 114 or the connecting link 115 may be broken whereby two additional bars 25c or 25d are effectively placed in the resistance circuit and whereby the resistance value is increased by 4%. If the resistance value is found to be approximately 2% too high, the connecting link 116 may be broken whereby the lower half of each of the bars 25e is effectively placed in the resistance circuit and whereby the resistance value is increased approximately by 2%. Similarly, if the resistance value is found to be approximately 1% too high the connecting link 117 may be broken whereby the lower half of the resistance bar 25f is placed in the circuit and the total resistance is increased by approximately 1%.

It will be apparent that increases of resistance can be made up to and including 11% by breaking or a cutting all of the illustrated connecting links, and that the total resistance may be increased in steps of 1% provided

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that the total increase required is determined in advance. It will also be apparent that additional connecting links may readily be employed to permit further increase in resistance and that by proper placing of the conducting bridge 113 or of one or more conducting spots 112 an increase in resistance can be made possible, which is only a fraction of 1%, for extremely precise requirements.

It is contemplated that the resistance of the resistors, as manufactured, be tested by automatic machinery which travels along the strips of resistor elements 24 with the resistance element and the protective coating deposited thereon and while still in the form of a large sheet such as the sheet 74 of Fig. 17. It is believed to be a relatively simple matter to provide testing apparatus which will progress along the sheet and measure the resistance of each resistor. It is further contemplated that a knife edge or scratching point be made to progress along the length of each resistor element during or immediately following the testing of each resistor. It is still further contemplated that apparatus be provided which is responsive to resistance measurements for raising and lowering the knife edge as it so moves. Accordingly, the testing apparatus may be so adjusted that when the resistance of a particular resistor is too high, by a certain percentage, the knife edge will be lowered as it passes over one or more of the connecting links 114-117, the severing of which will increase the resistance by the amount necessary to produce the desired total resistance.

While such testing apparatus is not disclosed in the drawings and does not form a part of the present invention, it will be apparent that it is desirable, in contemplation of the use of such machinery, that the portions of the links 114-117 which are selectively to be severed lie in a straight line, preferably, but not necessarily, parallel to the general direction of flow through the resistor. It will be noted that this is the case in the embodiment of the invention illustrated in Fig. 20 whereby the use of a testing and adjusting machine such as that suggested above is made possible.

As indicated above, the metallic resistance film according to the preferred embodiment of the invention is of such thickness and resistivity as to provide a resistance in the order of one thousand ohms per square. In order to produce resistors of high resistance, i. e., having a resistance of several thousand ohms or several megohms, it is necessary to resort to the circuitous patterns described above to obtain an increased ratio of length-to-width while still maintaining a resistor of the proportions suggested above.

Where the desired resistance is on the order of two thousand ohms or substantially less, a solid, i. e., substantially rectangular, resistance film may be employed. Such a resistance film and means for adjusting the resistance value thereof are illustrated in Fig. 20a. In the illustration of this embodiment of the invention a glass sheet 24c is shown having terminals 51 adhering thereto, this portion of the resistor being identical to that illustrated in Fig. 3. In addition to the terminals 51 there is deposited on the glass sheet 24c a series of pairs of substantially parallel strips of conducting material 121, 122 and 123. These strips may be of the same material and formed in the same manner as the terminals 51.

A metallic resistance film 25g is deposited in a rectangular pattern as illustrated in Fig. 20a and a protective coating, preferably of silicon monoxide, is deposited thereover in a vacuum in the same manner as described above in connection with previously described embodiments of the invention. In this instance, of course, a relatively simple mask is required to limit deposition of the metallic resistance film to the desired rectangular area. The conducting strips 121, 122 and 123 are so positioned on the sheet 24c that one end of each extends beyond one edge of the resistance film 25g.

After the sheet 24c has been removed from the vacuum

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chamber a series of connecting links 124, 125 and 126 are painted, rolled or screened onto the sheet in such position that the ends of each connecting link overlie the exposed ends of a pair of strips 121, 122 or 123, as shown.

Again the rough surface of these strips prevents formation of a continuous film of silicon monoxide, whereby the conducting links 124, 125 and 126 may make firm electrical contact with the respective strips.

Since the resistance of the material forming the strips 121, 122 and 123 is negligible compared to that of the resistance film 25g it will be apparent that the link 126, for example, short-circuits the resistance film lying between the two strips 123. Similarly, the link 125 short-circuits the resistance film lying between the strips 122. The width of the strips is of no material consequence but the width of the resistance film between the strips is significant in that it is this film which is short-circuited by the respective links and which may be inserted in the current path by interruption of the corresponding links. In the illustrated embodiment the width of the resistance film between the strips 123 is twice as large as the width of the resistance film between the strips 122. The resistance of the film between the strips 123 may, for example, represent approximately 4% of the total resistance whereas the resistance of the film between the strips 122 represents approximately 2% of the total resistance.

The width of the film between the strips 121 may be equal to that between the strips 122 as illustrated. However, since the strips 121 extend only half way across the resistance film, it will be apparent that the link 124 short-circuits only a fraction (approximately one-half) of the 2% of total resistance short-circuited by the link 125. The purpose of the abbreviated strips 121 is to provide more sensitive adjustment of the total resistance than would be possible with the strips 122 and the link 125 with a given small distance between such strips.

It will readily be seen that adjustments up to approximately 7%, in steps of 1%, may be accomplished by severing selected ones of the links 124, 125 and 126. Also, it will be noted that severable portions of these links are arranged in a straight line, as in the embodiment illustrated in Fig. 20, whereby a device for scratching or wiping away these links may travel in a straight line and may be made to bear against the resistor element to interrupt selected ones of the links.

Where a total resistance is required which is very small as compared to the resistance per square of the deposited metallic resistance film, resort may be made to a pattern of terminals such as that illustrated in Fig. 20b. In this instance a glass sheet 24d is provided with terminals 131 and 132 which are arranged as illustrated to provide a relatively short and wide current path therebetween. A metallic resistance film 133 is deposited on the sheet in a rectangular pattern, along with a protective film, in the manner previously described. The largest portion of the current may pass from the leg 134 of the T-shaped terminal 132 to the legs 135 and 136 of the U-shaped terminal 131. The length of the current path is obviously only a small fraction of the width of the current path, in direct contrast to the current path illustrated in Fig. 4, for example, wherein the length of the current path is many times greater than its width. Through this device a resistance of a few ohms may readily be obtained even though the resistance per square of the resistance film may be in the order of one thousand ohms as suggested above.

It will be noted that the leg 135 of the terminal 131 is foreshortened, and in its place there is provided a series of conducting spots 137, 138 and 139. These conducting spots as well as the terminals 131 and 132 are preferably formed of the same material and in the same manner as the terminals 51a and the conducting spots 69 of Fig. 7. The spots 137, 138 and 139 are connected to the leg 135 of the terminal 131 by a conducting link 140, as shown, this link being of the same material as the conducting links of Figs. 20 and 20a.

It will now be apparent that the total resistance of the resistor illustrated in Fig. 20b may be increased by interrupting the link 140 since such interruption substantially increases the resistance of the current path in the lower left-hand corner of the resistance film. It will readily be understood that the link 140 should be broken, wiped away or otherwise interrupted from left-to-right in Fig. 20b in order that the total resistance may be increased in three successive steps. Again, it will be noted, the movement of a device for successively interrupting the various legs of the link 140 may be along a straight line.

Each of the illustrated embodiments of the invention lends itself to mass production, with resulting low manufacturing cost. More specifically, it lends itself to the production of a large number of resistors or resistor parts in a large sheet incorporating hundreds of the individual resistor parts, most of the manufacturing steps being performed while the large sheet is intact.

At the same time the resulting resistor, particularly when constructed in accordance with the preferred embodiments, has performance characteristics superior to those of presently known low cost resistors, and equal to and in many instances superior to much more costly precision resistors.

Still further, the resistance of resistors constructed in accordance with the invention may be accurately controlled and, where even more precise resistance values are necessary, may readily be adjusted.

While particular embodiments of the invention have been shown, it will be understood, of course, that the invention is not limited thereto since many modifications may be made, and it is, therefore, contemplated to cover by the appended claims any such modifications as fall within the true spirit and scope of the invention.

The invention having thus been described, what is claimed and desired to be secured by Letters Patent is:

1. A resistor comprising an insulating base, an oxidizable metallic resistance film adhering to said base, a pair of terminals electrically connected to spaced points on said resistance film, and a layer of silicon monoxide covering substantially all the exposed surface of said resistance film.

2. The method of producing a resistor which comprises, evaporating a metallic resistance film in a circuitous pattern onto an insulating base in a high vacuum and evaporating an insulating coating onto all exposed surfaces of said resistance film in a continuation of said high vacuum.

3. The method of producing a resistor which comprises, evaporating a metallic resistance film in a circuitous pattern onto an insulating base in a high vacuum through a mask arranged in front of said base and having a circuitous cut away portion for permitting passage of evaporated metal, and evaporating an insulating coating onto all exposed surfaces of said resistance film in a continuation of said high vacuum.

4. The method of producing a resistor which comprises, evaporating a metallic resistance film in a circuitous pattern onto an insulating base in a high vacuum through a mask arranged in front of said base and having a circuitous cut away portion for permitting passage of evaporated metal, removing said mask from in front of said base without breaking said high vacuum, and evaporating an insulating coating onto all exposed surfaces of said resistance film in a continuation of said high vacuum.

5. The method of producing a resistor having a resistance element composed of a substantially pure chromium, and having a temperature coefficient of resistance lying between plus and minus .005% per degree centigrade, which method comprises, evaporating a resistance film of chromium onto an insulating base in a nonoxidizing environment.

6. The method of producing a resistor which comprises, evaporating a metallic resistance film onto an insulating base in a nonoxidizing environment, and evaporating a coating of silicon monoxide onto all exposed surfaces of said resistance element in a continuation of said nonoxidizing environment.

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