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RESISTOR

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My invention relates to resistors and more particularly to resistors of types suitable for use in radio receivers, wherein noise occasioned by variations in resistance during the passage of current therethrough must be minimum.

Resistors of types used in radio receivers must be "quiet". That is to say, since such resistors are usually utilized in connection with sensitive thermionic devices, their resistance must not fluctuate while they are conducting electric currents. This requirement must be met to a greater or less degree in the manufacture of all resistors of the types under discussion.

A resistor for use in radio receivers should also have a substantially zero temperature coefficient of resistance and a low load-coefficient of resistivity. That is to say, it should be so made that temperature changes occasioned either by atmospheric conditions or by the passage of electric current therethrough will not materially affect the resistance value.

It is, accordingly, an object of my invention to provide a new and improved resistor that shall be substantially free from noise when used in an amplifier.

Another object of my invention is to provide a resistor that shall have a substantially zero temperature coefficient of resistance during normal operation thereof.

Another object of my invention is to provide a resistor that shall have a low load-coefficient of resistivity.

It is also highly desirable that manufacturing methods be devised and materials provided whereby quantity production of resistors having accurately predetermined values may be had. It is, accordingly, a further object of my invention to provide such methods and such material.

A still further object of my invention is to provide a new resistor material capable of being molded into any desired shape with full assurance that the resulting device will have the predetermined resistance and temperature coefficient characteristics.

The foregoing objects and other objects ancillary thereto I prefer to accomplish, in short, by first coating particles of a filler material, such as asbestos, powdered glass, sand, or the like, or a mixture of filler materials, with a polymerizable resin in solution and thereafter causing conducting material, preferably graphite and/or carbon black, to be precipitated upon the coated particles from a colloidal solution thereof.

The novel features that I consider characteristic of my invention are set forth with particu-

larity in the appended claims. The invention itself, however, both as to its organization and its method of operation, together with additional objects and advantages thereof, will best be understood from the following description of a specific embodiment.

Substantially all fixed resistors used in radio receivers, amplifiers, and the like, include a filler, a conducting material, a binder, and a moisture-repellent impregnating material. The electrical and mechanical properties of the resistor depend not only upon the nature of these components but on the manner in which they are put together.

Previous to my present invention, I made many experiments in the effort to utilize asbestos, glass, or sand singly as well as various mixtures of sand or glass and asbestos, as fillers. For a binding material, I tried many grades of phenol formaldehyde resin in liquid and powdered form or in the form of varnish. For the conducting material, I tried dry graphite and carbon black, but in all of my early experiments I found that, if the conducting material was first mixed with the filler and the binder thereafter added, the resistors made from such a compound were extremely variable in resistance value and could not accurately be reproduced by factory processes.

According to my invention, therefore, I first take a predetermined amount of finely ground glass and air floated asbestos and intimately mix with it a solution of phenol formaldehyde resin (known as bakelite) in acetone. The principal function of the ground glass is to impart to the finished resistor a rough surface to which paint and sprayed metallic terminals will firmly adhere. For the mixing process, I prefer to use a device commercially known as a "kneader" and continue the kneading process until substantially all of the solution is evaporated. At this stage in the process, the mass of material has a dough-like consistency and if a small portion of it is examined under a microscope, it will be apparent that every particle of the asbestos and glass is covered with a film of unpolymerized resin left by the evaporation of the acetone.

The "mix" is next removed from the kneader and is crumbled into particles which are allowed to stand until all of the solution evaporates and it becomes quite hard and brittle. The material is next placed in a ball mill, or grinder of any convenient type, and is ground until substantially all of it becomes fine enough to pass an 80 mesh screen.

While the process of grinding is being carried

on, the conducting material may well be in course of preparation. For this material, I prefer to use a colloidal suspension of carbon in water, such as the graphitic material known to the trade as "Aquadag", manufactured by the Acheson Graphite Company, a gas-carbon suspension known as "Aquablack", manufactured by Binney & Smith Company, or a suitable mixture of the two.

In view of the fact that graphite has approximately one-tenth the resistance of carbon, such as is utilized in the manufacture of aquablack, these two commercial materials cannot be interchangeably utilized in the same proportions. It is, however, desirable to use aquadag for resistor elements having relatively low resistance and aquablack or mixtures of the two suspensions, suitably diluted, for resistors having relatively high resistance.

For resistors having high resistance values, it is particularly desirable to use mixtures of graphite and carbon black made from natural gas. If graphite alone is used for such resistors, the proportion thereof is so small that the particles are quite widely separated. This condition gives rise to noise which is obviated by the presence of carbon black particles that effectively "bridge" the graphite particles.

The 80-mesh resin coated particles are next intimately mixed with the colloidal carbon suspension, which has been diluted with water to a point whereat the liquid is substantially 1% carbon by weight, by a stirring operation and, for this purpose, mixing apparatus of substantially any well known commercial type may be utilized.

For the purpose of explanation of the foregoing paragraph, it is to be understood that the term "colloidal carbon suspension" is intended to include diluted aquadag, diluted aquablack, or a diluted mixture of the two. It is also within the scope of my invention to first mix the resin coated particles with either one or the other of the first-mentioned solutions, and to thereafter mix or add the other solution, thus causing successive precipitation of carbon in different forms on the particles.

Under usual conditions of manufacture, the introduction of the resin-coated filler material into the colloidal carbon suspension disturbs the electric charge relations existing in the said suspension, with the result that the carbon is precipitated onto the filler material and forms a conductive film over the entire surface of each minute particle thereof. Under certain conditions the colloidal suspension of the carbon persists and, in such case, I find it advisable to add to the mixture a small amount of hydrochloric acid which coagulates it and causes the precipitation hereinbefore mentioned. As an alternative, for the purpose of coagulating the colloidal suspension, I may add to the acetone solution of the resin, before coating the filler particles therewith, a small amount of furfural or of some other volatile material such as acetic acid, having an ionizable hydrogen atom with which it readily parts. For this purpose, I have also obtained fairly good results with small quantities of an organic acid such as malic, citric, tartaric, or the like.

After the carbon is precipitated onto the filler material particles, the supernatant liquid is either drained off or the solution is filtered in a filter press or the like. The cake resulting from the filtering process is dried at a temperature of approximately 40° C., for 24 hours, or, at least, for

a period of time sufficient to drive off substantially all of the residual moisture.

In order that the continuity of the carbon film on the filler particles shall not be interrupted, the dried cake must be handled rather carefully. In other words, it is highly inadvisable to subject the cake to any further grinding operations to prepare it for handling, and at this point in the process it is found best to manually crumble the cake into small particles suitable for charging a molding machine.

The crumbled material is next loaded into the hopper of an automatic "pill" making machine, such as is used in the drug industry, or into equivalent well-known apparatus, which forms it into cylindrical rods under a pressure of the order of ten tons per square inch. For the sake of uniformity, I prefer to form rods $\frac{3}{4}$ " in length and $\frac{1}{4}$ " in diameter if the power rating thereof is not to be in excess of one watt. The rods made as described are then placed in trays and baked in an oven at 170° C. for approximately one hour.

I am not, at this time, prepared to exactly explain all of the physical changes caused in the pill by the baking process and consequent polymerization of the resin coating underlying the carbon on each particle of filler.

It appears, however, that during the baking step of the process, the carbon films on the particles merge together to provide what might be termed a "honeycomb" structure, of conducting material, and that the polymerization of the binder serves to lock the elements of the said honeycomb structure firmly in place, without disturbing the continuity of the carbon contacts. However, in view of the fact that the carbon films are extremely thin, it is, of course, probable that some of the resin may seep through them and bond with resin from other particles. As a matter of fact, the binder does not appear to have any pronounced insulating action and it may well happen that the theory first above given is correct.

In order that my disclosure shall be complete, the following specific directions for making 1000 resistors, each having a resistance of 700 ohms and each capable of dissipating one watt, are given:

For the above purpose, I take 5 lbs. of glass ground to pass a 150 mesh screen, $2\frac{1}{4}$ lbs. of air-floated asbestos, and mix them in a kneader with 1.62 lbs. of phenol-formaldehyde resin dissolved in 8 lbs. of acetone.

To coat the amount of filler material specified, in order to obtain the desired resistance characteristic, requires .126 lbs. of graphite. This weight of graphite is contained in .63 lbs. of commercial aquadag which is diluted by adding to it approximately $5\frac{1}{2}$ pints of distilled water to form a colloidal suspension having the required density.

The following table gives relative proportions of filler, resin, and carbon for a number of finished resistors $\frac{3}{4}$ " long and $\frac{1}{4}$ " in diameter:

Asbestos	Resin	Graphite	Carbon black	Glass	Resistance
Percent	Percent	Percent	Percent	Percent	
72	25	3			700 ohms.
73	25	2			2000 ohms.
74	24.5	1.5			500000 ohms.
24	18	.7	2.3	55	1.2 megohm.
24	18	1.2	2.3	54	17000 ohms.
24	18	1.4	2.3	54	11000 ohms.

From the foregoing table, it will be apparent

that a resistor having any desired resistance characteristics may be made by suitably choosing the relative amounts of filler and conducting material. It will also be noted from the table that the variation in the resin content plays a very minor part in the resistance of the finished article, which is in accordance with the theory hereinbefore advanced.

After baking, the resistor rods must, of course, be provided with suitable terminals. For this purpose, I find it best to utilize the Schoop metal spraying process and I apply to each end of the resistor a ring of copper or tin extending inwardly from the end a distance of $\frac{1}{4}$ ". Obviously, the resistance of the rod measured from end to end can be further controlled at this point in the process by adjusting the width of the sprayed terminals. As a general rule, however, this is not done in the factory, for the reason that it is much more convenient to so arrange the spraying machinery that all resistors are provided with terminals of the same width.

After the terminals have been sprayed onto the ends of the rods, the rods are immersed in a moisture-repellent impregnating material such as melted carnauba wax, aerclor, halowax, sincera wax, cerawax, paraffin, linseed oil, or the like, which has no solvent action on the polymerized resin at any operating temperature. The melted wax is preferably maintained at a temperature of 170° C., and the rods are kept therein for approximately forty five minutes. Carnauba wax is particularly advantageous to use as the impregnating material since, by reason of its expansion within the interstices of the resistor rod, at temperatures below its melting point, it compensates, to some extent, for changes in resistance occasioned by temperature rise. I have also found linseed oil to be quite satisfactory, since it oxidizes and forms a surface coating which is thoroughly waterproof. Linseed oil, however, necessitates an extra baking step to effect this oxidation.

A resistor manufactured according to my improved method offers many advantages not heretofore obtained. In the first place, the process utilizes carbon which can be purchased in its processed form and is immediately available. Secondly, the resistance values can be duplicated fairly accurately and, in addition, the electrical characteristics can be accurately determined and controlled, while the finished resistors exhibit extremely low load coefficients of resistivity. Naturally, I am aware that certain of the mentioned advantages have been approached in the past, but it is my belief that no resistor now on the market exhibits them to as great an extent as a resistor manufactured according to my improved process.

Although I have disclosed herein certain specific proportions of filler, resin, and conducting material, these are given merely by way of example and are not to be construed as in any way circumscribing the scope of my invention. Many other modifications will be apparent to those skilled in the art and my invention, therefore, is not to be limited except insofar as is necessitated by the prior art and by the spirit of the appended claims.

I claim as my invention:

1. An as element of a resistor device, a particle of inert, substantially non-conductive filler material, a coating of insulating material thereon, and a film of conducting material upon the outer surface of the insulating material.

2. As an article of manufacture, a resistor composed of particles of inert filler, substantially all of said particles being respectively coated with an insulating material carrying an outer film of conducting material, the films of conducting material being in intimate contact with each other throughout the mass of said resistor.

3. The invention set forth in claim 2, wherein the insulating material is a polymerized phenol formaldehyde resin.

4. The invention set forth in claim 2 wherein the conducting material films are bonded together into a quasi-honeycomb structure.

5. The process of manufacturing a material from which resistors may be formed which comprises coating a plurality of particles of inert material with an insulating layer and thereafter depositing a conducting surface film upon substantially all of said particles.

6. The process of manufacturing a material from which resistors may be formed which comprises coating the surface of a plurality of particles of inert filler material with a polymerizable material, and thereafter causing a film of conducting material to be deposited upon the surface of the polymerizable coating.

7. The method of manufacturing a material from which resistors may be formed which comprises mixing a mass of inert material particles with a solution of a polymerizable material in a volatile solvent, causing the solvent to evaporate and then applying to the surface of substantially all of said particles an adherent coating of conducting material.

8. The invention set forth in claim 7 characterized in that the inert material is a mixture of asbestos particles and ground glass.

9. The method of manufacturing a material from which resistors may be formed which comprises moistening a mass of air-floated asbestos with a solution of a phenol formaldehyde resin in a volatile solvent, causing the solvent to evaporate, mixing the residuum with a colloidal suspension of carbon, causing the carbon to be precipitated from the suspension onto the surfaces of substantially all of the particles of asbestos, and thereafter removing the remaining solute.

10. The method of manufacturing fixed resistors which comprises intimately mixing a mass of comminuted inert filler material with a solution of phenol formaldehyde resin in a volatile solvent, causing the solvent to evaporate whereby the resin is deposited as a coating upon the particles of filler, mixing the coated particles with a colloidal suspension of carbon, causing the suspension to coagulate to thereby precipitate the carbon onto the surfaces of the particles, removing the surplus vehicle of the suspension, molding the residuum into appropriate shapes, and thereafter baking the molded articles at a temperature sufficiently high and for a sufficient length of time to cause the resin to polymerize.

11. The invention set forth in claim 10 characterized in that the inert filler material is asbestos and ground glass.

12. The method of manufacturing a material from which resistors may be formed which comprises moistening a mass of inert filler particles with a solution of phenol-formaldehyde resin and a reagent capable of causing the coagulation of a colloidal suspension of carbon in a volatile solvent, causing the solvent to evaporate, and introducing the resin-coated filler particles into a colloidal suspension of carbon.

13. The method of manufacturing a material from which resistors may be formed which comprises moistening a mass of inert filler particles with a solution of phenol-formaldehyde resin and
5 furfural in a volatile solvent, causing the solvent to evaporate, and introducing the resin-coated filler particles into a colloidal suspension of carbon.

14. The method of manufacturing a material
10 from which resistors may be formed which includes moistening a mass of inert filler particles with a solution of a phenol formaldehyde resin and an organic acid dissolved in acetone, causing the solvent to evaporate, and introducing the
15 resin-coated filler particles into a colloidal suspension of carbon.

15. A resistor element in the form of a rod constituted by a plurality of particles of inert filler, substantially all of said particles having a

first coating of an insulating material and an outer coating of graphite and carbon black, the said particles being in such intimate contact with each other that a substantially uninterrupted electrically conductive path is established between
5 the ends of the rod.

16. The method of manufacturing a resistor which comprises coating each of a plurality of particles of inert filler with polymerizable resin, superimposing a film of conducting material upon
10 the resin coating, compressing the filmed particles into a coherent mass, polymerizing the resin coating to lock the particles in place and thereafter impregnating the mass with a moisture repellent material incapable of dissolving the polymerized
15 resin at temperatures encountered during ordinary use of the resistor.

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