

PATENT SPECIFICATION

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(54) METHODS OF MAKING ELECTRETS

(71) We, WESTERN ELECTRIC COMPANY, INCORPORATED, of 195, Broadway, New York City, New York State, United States of America, a Corporation organised and existing under the laws of the State of New York, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention has to do with electrets of the sort used as the vibratile diaphragm of electroacoustic transducers, as precipitators, as data storage elements, as stators in electromotors, in electrometers, dosimeters, air filters, and as similar electronic components.

Dielectric materials in the form of thin films, for example, of various polymers such as polyesters, one of which is known by the brand name "Mylar®," various fluorocarbons, such as the one available commercially with the brand name "Teflon®," various polycarbonate resins and the like, are used extensively in a variety of applications. For example, they are used in electroacoustic transducers in the fabrication of capacitors, precipitators, dielectric storage elements, and the like. In a typical electroacoustic transducer, such as an electrostatic microphone or loud speaker, for example, a thin film of such a material is employed as the vibrating element. To avoid the need for external bias, the moving film is permanently polarized or charged; when so charged, it is known as an electret. Film electret transducers, for example, of the sort described UK Patent No. 1,033,001 have all of the advantages of conventional capacitor units but virtually none of their disadvantages. Unlike the capacitor transducer, an electret unit requires no separate power supply and is mechanically much simpler. It also has a higher capacitance which allows greater freedom in circuit design. Perhaps even more importantly, it has high sensitivity, good frequency response, and low distortion.

Several methods of producing permanent electric charges on dielectric materials have [Price 25p]

been described in the art. Among these are thermal procedures using the simultaneous application of heat and an electric field, corona and Townsend discharge methods, and electron bombardment techniques using electron beams. Due to charge realignment, charge separation, or charge injection, these methods yield electrets characterized by a heterocharge, a homocharge, or a combination of both.

One of the most widely used arrangements for charging polymer films employs a system for impressing a relatively high voltage across a film held between a pair of electrodes. Typically a dielectric insert is sandwiched together with the film between the electrodes and the sandwiched elements are either in contact or held apart to establish air gaps between the layers. During application of voltage, breakdown occurs in one or more of the air gaps or in all, but not in the film. The resultant field impressed on the film therefore is insufficient to break it down but is nonetheless sufficient to form a homocharge. Because of the air gaps and local breakdown phenomena, charging of the film is inherently nonuniform, and the resultant surface-charge density of the electret is likewise nonuniform.

It is thus an object of this invention to provide an improved method of making an electret.

According to the present invention there is provided a method of electrostatically charging polymer material to form an electret, comprising forming a sandwich, the sandwich comprising two electrodes, a foil of the polymer material and a layer of dielectric material, the dielectric material and the polymer material to be formed into the electret being between the electrodes, the method further comprising applying between the electrodes, a potential difference sufficient to cause partial breakdown in the foil but insufficient to cause breakdown of the dielectric material.

It is an advantage of the embodiments of this invention that large full trap densities are achieved in thin film electrets.

In an embodiment of the invention a field,

of sufficient strength to cause breakdown in the polymer films is applied to a sandwich arrangement consisting of the polymer film which has a thin conductive layer bonded to one of its surfaces (the resulting film and conductive layer is commonly called a "metalized foil"), and another much thicker dielectric material of selected conductivity. By proportioning the dimensions of the dielectric insert and by selecting the material with the proper conductivity, with the resistance of the dielectric layer preferably greater than that of the polymer foil, the insert withstands the excitation applied to a pair of encompassing electrodes and does not itself breakdown. It is nonetheless able to control the actual breakdown of the polymer foil short of its destruction. Localised channels through the foil may be broken down (to provide partial breakdown) but complete breakdown of the areas where charge is deposited does not occur. No air gaps are needed; the elements of the sandwich may be held tightly together. By eliminating all air gaps, the possibility of nonuniform charging is also reduced. Processing may take place at room temperature and yet produce a uniform homocharge in the foil of high density and long life.

Embodiments of the invention will now be described with reference to the accompanying drawing in which:

FIG. 1 illustrates in simplified form the construction of an electrostatic acoustic transducer which illustrates the manner in which a thin film electret is utilized as the vibrating element;

FIG. 2 illustrates schematically a suitable arrangement for preparing thin film electrets, and

FIG. 3 illustrates effective surface charge as a function of time after charging on various thin film electrets prepared in accordance with embodiments of the invention.

One of the most important uses for thin film electrets is in the field of electroacoustic transducers. Since the electret contains a permanent static charge, it is ideally suited for use as the vibrating element of an electrostatic transducer, no additional bias supply voltage is required when it is used. A typical electroacoustic transducer which employs a thin film electret is shown in FIG. 1. It consists of an electrically charged plastic film 10 stretched over a metal backplate 11. Typically, film 10 is composed of a polymer material, such as, polyethylene terephthalate (PET), known commercially as Mylar®, or polyfluoroethylene-propylene, known commercially as Teflon FEP® or Teflon TFE®, and polycarbonate (PC) with a thickness of about 0.001 inch. An even thinner metal layer 12 is evaporated onto the side of the film not facing the backplate, i.e., the outer surface of film 10. The resultant film and conductive layer is termed a metal-

ized "foil." The backplate surface is generally arranged so that the foil contacts its surface at discrete points or along discrete lines only. In the areas where no contact is made, shallow pockets permit it to vibrate when sound waves impinge on it. In addition, backplate 11 is perforated and supported above an air cavity 14. This arrangement reduces the stiffness of the air cushion behind the diaphragm and lets the film vibrate with a greater amplitude, thus to increase transducer sensitivity.

Because of the permanent charge on foil 10-12, an electric field is established between the foil and backplate 11. The foil and backplate are connected, by means not shown, to a high impedance input circuit. Motion of the foil, as a result of an impinging sound wave, for example, causes a small voltage to be generated in the input circuit. This voltage is proportional to sound pressure.

Reproducibility of the sensitivity of the electrostatic transducers discussed above, together with high sensitivity, good frequency response, and low distortion, depends, in large measure, on the uniformity of charge distribution throughout the body of the electret diaphragm, on the density of the electret charge, and on the ability of the electret to retain charge despite external influences. Thus, a useful lifetime depends on the low decay rate of the electret charge.

Electret films with the requisite properties for use as the vibrating element of an electrostatic transducer, as well as for other electret applications, are fabricated by applying a controlled electric field to a polymer foil sufficient to establish a voltage drop across the foil in excess of its breakdown voltage. FIG. 2 schematically illustrates a typical charging configuration.

As illustrated in FIG. 2, two metal electrodes, 21 and 22, each typically about 6 centimeters (cm) in diameter are employed to encompass a polymer foil 10-12 and an auxiliary dielectric insert 23. Typically, the foil is about 2-25 micro-meters (μm) thick and the dielectric plate 23 is formed of one or two sheets of soda-lime glass, each approximately 0.1 cm thick. Preferably the elements of the sandwich between the electrodes are in close proximity to one another so that any irregular air gaps between the elements are the result of surface roughness only. For clarity of exposition, the extent of the air gaps between the elements shown in FIG. 2 is greatly exaggerated.

A voltage of about 30 kilovolts (kV) from a conventional power supply 20 is applied across the sandwich by way of electrodes 21 and 22 for a period of about one minute. This interval of application has been found to be optimum in practice. By properly choosing the voltage and the dielectric inserts, the current density will be in the range of 10^{-8} to 10^{-6} Amperes per square centimeter (A/

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cm²), which was found optimal for this process. This value is much above a typical breakdown current for most polymer materials. A large part of the current flows through localized channels in the polymer and charge deposition probably occurs in areas remote from these channels. That is to say, breakdown occurs at discrete locations only. Yet the remainder of the foil is subjected to a pre-breakdown condition and charge deposition occurs primarily in the remainder, i.e., in areas of the foil remote from the point of breakdown. Application of heat is not necessary; application at normal room temperature is perfectly satisfactory. Following application, the sign of the charge on polymer film corresponds to a homocharge. Depending upon the polarity of the applied electric field, the film has a net positive or net negative charge on its nonmetallized side. Of course, a voltage in the prebreakdown range across the film also produces some charge deposition but the resulting electret charge density is correspondingly smaller.

A glass insert 23 is preferred for controlling polymer breakdown because it has a resistance sufficiently high, on the order of 10⁹ to 10¹² ohms for an area of 10 to 100 cm², to pre-

vent the breakdown of the polymer from becoming destructive, yet low enough to allow a sufficiently high voltage to develop across the polymer. Furthermore, a glass insert makes the spacing of the electrodes relatively uniform and thus allows a greater field to be applied across the polymer for the same electrode smoothness than would be possible without an insert. It has been found in practice that the field in a dielectric insert composed of layers of soda-lime glass is on the order of 250 kv/cm, which is a value in the prebreakdown range.

The greatest effective surface charge densities found for three representative polymer films of various thicknesses, each metallized on one side and charged as described in the foregoing embodiment, are tabulated below. Densities, as measured by a nondestructive method, for both charge polarities are shown. These values, obtained about 60 seconds after the termination of the charging process, are given as deviations from a nominal value of 10⁻⁶ C/cm². In addition, full trap densities for these materials, calculated from the charge densities, are shown in the last column of the table.

Material	Thickness t (μm)	Effective Surface-Charge Density (10 ⁻⁶ C/cm ²)	Full-Trap Density (10 ¹⁶ cm ⁻³)
PET	3.8	+1.0	3.3
		-1.2	4.0
	12.7	+1.0	1.0
		-1.4	1.4
	25.4	+0.6	0.3
		-0.9	0.4
FEP	12.7	+0.4	0.4
		-0.5	0.5
	25.4	+0.5	0.2
		-0.5	0.2
PC	2	+1.0	6.0
		-1.0	6.0
	12.7	+0.6	0.6
		-0.8	0.8

The internal fields corresponding to the greatest charge densities, as shown in the table, are, for example, 4×10^6 V/cm for PET and are thus just below the breakdown fields. The greatest effective surface charge does not increase with foil thickness because the charges are initially trapped within a narrow layer, probably close to the surface.

Surface charge as a function of time for several PET and FEP electrets stored in a desiccator is illustrated by way of example in FIG. 3. Four to eight months after polarization the negative and positive charges on PET are still about 2 to 3 times greater than on foils produced with corona discharge or by electron bombardment. Positively charged FEP electrets have been found to be subject to a more rapid charge decay than the negatively charged ones.

As opposed to thermal electrets, low temperature currents due to depolarization of meterocharges are very minute. The absence of a large heterocharge is attributed to the fact that charging takes place at room temperature. Moreover, the high temperature current due to homocharge depolarization from PET charged with this method shows two maxima. This indicates the presence of two trap depths which may be related to the glass transition and the relaxation of glycol linkages in the foil.

WHAT WE CLAIM IS:—

1. A method of electrostatically charging polymer material to form an electret, comprising forming a sandwich, the sandwich comprising two electrodes, a foil of the polymer material and a layer of dielectric material, the dielectric material and the polymer material to be formed into the electret being between the electrodes, the method further comprising applying between the electrodes, a potential difference sufficient to cause par-

tial breakdown in the foil but insufficient to cause breakdown of the dielectric material.

2. A method according to claim 1, wherein the thickness and desistivity of the dielectric material are selected to ensure that the resistance of the dielectric layer is greater than that of the polymer foil.

3. A method according to claim 1 or 2, wherein the foil of polymer material has one surface coated with conductive material.

4. A method according to any one of the preceding claims, wherein the two electrodes are pressed towards each other to ensure good contact between the respective layers of the sandwich.

5. A method according to any one preceding claim, wherein the dielectric material comprises at least one sheet of Soda-lime glass.

6. A method according to any one preceding claim, wherein the thickness of the polymer foil and the thickness of the dielectric material are selected to establish a steady state current density lying within the range 10^{-9} to 10^{-6} Amp./cm².

7. A method according to any one preceding claim, wherein the dielectric material has a resistance within the range of 10^9 to 10^{12} ohms for an area of 10 to 100 cm².

8. A method according to any one preceding claim, wherein the potential difference applied between said electrodes is substantially 30 kV.

9. A method of making foil electrets substantially as herein described with reference to the accompanying drawing.

10. A foil electret having been manufactured by a method according to any of the preceding claims.

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Surface charge as a function of time for several PET and FEP electrets stored in a desiccator is illustrated by way of example in FIG. 3. Four to eight months after polarization the negative and positive charges on PET are still about 2 to 3 times greater than on foils produced with corona discharge or by electron bombardment. Positively charged FEP electrets have been found to be subject to a more rapid charge decay than the negatively charged ones.

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tial breakdown in the foil but insufficient to cause breakdown of the dielectric material.

2. A method according to claim 1, wherein the thickness and resistivity of the dielectric material are selected to ensure that the resistance of the dielectric layer is greater than that of the polymer foil.

3. A method according to claim 1 or 2, wherein the foil of polymer material has one surface coated with conductive material.

4. A method according to any one of the preceding claims, wherein the two electrodes are pressed towards each other to ensure good contact between the respective layers of the sandwich.

5. A method according to any one preceding claim, wherein the dielectric material comprises at least one sheet of Soda-lime glass.

6. A method according to any one preceding claim, wherein the thickness of the polymer foil and the thickness of the dielectric material are selected to establish a steady state current density lying within the range 10^{-4} to 10^{-6} Amp./cm².

7. A method according to any one preceding claim, wherein the dielectric material has a resistance within the range of 10^9 to 10^{12} ohms for an area of 10 to 100 cm².

8. A method according to any one preceding claim, wherein the potential difference applied between said electrodes is substantially 30 kV.

9. A method of making foil electrets substantially as herein described with reference to the accompanying drawing.

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