Advance Physics Letter

A Review of Applications of Polymer Electrets

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Abstract: In this review uses of Polymer electrets as an important class of organic materials finding its use in variety of electronic and electrical engineering industry ranging from photovoltaic cells, transducers, dosimeters and other applications are discussed.

Key words: Polymer, Electrets, ferroelectrets, bio-medicines.

I. INTRODUCTION TO ELECTRETS

An electret can be conceived as a dielectric material that produces a permanent electric field which could result due to permanent ordering of molecular dipoles or from stable uncompensated surface or space charge.

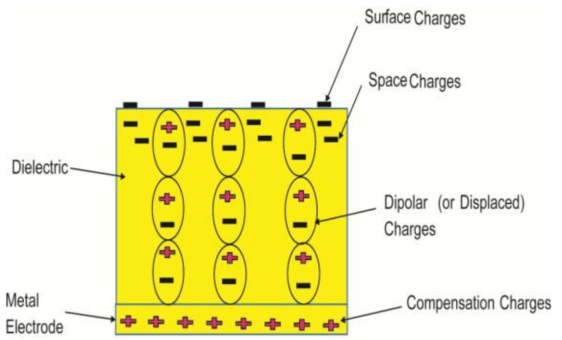

Fig. 1 : Schematic cross section of a one-sided metallized electret having deposited surface charges, injected space-charges, aligned dipolar charges (or macroscopically displaced charges), and compensated charges [1].

The electret charge may consist of “real charges”, such as surface-charge layers of space-charges; it may be “true” polarization; or it may be a combination of these. This is schematically shown in fig 1.

Due to the charge storing properties and wide applications of electrets, research in this field has grown significantly since the term ‘electret’ was coined by Oliver Heaviside in 1892 {1885*} [1]. The systematic research on materials used by Gray [2], who earlier described the properties of electrets without coining the term, actually began in 1919 when the Japanese physicist M. Eguchi [3,4] used the thermal method along with the application of an electric field to melted carnauba wax and resin and allowed them to cool in the electric field. Eguchi observed the opposite charges after the used the thermal method along with the application of an electric field to melted carnauba wax and resin and allowed them to cool in the electric field. Eguchi observed the opposite charges after the decay of initial charge of the materials. The charges were later named ‘hetero-charges’ and ‘homo-charges’ respectively.

II. POLYMER ELECTRETS

One of the important classes of organic material that have gained prominence in the electret research during the past 40 years are polymers. The polymer electrets and their study can now be treated as a specialised branch among the studies in dielectrics and polymer science. The aim of the chapter is to emphasize the important developments and advances in the field of polymer electrets.

Polymer electrets are dielectric materials that exhibit a quasi permanent electrical charge [1]. The type of charges which an electret has can either be “real” or “polarized” and, depending upon the type of charges, the electret may be called “charge electrets” and “dipole electrets” respectively. Charge electrets find their use in photovoltaic solar cells, acoustic transducers, air and gas filters, radiation dosimeters and micro-relay switches [5]. True polarization electrets with a (quasi)-permanent preferential dipole orientation are employed in hydrophones, ultrasound applications, infrared thermal imaging sensors, microcalorimeters due to their piezo- and pyroelectric response [6] or (for second order nonlinear optical responses) in electro-optic modulators and switches, etc. [7].

Polymers have been with us since the very beginning. Natural polymers include such things as tar and shellac, tortoise shell and horns, as well as tree saps that produce amber and latex. These polymers were processed with heat and pressure into useful articles like hair ornaments and jewellry. Natural polymers began to be chemically modified during the 1800s to produce many materials. The most famous of these were vulcanized rubber, gun cotton, and celluloid. The first semi-synthetic polymer produced was Bakelite in 1909 and was soon followed by the first synthetic fiber, rayon, which was developed in 1911.

Polymeric materials are often of organic origin and consist mainly of light elements, such as carbon and hydrogen. Many common classes of polymers are composed of hydrocarbons. These polymers are specifically made of small units bonded into long chains. Carbon makes up the backbone of the molecule and hydrogen atoms are bonded along the backbone. Here is a diagram of polyethylene, the simplest polymer structure, given below:

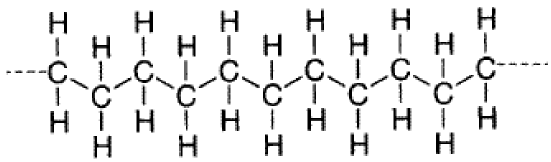

Fig. 2. Chemical structure of polymer

In the very beginning of the century the phenolics were adapted for housing and wiring platforms, replacing coated materials. Later, wire and cable insulation, originally combinations of cotton, silk and other fibers and paper, were made of newly invented thermoplastics such as vinyls and nylons. Other plastics such as ABS and acrylics found application as insulation housings.

In the middle of the twentieth century, the emergence of two very important plastics namely, epoxies and polytetrafluoroethylene (PTFE) (more commonly known as Teflon®), changed the scenario of the electronic industry. The epoxies became the material of choice for emerging printed circuit boards and somewhat later, integrated circuit encapsulations. PTFE garnered a number of speciality applications, such as microwave circuitry, because of its extremely low moisture absorption and insulating properties.

The photoimageable resins, based on acrylics, provided a new pathway to high density circuitry both at integrated-circuit and printed circuit level, which in turn led to the development of photoimageable versions of other plastics for permanent resists etc.

One of the major material developments was that of polyimides. First as a magnet wire coating, then as a substrate for flexible circuits, polyimides have found way into almost every level of electronic packaging due to their unparalleled temperature stability, flexibility in fabrication and excellent electrical properties.

The importance of polymers has led to the new emerging fields in the physical and chemical sciences. The major physical properties which are under study by the various research groups all over the world are thermal, mechanical and electrical in broad sense. For the last 40 years, polymer electrets have gained significance and importance as they possess good charge storing capability. In 1927 piezoelectricity and pyroelectricity were theoretically and experimentally established to be the properties of the electrets; preferentially with ordered dipoles [8, 9]. The discovery of the strong piezoelectric effect induced by high electric fields to the polymer electret polyvinylidiene fluoride (PVDF) by Kawai [10] paved the way for new era in the electret research. However, this also led to the controversy on the role of charges and dipoles in the material [11].

The nature and origin of molecular motions in macromolecular polar and non-polar polymers are morphology dependent and in turn can affect the performance of electrets [12]. The stabilization of the polymer structure is due to the forces present in these materials, which are generally divided into primary (intra-chain) and secondary (inter-chain) forces. The primary forces result from the covalent bonding (2.2-8.6 eV) linking the chain backbone atoms together. There are four secondary forces in polymers, i.e. (i) ionic bonding (0.43-0.87 eV), (ii) hydrogen bonding (0.13-0.30 eV), (iii) dipolar interaction (0.07-0.13 eV) and (iv) Van der Waals (0.002-0.009 eV) [12]. The phenomena associated with the secondary forces are more temperature dependent than their primary counterpart because of the fact that secondary forces have low values of dissociation energies. The secondary forces strongly influence the nature and degree of molecular motions in polymers, which in turn, affect their dielectric behaviour, charge transport and charge storage properties [12].

Different aspects of electret research which are presently under study by the workers of different countries are charging techniques and charge profiles, charge transport and recombination, photoelectrets and their optical properties, non linear effects of polymer electrets, thermally stimulated effects, photo stimulated current or depolarization, radiation charged electrets and their effects, bioelectrets, ferro-, piezo-, and pyroelectricity in polymer electrets and the applications of electrets.

III. APPLICATIONS OF POLYMER ELECTRETS

Some of the oldest practical devices using permanent electrification effects in dielectrics are electret transducers (microphones, earphones etc.) [1]. An important application of charge-storage phenomena of great practical importance is in the field of electrophotography. The production of a charge pattern on an appropriate carrier is a basic process which is used in many electrographic methods was studied in early 1930s [1]. The breakthrough in this field came a few years later when investigations of photoconductive image formation led to the development of Xerographic reproduction methods [1]. Non photographic methods have been used in the recording of alphanumeric characters, facsimile.

The popularity of minimally invasive surgical (MIS) procedures over traditional open procedures have led to the development of new instruments that address the limits of existing technology and enable more widespread use of minimally invasive approaches.

Robotic surgical instruments have the potential to provide improved dexterity and range of motion within the confines of the human body when compared with manually actuated instruments. The high strain response of electron irradiated P(VDF-TrFE) copolymer makes it a candidate actuator material for robotic instruments that provide electronic meditation and multiple degree of freedom of tip movement [13].

Other electret devices include gas filters, motors, relay, switches, optical display systems and radiation dosimeters.

Electret motors employ stators or rotors of charged dielectric at the experimental level [14]. First micromachined rotational electret power generator, linearized theoretical model of electret power generation, and novel method to produce uniformly charged electret has been reported [15].

Polymer electrets have been reported as efficient devices for collecting, detecting and even for controlling various types of pollutants [16]. The analysis and identification pollutants sticking onto the surfaces of electrets prepared from polymethylmethacrylate and polytetrafluoroethylene was done by scanning electron microscope, mass spectrometric, and near infrared spectrometric techniques. Electret samples exposed to atmospheric gases at their saturation vapour densities reveal structural changes when studied by means of the aforesaid techniques [16].

A large number of pyroelectric applications for polymer electrets prior to 1990 are reported by Wang *et al.* [17] and Xiao *et al.* [18]. Pyroelectric properties of polymers find use in infrared detectors, direct detection of thermal energy. Pyroelectric detection can be used to study ablation of polymers with ultraviolet lasers [19]. The authors determined the ablation velocity and the nature of species that are ablated from the surface.

An interesting application of the measurement of heat produced in the early development of eggs of the Japanese pond frog was reported by Takaizawa *et al.* [20] using pyroelectric titration calorimetry.

Ferroelectric composite materials are employed in a wide range of applications such as hydrophones, pulse-echo mode transducers, dynamic strain measurements, smart sensors, bimorphs and medical ultrasound transducers [1].

Non linear optical (NLO) polymers can be considered to be an addition to the known classes of electret materials and because their study provides a new access to some electret properties by way of optical and other techniques specially developed for NLO polymers [1]. The applications of NLO polymers are in photonics which is in its early stage of its development. Some of the proposed devices using NLO polymers are electro-optical switch, electro-optical modulator, waveguide frequency doubler etc.

Electrets also find use in medicine in anti thrombus-formation surfaces, artificial membranes and the electret state in bones [1]. The possible use of electret membranes has been discussed by many authors [21, 22].

A theoretical model to explain the biological function of protein in terms of electrets has been reported [23].

All kinds of tissues and components in the body, such as blood vessel, skeleton, muscle tendon, collagen, keratin, enzyme, DNA and RNA exhibit electret effects. Electret properties of collagen, chitin, skin tendon and soft tissue had been studied by several workers, such as S. Mascarenhas [1] and E. Fukuda [24]. Compound bioelectrets of I & III collagen/chitosan have been reported and their TSDC (thermally stimulated discharge current) have been analyzed by Xiangyang *et al.* [25].

The changes in content of fluorescein isothiocynate (FTIC) marked albumin in pulmonary homogenate in scalded rats were measured to study the changes in pulmonary vascular permeability and the influence of electret on the permeability [26].

Teflon FEP and PTFE are widely utilized as biomaterials in medical field. Studies on the healing effect of PTFE Electrets on pig wounds have been made and effect of a PTFE electret on accelerating the wound healing was investigated by determining the content of DNA from epithelial cell on the wound [27].

Study of pyroelectricity and piezoelectricity in various types of biological systems has been made and the presence of natural polarity in the structure of various parts of animals and plants has been reported [28, 29, 30].

FEP electret substrates are reported [31] to provide a suitable means of investigating the biological response of neuronal cells contacting a charged surface.

IV. CONCLUSIONS

For the past four decades, charge-storing electret polymers have found numerous applications in, e.g. transducers, gas filters and dosimeters etc [1]. Polymeric electrets can be conceived as complex systems. The charge storage in polymer electrets play an important role for electromechanical-transducer application. However, the chemical and physical characteristics do affect the dielectric properties of polymer electrets but microscopic mechanisms of charge retention are still not properly understood. One of the objectives of the study of polymer electrets is to understand the charge retention mechanism and to contribute further in explaining it. Thermal and optical techniques can be employed to describe the charge trapping and detrapping behaviour of polymer electrets. The information received from the aforesaid techniques can provide a picture to understand the charge retention mechanism. Moreover, this information can also provide the information in identifying the probable trap sites and also explain the long-term storage phenomenon in polymer electrets.

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