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Long term stability of electrets used in electret ion chambers

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ABSTRACT

Commercially available electret ion chambers have been using electrets for more than 15 years. As a quality control procedure, a few electrets from each production batch are set aside for studying their long term stability. These are measured after storage of 1–13 years, to calculate the decay rates for different storage periods. Two types of electrets are studied. The first type is the Teflon® electret made of PTFE Teflon® (polytetrafluoroethylene) with a thickness of 1.524 mm and the second type is Teflon® electret made of FEP Teflon® (fluorinated ethylene propylene) with a thickness of 0.127 mm. In both cases, one side is carbon coated. The first type shows an average decay of about 4% per year. The second type shows an average decay rate of about 1% per year. The decay rate does not change significantly over the years of study. After accounting for decay due to ions in storage conditions, the half life (time required to decay by 50%) of 1.524 mm and 0.127 mm thick electrets is 14 and 68 years, respectively. Such unusually long half lives make the electrets useful for a number of practical applications where a high electrostatic field is needed over an extended period, without having to use batteries or high voltage sources.

1. Introduction

An electret is a piece of dielectric material exhibiting a quasi-permanent electrical charge. This means that the inherent charge decay of electrets is small compared to the periods over which studies are performed with the electret. Usually electrets are made of Teflon®[1] of PTFE type (polytetrafluoroethylene) or FEP type (fluorinated ethylene propylene). These are most suitable materials for making electrets due to their very high resistivity. Sessler's review article [1] on electrets provides a very good summary of the electret technology. The electrets have found a large number of practical applications where electrostatic field is required without the use of battery or power supply. Such applications include their use as transducers in microphones and other electronic instrumentation, and in electret ion chambers. Electret ion chambers [2–5] have used the electrets for measuring radioactive gases and environmental gamma radiation. For most applications, the inherent rate of decay should be much smaller than the decay rate being measured due to the effect of the parameter being measured. The stability of electrets, produced by different methods, has been studied [1] to examine their suitability for practical applications. None of the studies have gone beyond 1–2 years. No additional studies have been reported in recent years on the stability study extending over 1 or 2 years. Commercially available electret ion chambers have been using electrets for more than 15 years. As a quality control procedure, a few electrets from each production batch are set aside for studying their long term behavior. This has provided a unique and rare opportunity to examine their stability during a long storage periods from 1 year to 13 years to characterize their decay rates over that time period.

2. Electret ion chamber system

Electret ion chambers (EICs) are very widely used for measuring radon and other ionizing radiations such as alpha, beta, and gamma, etc. The EIC is a passive integrating ionization monitor consisting of a very stable electret mounted inside an electrically conducting plastic chamber. The electret, a charged Teflon® disk, serves as a source of electrostatic field for ion collection and as an integrating ion sensor. Radon gas passively diffuses into the chamber through filtered holes, and the alpha particles emitted by the decay process ionize air molecules. Negative ions produced inside the chamber are collected on the positively charged electret, causing a reduction of its surface charge. The reduction in charge is a function of the radon concentration, the duration of the testing period, and the chamber volume. This change on surface charge of the electret is measured by an electret charge reader. The charge reader measures the surface potential of electret in volts. This can be converted into charge, if required. The data is analyzed using

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[1] Teflon® is a trade mark of the product manufactured by E.I Dupont de Nemours and Co., Wilmington, DE 19898.

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Fig. 1. Electret ion chamber system, chamber, electret (cover removed) and electret reader.

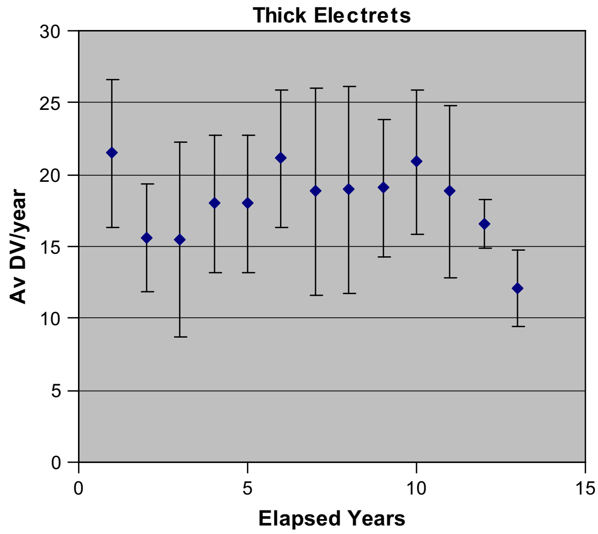

Fig. 2. Average decay per year (decay rate) after different stated storage periods for thick electrets.

software developed for such analysis. The basic component of the EIC system consists of the electret, chamber and the electret voltage reader (Fig. 1). There are chambers of different volumes and electrets of two sensitivities to meet a wide range of monitoring situations. Typically a thick electret (1.542 mm) gives higher sensitivity and is used for short duration (2–7 days) measurements, and thin (0.127 mm) electret gives lower sensitivity and is used for longer duration (one month to one year) measurements. One side of these electrets is carbon coated. These are termed true integrators because any collection of ion permanently neutralizes its contribution. These are also used for measuring environmental gamma radiation and several other applications. Full descriptions are available in the published literature [2–5].

Fig. 1 shows electret open, the chamber used for measuring radon and the electret reader.

3. Electrets

Two types of electrets are used in EIC system. One side of these electrets is carbon coated. One type is the Teflon® electret made of PTFE Teflon® (polytetrafluoroethylene) with a thickness of 1.524 mm and the other type is Teflon® electret made of FEP Teflon® (fluorinated ethylene propylene) with a thickness of 0.127 mm. Subsequently in this note, the former is referred to as thick electret and the latter is referred to as thin electret.

These are prepared by glass discharge method and are further annealed. Details are found in Refs. [2,3].

Fig. 1 shows a thick electret inside its holder and the electret reader.

4. Electret reader

Fig. 1 shows a commercially available electret reader (SPER-1, manufactured by Rad Elec Inc. Frederick, MD 21704, USA), which is used in this study. The reader uses a method popularly known as shutter method [1], also called as capacitative probe method. An electret receptor on the instrument receives the electret and firmly positioned at a fixed distance from the charge sensor. A metallic shutter shields the electrostatic field in closed position. When the shutter is pulled out and released, the induced charge on the sensor converts the reader display to read surface potential in volts. Being a non-contact method an electret can be read repeatedly or at any other future time.

The surface charge on the electret is related to the surface potential by Eq. (1) [3]

$$Q = (\varepsilon_0 \varepsilon V)/T \tag{1}$$

where Q is the surface charge density in C cm^{-2}, ε_0 is the permittivity of space (8.854×10^{-14}) C V^{-1} cm^{-1}, ε is the dielectric constant of Teflon (2.0), V is the surface potential in V, and T is the thickness of electret material in cm.

Therefore, 1 V reading on the electret reader corresponds to 1.16×10^{-12} C cm^{-2} on thick electret, and 1 V reading corresponds to 1.39×10^{-11} C cm^{-2} on thin electret.

Since studies relate to the stability or decay, the relative quantities are important. All readings taken on electret are reported in volts. But these can be readily converted into C cm^{-2} (if required).

5. Materials and methods

Electrets are normally stored in their storage caps with a small air volume of about 2.5 ml. The electret holder and the storage screw cap are made of electrically conducting plastic. These electrets can be read by non-contact method using a standard electret reader. Electrets are produced by ion injection method using high voltage discharge through glass. Detailed method of production of these electrets is described elsewhere [2,3]. Electrets are held firmly in a holder and covered with a cap. The cap has small filtered opening for environmental equilibration.

At least 50 electrets manufactured over each year are set aside as control electrets for long term studies. Such electrets are used in this study. Electrets are read using electret readers and compared with the reading taken during the respective year of manufacturing. This data is used for calculating decay per year and the percent decay per year. For example if the reading has dropped 80 V in 5 years from 600 V to 520 V, the decay rate is $80/5 = 16$ V per year and the percentage decay rate is $(16/560) \times 100 = 2.86\%$ per year. The mean and standard deviations are calculated for a set of about 50 electrets from each year.

6. Decay due to ions in air

Electrets are stored by covering the electret with a storage cap. The storage cap is separated from electret surface by 2–3 mm of air space and with an air volume of 2.5 ml. This works like an electret

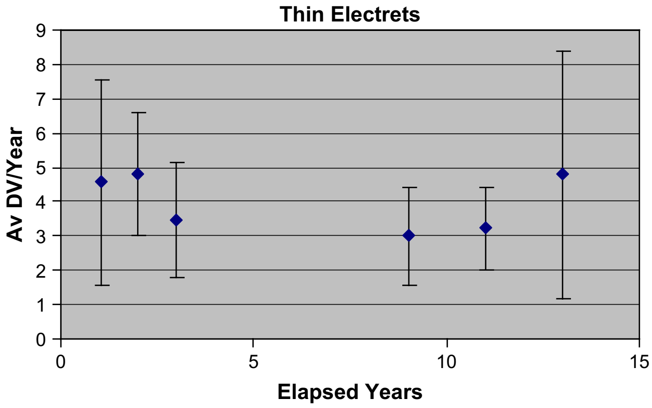

Fig. 3. Average decay per year (decay rate) after different stated storage periods for thin electrets.

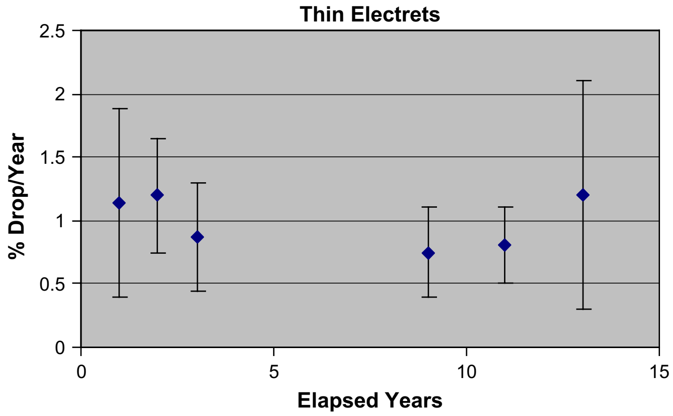

Fig. 5. Percent decay per year (decay rate) for different stated storage periods for thin electrets.

ion chamber with a small volume of air. Therefore the radon and the gamma radiation do produce some ions inside the storage cap and cause some decay. These electrets are stored in a room with a radon concentration of about 40 Bq m^{-3} and gamma radiation level of about 80 nGy h^{-1}. The electret discharges due to these sources inside the storage caps [2,3] can be calculated and these work out to be about 25% of the total decay during storage. The balance of the decay rate is attributable to the inherent decay rate.

7. Results and discussion

Figs. 2 and 3 give the average decay rates in volts per year for different stated storage periods, for thick electrets (1.542 mm) and for thin electrets (0.127 mm). Figs. 4 and 5 give the percent decay rates for thick and thin electrets for stated storage periods, respectively.

After the stated storage period of one year represented by the first data set, the discharge rates do not change significantly over the entire period of study. The deviations are wide, attributable to electret differences in manufacturing and annealing procedures.

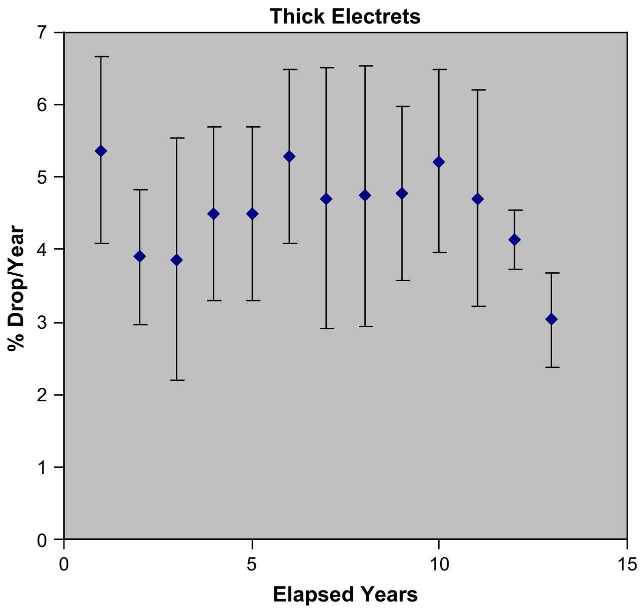

Fig. 4. Percent decay per year (decay rate) for different stated storage periods for thick electrets.

The percent decay rate of the thick electrets (Fig. 4) is about 4% per year. This means it takes nearly 12.5 years for the electret to decay by 50% and can be called as half life during the storage. Similarly the half life of thin electrets comes out to be 1% decay per year, leads to a half life of 50 years.

Some data for thin electrets for stated periods of 5–9 years is missing, simply because the samples were lost. But the conclusions do not change and nothing unusual is expected during this period, as demonstrated from the data on thick electrets.

For calculating the inherent decay rates of electrets, decay due to collection of ions from air in storage caps should be taken into account. If these are taken into account, the half life of thick and thin electrets works out to be about 14 and 68 years, respectively.

The differences between the half lives of thick and thin electrets can be explained. The charge density of an electret needed to produce the same surface voltage is in the inverse relationship to the thicknesses. This means thin electret carries nearly 12 times more charge density for the same surface potential relative to thick electret. Therefore, same neutralizing charges decay (percent wise) thick electret much more than thin electret.

8. Conclusions

It can be concluded that the normal usage period of a maximum of one year, for application in EIC, is small compared to the decay parameters obtained in this study. For some very accurate work the inherent decay rate corrections obtained in this study are usable for such applications. Thin electrets have much longer decay half time compared to thick electret. These or similarly produced electrets can be used with confidence for several other applications requiring large usage periods.

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