ELECTRET DOSIMETRY

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Electrets are the electrical equivalent of magnets : they create a permanent electric field in their surrounding. This analogy, however, is formal since the physical processes involved in electrostatics and magnetism differ widely. More specifically, monopolar electrical charges do exist, whereas the magnetic properties of matter arise from dipoles only. The application which is presented in this paper is a direct consequence of the fact that ionizing radiations in a gas produce electrical charges which are acted upon by the permanent electric field of the electret. This concept, termed electret dosimetry, will be exposed after a brief, general introduction to electrets. Practical devices will subsequently be described, and the prospects of this new field will be outlined.

REVIEW OF THE ELECTRET STATE

When a dielectric plate is subjected to an electric field, a macroscopic polarization arises from three main processes :

- dipoles tend to orient themselves parallel to the electric field,
- ions migrate through the material, with a velocity which is directly related to their mobility and to the transport mechanisms involved,
- electric charges are transferred from the electrodes into the dielectric plate. They may be trapped, or they may migrate under the influence of the local electric field.

Once the electret is formed, the polarizations created by these various processes decrease in time with various time constants. In most cases, the polarization due to injected charges is the most permanent one. For this reason, several methods have been developed to inject charges in a controlled fashion into an insulating dielectric. Electrets may, for instance, be manufactured by Corona discharges in the gas surrounding the electret. The electric field accelerates the electrons or ions of the plasma and injects them into the dielectrics. This is a very convenient way to manufacture electrets with very long lifetimes, exceeding tens of years.

The most widely used electret-forming materials are polymer films. They are inexpensive, and they may be manufactured in various lengths, widths and thickness.

BASIC PRINCIPLES OF ELECTRET DOSIMETRY

The basic idea behind the use of electrets in dosimetry is straightforward ; it was proposed as early as 1920(1) : if an electret surrounded by an ionizable medium, such as air, is subjected to ionizing radiations, the charges created in the air will be attracted by the electret and be injected into it. Therefore, the apparent charge of the electret will decrease with increasing radiation dose. This idea, however, did not lead to any practical device through :

i) a lack a reproducibility of the phenomena : the materials used, mainly organic waxes, and the manufacturing methods, which were essentially empirical, could hardly lead to industrial applications,

ii) the absence of convenient and accurate methods for taking advantage of the charge decay.

The situation of electrets has changed drastically during the last few years, and a very large amount of research has brought the electret to an industrial stage. The Laboratoire d'Electricité Générale de l'E.S.P.C.I. has used its expertise in the field of electrets to design various prototypes of electret dosimeters, some of which are now under development by the Société BEFIC in France.

1) The electret ionization chamber

The basic equations governing the behavior of an electret ionization chamber have been described by various authors(2). We summarize them briefly, with reference to Figure 1 : an electret of thickness d_2 and permittivity ε_2, bearing a charge Q, is separated from two plane parallel electrodes by two air gaps of permittivity ε_1, of thickness d_1 and d_3. The total amount of charges created by a dose D in the ionization chamber is known to be : $n = \alpha D(d_1 + d_3)S$ where S is the area of the chamber and α is of the order of 3.5×10^{-4} Cb/m^3. Therefore, neglecting edger effects, the change in the total charge of the electret will be given by : $\Delta Q = \alpha D(d_1 + d_3)S$.

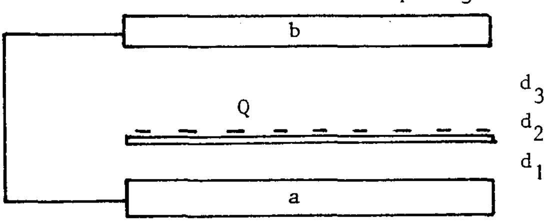

Figure 1

The decrease of the charge of the electret is linear with the dose, which is a very attractive feature. In pratice, several possibilities will be discussed below to take advantage of this charge decrease.

2) Principles of practical electret dosimeters

In order to take advantage of the decrease of the charge of the electrets, mechanical or electrical effects may be used. Mechanical effects have been used to make alarm dosimeters, which have been described in a previous paper(3).

In order to perform a real measurement of the dose, electrical effects are apt to be more accurate and reliable than mechanical ones. Several embodiments for electret dosimeters may be considered. The principle of one of these will be discussed with reference to Figure 2 : the electret lies between two parallel plates. A grounded shutter may be moved to screen electrode b from the electret. When the shutter is away from electrode b, a charge Q_b is present on this electrode, given by : $Q_b = Qd_1/(d_1 + \varepsilon_1 d_2/\varepsilon_2 + d_3)$.

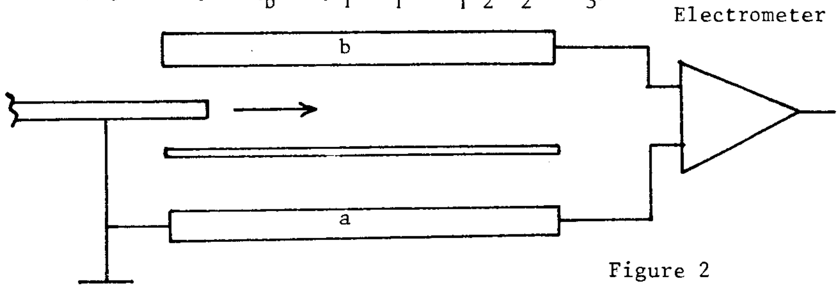

Figure 2

When the shutter is moved to screen electrode b, the charge Q_b drops to zero ; therefore, the value of the charge $- Q_b$, flowing through the electrometer, is displayed. Thus, in such a device, the charge measured when the shutter is moved is proportional to the charge of the electret. Therefore, the variation of the measured charge between two measurements is proportional to the dose, according to the relation : $\Delta Q_b = - \alpha DSd_1(d_2+d_3)/(d_1+\varepsilon_1 d_2/\varepsilon_2+d_3)$.

Assuming d_2 to be much smaller than d_1 and d_3, the sensitivity of such a dosimeter is given by : $\Delta Q_b/D = \alpha Sd_1$ Cb/Rad.

A remarkable feature of such devices is that the sensitivity depends on d_1 only and is independent on d_3. Conversely, the dynamic range D_o, which is the dose necessary to cancel out the charge of the electret, depends on d_3 : $D_o = Q_o/\alpha S(d_1+d_3)$, where Q_o is the initial charge of the electret. As a typical examples, an electret dosimeter embodying a 10 cm^2 electret with an initial charge of $5x10^{-9}$ Cb, with thicknesses d_1 = 0,4 cm, d_3 = 0,6 cm, has a sensitivity of $1,4x10^{-12}$ Cb/mRad and a dynamic range of 1,4 Rad. Considering the fact that a sensitivity of 10^{-12} Cb is easily achieved by modern electrometer amplifiers, an overall sensitivity of 1 mRad can be expected. Smaller dimensions may be used when such a high sensitivity is not required. The linearity is excellent over the whole range. The energy response of such a device is flat down to 80 keV. A twofold increase in sensitivity, occurring at very low energies, can be easily reduced or compensated.

CURRENT DEVELOPMENT AND PROSPECTS OF ELECTRET DOSIMETRY

As can be seen from the above descriptions, electret dosimeters will be very simple and rugged. Two kinds of electret dosimeters may be considered : direct-reading dosimeters and indirect-reading dosimeters.

Direct-reading dosimeters are self-contained dosimeters incorporating the electret in its ionization chamber, the movable shutter and all the electronic components necessary to perform the measurement of the charge and display the dose. The use of large scale interation circuitry allows to pack all these functions in a small space. Moreover, CMOS circuitry and liquid crystal displays permit a very low power consumption. A direct-reading dosimeter for use in nuclear plants has been developed : apart from the above features, additional circuitry has been included in order to allow a non-contacting transmission of data to computer terminals at the entrances or exits of critical zones. Such a dosimeter incorporating all of these functions weighs about 300 g and has external dimensions of : 14 x 7 x 2.5 cm.

Indirect-reading dosimeters are dosimeters which do not display the dose directly : an external dose reader must be used in order to get the necessary information. Such electret dosimeters are considerably simpler than the former since the dosimeter does not incorporate any electronic components ; they are extremely light weight and compact. If the required sensitivity is, for instance, 100 mRad, the overall dimensions can be 1 cm x 1 cm x 0.1 cm.

Both these types of electret dosimeters can be made with widely varying sensitivities, dynamic ranges, and functions. Since the principle and basic equations are extremely simple, the geometric and electrical parameters may be easily varied to meet the specific needs of the potential users.

CONCLUSION

The present paper has outlined the fundamental concepts and applications of electret dosimetry. The main advantages of electret dosimeters on most existing radiation monitoring devices are the following :

- the electret behaves as an electrically readable film : the dose can be read electrically without destroying the information carried by the film itself,
- the dose measurement does not depend on the reliability of the electronic components present in the dosimeter : should any failure occur, the information is still present on the electret and may be read by any other electret dosimeter,
- the principle of electret dosimetry is extremely simple and allows it to be adapted to all kinds of needs,
- the linearity is excellent.

Therefore, at this stage of development, electret dosimetry seems an extremely promising new method in radiation protection.

This work has been supported in part by a grant from the Fondation Jean Langlois.

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