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Electret condenser microphones for acoustic measurement

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In recent years, condenser microphones which are polarized with an electret film (herein referred to as "electret microphones") are increasingly used instead of condenser microphones which need an external voltage source for polarizing (herein referred to as "condenser microphones") as acoustic measurement microphones, especially for sound level meters. This is because electret characteristics have been remarkably improved, due to great progress in electret source materials and manufacturing technology. In this paper, first we will present an outline of electret materials and some evaluation methods of electret characteristics. Then we will state the respective advantages of condenser microphones and electret microphones. And finally we will introduce two samples of electret microphones which were designed for sound level meters by Rion Co., Ltd.

Keywords: Electret, PTFE, Surface voltage, Thermal current

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1. INTRODUCTION

In general, the following conditions are considered necessary for microphones used for acoustic measurement:

1) Flat frequency response and wide frequency range.
2) Long-term stability and resistance against any external environmental changes (temperature, relative humidity and static pressure) or mechanical shock.
3) High sensitivity and small size.
4) Wide dynamic range of measurable sound pressure level.
5) The manufacturer can produce quality microphones in sufficient quantity.

To satisfy these conditions, condenser microphones have been widely used for acoustic measurements until recently. However, for measurements of ultrasonic or infrasonic frequencies and for extremely high sound pressure levels, other types of microphones are also being used.

In recent years, electret microphones are increasingly being used instead of condenser microphones as acoustic measurement microphones, especially for sound level meters. Electret microphones have been used in electrical devices for commercial and private use (tape recorders, transceivers, interphones, etc.) since the 1960's. However, it was not until the 1980's that the stability of the electret film's surface voltage became acceptable for use in acoustic measurement.

2. ELECTRET MATERIALS

About 1920, Eguchi was the first to discover the electret phenomenon using carnauba wax. Although it was clear that many materials, for example, wax,[1,2] ceramics and high molecular compounds,[3-8] can be polarized to become electrets, in many cases, molecular compounds are used for acoustic equipments. In particular, fluorine-contained polymers FEP (Fluorinated Ethylene Propylene)[9] and PTFE (Poly-Tetra Fluoro Ethylene) are used frequently. Typical material constants of PTFE and FEP are shown in Table 1. As a result of our experiments under many poling conditions (temperature, voltage, current, time, etc.) and several methods, a polymer which has high volume resistance and low relative

Table 1 Typical material constants of FEP and PTFE.

Material constants	(Unit)	PTFE	FEP
Specific gravity	—	2.14–2.20	2.12–2.17
Melting point	(°C)	327	265–275
Highest temperature for continuous using	(°C)	260	204
Linear expansion coefficient	(10^{-5}/°C)	10	8.3–10.5
Volume resistance ratio	(Ωcm)	$>10^{18}$	$>2\times10^{18}$
Dielectric constant	—	<2.1	<2.1
Dielectric loss	—	<0.0002	<0.0002
Dielectric breakdown intensity of electric field	(kV/mm)	18.7	19.5–23.4
Elongation percentage	(%)	200–400	250–330
Tensile modulus of elasticity	(10^3 kg/cm²)	4.1	3.5
Water absorption coefficient	(%)	0.00	<0.01

dielectric constant is good for making a stable electret.

3. ELECTRET EVALUATION METHOD

The following items are considered important for evaluating electret characteristics.

3.1 Surface Voltage of the Electret Film

Homo-charges are trapped in the polarized PTFE or FEP film,[9] and its charge density distribution is denoted as an unknown function $\rho(z)$ of charge depth z. Therefore we can suppose a model which only a layer of charge density σ is trapped at the mean depth $\langle z\rangle$ like Fig. 1. σ and $\langle z\rangle$ are denoted as

$$\sigma=\int_0^{d_0}\rho(z)dz\,, \tag{1}$$

$$\langle z\rangle=\left(\int_0^{d_0}z\rho(z)dz\right)\Big/\sigma\,. \tag{2}$$

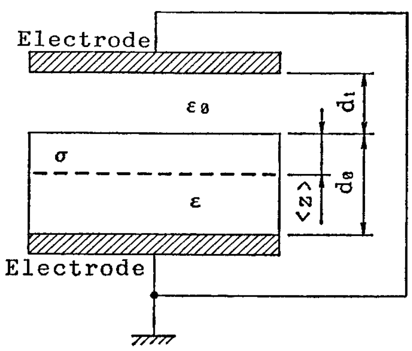

Fig. 1 Model of the electret film. d_0: Thickness of electret film, d_1: Thickness of air layer.

So, the surface charge density σ_s and the surface voltage V_s can be written as

$$\sigma_s=\frac{d_0-\langle z\rangle}{d_0}\sigma\,, \tag{3}$$

$$V_s=\frac{d_1}{d_1+(d_0/\epsilon)}\frac{d_0-\langle z\rangle}{\epsilon\epsilon_0}\sigma\,, \tag{4}$$

where ϵ and ϵ_0 are the relative dielectric constants of electret film and air respectively. When surface voltage is measured using an usual surface voltage meter, d_1 is much greater than d_0. So, Eq. (4) can be written as

$$V_s=\frac{d_0-\langle z\rangle}{\epsilon\epsilon_0}\sigma\,. \tag{5}$$

From Eq. (5), the following relations are evident. The surface voltage of the electret film becomes lower when the dielectret constant becomes smaller or when the mean depth of the charge becomes deeper.

3.2 Thermal Current (Discharge Current) of the Electret

When an electret film is placed in an oven, both surfaces are shorted while the temperature is increased at a constant speed. A thermal electret current will flow from one surface to the other surface. We can predict the mean depth ratio of the charge from measuring the thermal current. The block diagram of the measuring setup is shown in Fig. 2.

It is considered that the thermal current I is caused by the mean depth change, so from Eq. (3), it is represented as

$$-I=A\frac{\sigma}{d_0}\frac{d}{dt}\langle z\rangle\,, \tag{6}$$

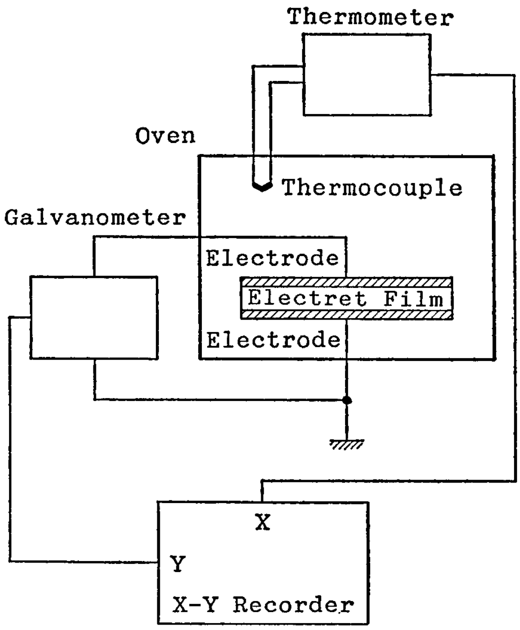

Fig. 2 Block diagram of thermal current measuring setup.

where A is the surface area of the electret film. The total charge Q_I of the thermal current is denoted as

$$Q_I=\int Idt=A\frac{\sigma}{d_0}\langle z\rangle\,. \qquad (7)$$

Using Eqs. (5) and (7), we can get the following equation

$$\frac{\langle z\rangle}{d_0}=\frac{Q_I/A}{\epsilon\epsilon_0(V_s/d_0)+Q_I/A}\,. \qquad (8)$$

Therefore, because we can calculate the charge Q_I from the result of the thermal current measurement and can easily measure the surface voltage V_s, we can determine the mean depth ratio of the charge $\langle z\rangle/d_0$. This ratio depends on the material and the manufacturing method of the electret. The mean depth ratio of the charge of the electret film used for electret microphones for acoustic measurement is from about 0.3 to 0.5.

Some thermal current curves of electret film under several poling temperatures are shown in Fig. 3. If the poling temperature increases, the peak temperature of the thermal current curve also increases. As a result of our experiments, an electret film whose thermal current curve has a high temperature peak is considered stable. However, if the poling temperature becomes too high, the surface voltage of the electret film is not sufficient for microphones because the mean depth ratio of the charge becomes too deep. Therefore the manufacturer has to choose

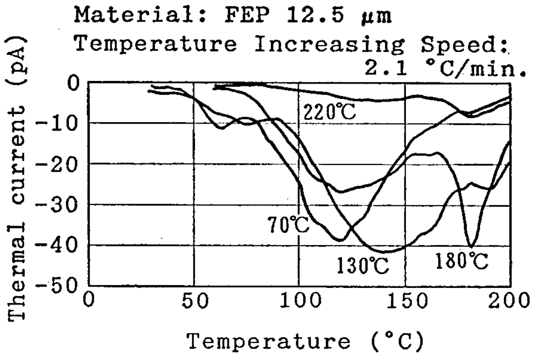

Fig. 3 Example of thermal current under various poling temperatures.

an adequate poling temperature for making a good electret film.

3.3 Resistance Against High Temperature and Humidity, and Estimation of Lifetime

Before using an electret film for microphones, we have to check that its surface voltage is stable enough for a long time period and will not change with changes in temperature or humidity.

FEP and PTFE electret films polarized under optimum conditions are very stable so we cannot effectively measure any change in their surface voltage under normal conditions (temperature: -10 to 50°C, relative humidity: less than 90% RH). Therefore, we must first measure the surface voltage decay of electret films under very high temperature and high humidity conditions using an oven which can control temperature and relative humidity with sufficient accuracy. Based on these results, we aim to predict its lifetime at room temperature and relative humidity. Two examples are shown in Fig. 4 and Fig. 5. Figure 4 shows the surface voltage decay at 180°C, and Fig. 5 shows the surface voltage decay at 80°C, 95% RH.

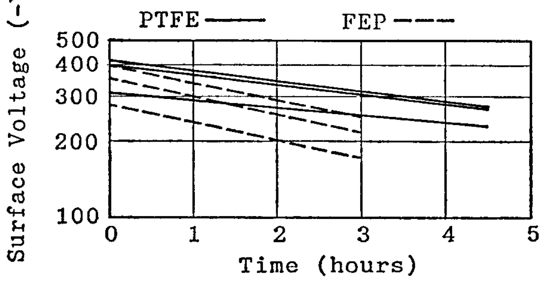

Fig. 4 Surface voltage decay of the electret film under high temperature condition.

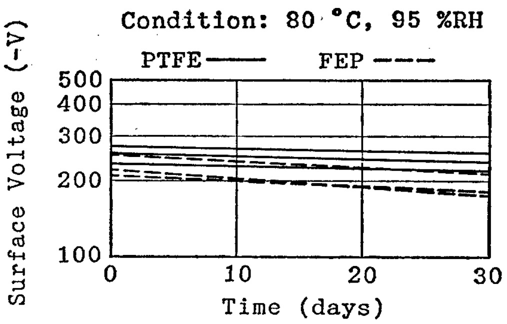

Fig. 5 Surface voltage decay of the electret film under high humidity condition.

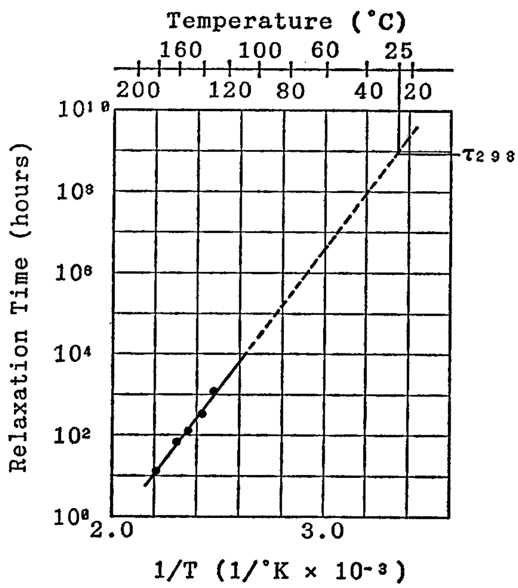

Fig. 6 Example of the relaxation time.

Where a surface voltage is denoted as a function $V_s(t)$ of time t, because that V_s is proportional to the surface charge density, so it is considered that its decay is represented by the following equation[9]

$$V_s(t)=V_0\exp\left(\frac{-t}{\tau}\right), \qquad (9)$$

where V_0 is the initial surface voltage and τ is relaxation time. τ can be written as a function $\tau(T)$ of absolute temperature T[4,5]

$$\tau(T)=\tau(0)\exp\left(\frac{E}{kT}\right), \qquad (10)$$

where k is Boltzmann's constant and E is activation energy. Therefore, after measuring surface voltage decay at several different high temperatures, we can get some relaxation times for each temperature. Drawing a line connecting the relaxation times plotted on a graph, and extending that line to the room temperature region on the graph, we can predict the surface voltage decay at room temperature. A sample graph is shown in Fig. 6.

The relaxation time of PTFE at 25°C, τ (298) determined by this method is 110 thousand years (10^9 hours). Assuming the sensitivity level change if an electret microphone depends only on the change of surface voltage of the electret film used, it will take more than ten thousand years for a decrease of 1 dB in sensitivity level at room temperature. Even if used continuously at 50°C, it will take more than 100 years for the sensitivity level to decrease by 1 dB.

When optimum poling conditions are selected, even though the surface voltage decay of FEP is slightly faster than that of PTFE, the both of them are considered to have sufficient lifetimes for microphone use.

However, we could not predict exact lifetimes under high humidity conditions at room temperature due to the following reasons.

1) It is difficult to control an oven at high humidity without condensation and with high accuracy at temperatures over 80°C. Therefore, we cannot draw an estimation line with sufficient accuracy.
2) It is difficult to keep the air in an oven clean. The surface voltage decay of the electret film is therefore accelerated by air-borne dust particles.

When there is dust or flaws on the electret film surface, the surface voltage will decrease quickly. Therefore it is important to keep the electret film clean.

3.4 Surface Voltage Decay in Solvent Atmosphere

To produce microphones, solvents, adhesives or detergents are sometimes used. We placed samples in a supersaturation atmosphere of these materials for 66 hours at room temperature, and measured their surface voltage decay. In four solvents used for this experiment (toluene, methyl alcohol, butyl and thinner—in order of decreasing effectiveness), the surface voltage was between 0 to 5%. However, with some alcohol detergents, α-ciano acrylate adhesives and rubber adhesive, the surface voltage became almost 0 V.

The characteristics of the electret film depend on the material, the production method and the production conditions. Therefore, the manufacturers have to choose the best material, method and conditions for making stable electret films, based on experiments and investigations. However, details of the exact method and conditions in which the materials can be produced easily and uniformly have not yet been published due to policies of the respective companies.

4. ADVANTAGES OF ELECTRET MICROPHONES

An obvious difference between condenser microphones and electret microphones is that condenser microphones need an external voltage source for polarizing whereas electret microphones do not.

4.1 Condenser Microphones

There are both advantages and disadvantages in using an external voltage source.

The sensitivity of the condenser microphone depends directly on its DC bias voltage. Therefore, the main advantage of condenser microphones is that it is very easy to check and control the DC bias voltage supplied from the external source. Measuring the surface voltage of an electret film built into a microphone is not impossible but difficult. In this regard, condenser microphones, not electret microphones, are suitable for laboratory standard microphones used for calibrating other microphones.

However, the disadvantages of using an external voltage source are concentrated in the following two points.

1) A voltage source is requires to supply the DC bias voltage.

Any AC component in the DC bias voltage becomes a noise component. The best method to decrease noise caused by the voltage supply is to use batteries or a specially stabilized voltage supply. However, sometimes this can be large and heavy. Therefore, usually a DC-DC converter potentially disturbs the measurement, although this is seldom found to be a problem.

Recently sound level meters have become smaller, lighter and incorporate many functions. Therefore, a DC-DC converter is often too large to be built into such sound level meters.

2) Sometimes leakage of the DC bias voltage on the surface of an insulator occurs under high humidity conditions.

Usually DC bias voltage is 200 V, but for portable sound level meters, it is 60 V. Under high humidity conditions, because the surface resistance of the insulator decreases, DC bias leakage from the insulator decreases, DC bias leakage from the backplate through the surface of the insulator to the microphone case can occur intermittently. When this leakage occurs, there will be a very high pulsive noise and it will be impossible to measure anything. This phenomenon often occurs with microphones of small diameter biased with 200 V.

Another disadvantage is that with positive static pressure applied to the diaphragm, discharge between the diaphragm and the backplate is likely to occur. In such a case, a hole will be made in the diaphragm and the microphone will be damaged completely.

4.2 Electret Microphones

The advantages and disadvantages of condenser microphones as stated in the previous section are reversely the disadvantages and advantages of electret microphones. In particular, the main advantage of electret microphones is that discharge and leakage never occur with electret films, because charges in the electret film are stationary. Another advantage is that it is possible to make the preamplifier smaller, because it is not necessary to use any capacitors with high breakdown voltage.

5. SAMPLES OF ELECTRET MICROPHONE FOR PRACTICAL USE

We developed two types of electret microphones using the advantages explained in the previous section. Before developing these microphones, we

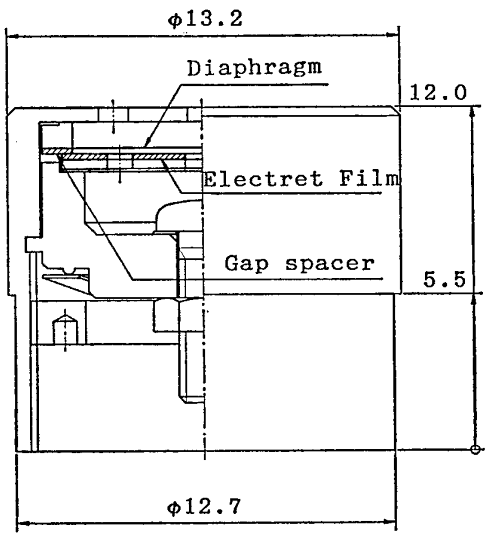

Fig. 7 Half-cross section of microphone UC-52.

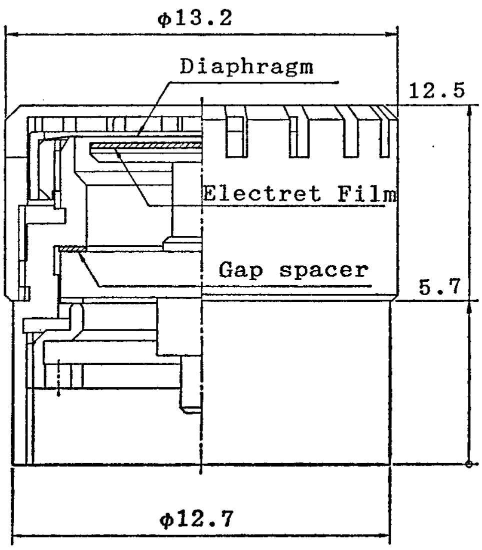

Fig. 8 Half-cross section of microphone UC-53.

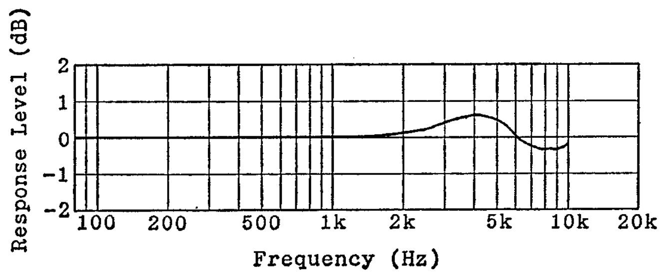

Fig. 9 Typical frequency response of UC-52.

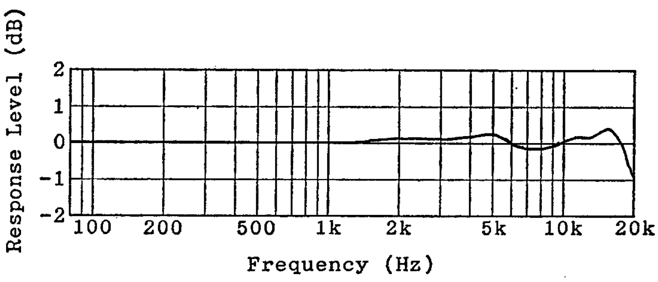

Fig. 10 Typical frequency response of UC-53.

decided that the main purpose of the microphones was to be for use in sound level meters. Therefore, one type is used exclusively for Type 2 sound level meters in accordance with the IEC 651, with low production costs. The other microphone type is for Type 1 sound level meters, which are designed based on a previously designed condenser microphone. Nominal diameters are both 1/2″.

A half-cross section of UC-52, the microphone for Type 2 sound level meters is shown in Fig. 7. The microphone UC-53 for Type 1 sound level meters is shown in Fig. 8. In both figures, the thickness of the electret film and the gap spacer are emphasized and are not in exact scale.

The structure of the UC-52 differs from that of conventional measurement microphones. The gap spacer, which accurately maintains the distance between diaphragm and backplate, is placed directly between the diaphragm and the backplate. This structure is often found in consumer-use microphones. However, this kind of structure has become possible only through the use of electret microphones. In this case, it is not possible to fine tune the frequency response by adjusting the tension of the diaphragm, but manufacturing costs can be kept very low.

The basic structure of the UC-53 is similar to that of the UC-30, a conventional condenser microphone with 200 V bias voltage. An electret film is fastened to the backplate with adhesive.

In both types of microphones, the electret film is made of PTFE and is 25 μm thick, and its surface voltage is controlled to minus a few hundred volts. The diaphragm is titanium alloy and is 2 μm thick.

Typical frequency response of UC-52 and UC-53 are shown in Fig. 9 and Fig. 10. The specifications compared to that of UC-30 are shown in Table 2.

Although the construction of the UC-53 and the UC-30 is almost the same, the signs of their temperature coefficients are inverse. This can be ascribed to the fact that with increasing temperature, the dielectric constant of PTFE slightly decreases, causing the surface voltage of the electret film to increase.

Equivalent inherent noise levels depend on preamplifiers.

There are several points to be considered regarding the use of electret microphones.

When the electret microphone is connected to an external voltage supply through the preamplifier by mistake, the sensitivity decreases and the frequency response changes. However, these changes are temporary. Therefore, after shorting the two terminals of the microphone, the sensitivity and the frequency response return to their previous state.

An electret microphone is equivalent to a condenser microphone biased with a negative voltage. Therefore, the phase relation between the electret

Table 2 Typical specifications of UC-52, UC-53 and UC-30.

Type		UC-52	UC-53	UC-30
Frequency range	(Hz)	20–8,000	10–12,500	10–20,000
Sensitivity levels*	(dB)	−32	−28	−27
Capacitance	(pF)	18	11	18
Equivalent noise level**	(dB)	24	20	20
Temperature coefficient***	(dB/°C)	−0.01	+0.005	−0.007

* 0 dB=1 V/Pa at 1,000 Hz.
** A weighted level with the pre-amplifier NH-17 (for electret microphone) or the pre-amplifier NH-05 (for condenser microphone).
*** at 250 Hz.

microphone and the condenser microphone is inverse. When a positive sound pressure is applied to the diaphragm, the output voltage of the electret microphone is positive in the low frequency range.

The electret film can be damaged under high humidity conditions with air-borne dust and by some solvent vapors, detergent vapors or adhesive vapors in the atmosphere. But the air in the microphone can normally be considered clean, and no special care is necessary to maintain and use the microphone. However, storage or use under very bad conditions for an extended period of time should be avoided.

6. SUMMARY

Recently, electret microphones are practical not only for commercial use but also for acoustic measurement applications. The fact that electret microphones need no bias voltage supply is an advantage for sound level meters or sound analyzers, especially portable ones. Also, the advantages that an electret film does not suffer from discharge or leakage is useful in redesigning condenser microphones with small diameters into electret microphones.

Preamplifiers to be connected to electret microphones do not need any parts with high breakdown voltage. Therefore, if an ultraminiature integrated circuit for impedance conversion is developed, the microphone system (consisting of microphone and preamplifier) can be very small. Such systems will be useful for applications which use several microphones, such as a sound intensity probe or microphone array.

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