THE PULSE METHOD OF DETERMINING THE COEFFICIENT
OF THERMAL ACTIVITY IN MATTER

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A description is given of an experimental setup and we present the results from the measurement of the coefficient $\varepsilon = \sqrt{\lambda c \gamma}$ for dielectric materials and thin films by the method of applying heat in pulses to a film thermometer in contact with the material being investigated.

A promising method of determining the complex $\sqrt{\lambda c \gamma}$ is the pulse method which essentially involves the following. A thin-film thermometer, functioning as a resistance thermometer, is applied to the surface of a specimen or a thin coating. A current pulse, strictly rectangular in shape and of a specific duration, is passed through the thermometer. The change in the temperature of this sensor or, in other words, in the specimen surface, is recorded by means of electronic oscillographic equipment [1].

To eliminate from these calculations the area of the film − a quantity that is difficult to measure − a comparative method is proposed in [2] to measure the thermophysical constants of the backing for the film thermometers.

In this event, a current pulse is also passed through the thermometer in an air atmosphere and we determine the change in the sensor temperature in the form of a curve on the screen of an oscilloscope. Since the thermal conductivity of the air is many times smaller than the thermal conductivity of the backing material, for the duration of the pulse we can neglect the transfer of heat between the medium and the backing, and the backing can be treated as a semi-infinite body at whose end, for some short period of time (in hundredths of microseconds) a constant heat flux is to be found. The surface temperature then varies as a function of time, according to the parabolic law [3]

$$T_a = \frac{2}{\lambda} q \sqrt{\frac{a\tau}{\pi}}. \tag{1}$$

If the specimen (the backing) with the thermometer is placed into a liquid of known thermal properties such as, for example, alcohol, on passage through that film of a current pulse of the same magnitude, because the heat flux is propagated both through the backing and through the liquid, the temperature of the contact between the two semi-infinite media can be represented [3] as follows:

$$T_l = \frac{2}{\lambda} q \sqrt{\frac{a\tau}{\pi}} \frac{K_\varepsilon}{1 + K_\varepsilon}, \tag{2}$$

where $K_\varepsilon = \varepsilon_x / \varepsilon = \sqrt{\lambda c \gamma / \lambda_l c_l \gamma_l}$ is the ratio of the coefficients of thermal activity for the backing and the liquid.

As a result, for corresponding instants of time

$$\frac{T_l}{T_a} = \frac{K_\varepsilon}{1 + K_\varepsilon}. \tag{3}$$

From (3) we easily determine $\varepsilon_x = \sqrt{\lambda c \gamma}$ in terms of the experimentally derived temperatures.

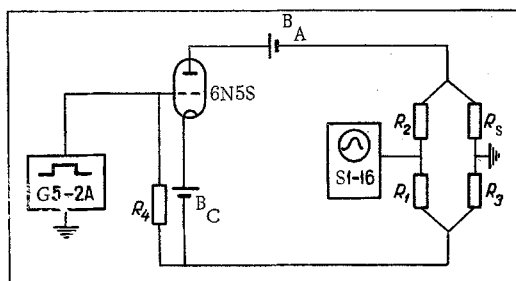Fig.1. Circuit diagram for the installation used to perform measurements by the pulse method.

TABLE 1. Coefficient $\sqrt{\lambda c \gamma}$ for Certain Substances

Material	$\sqrt{\lambda c \gamma}$, J/m^2 · deg · sec $^{1/2}$	Material	$\sqrt{\lambda c \gamma}$, J/m^2 · deg · sec $^{1/2}$
Melted quartz	1530	Plasticine	628
BD-1 glass	1570	Silicate glue	640
S48-3 glass	1380	Lacquer—acetone solution	378
Glass-ceramic	2160	Rosin	310

This method can be developed to determine the complex ε for dielectric fluids, resins, paints, glues, lubricants, polymer and organic coatings, i.e., substances capable of wetting a film sensor or which can be in tight thermal contact with that sensor.

In this case, the composition or coating under investigation is applied to a heat-sensing device that is combined with a backing, with this system making up a three-layer [sandwich] combination.

On the basis of considerations analogous to those described above, we can demonstrate that

$$\varepsilon_{xx} = \frac{\varepsilon_x (T_a - T_{xx})}{T_{xx}} , \tag{4}$$

where ε_{xx} is the coefficient of thermal activity for the material being investigated, said material in contact with the film thermometer; T_{xx} is the intermittent (pulse) rise in the contact temperature between the backing and the material being studied.

The experiment is also carried out twice: once in air, and once in contact with the composition of interest to us.

This method makes it possible to determine the values of ε for thin dielectric film coatings and layers with a thickness of 10 μm and more, applied to a system made up of a heat sensor and a backing. For pulses lasting from 100 to 500 μsec such coatings and films can be treated as semi-infinite bodies. Calculations have shown that with an error of less than 10% this condition is satisfied for Fo $\leq$ 0.36. For example, for Alundum ($a = 4 \cdot 10^{-3}$ m^2/h) for $\tau_{pulse} = 100$ μsec the minimum film thickness is 10 μm.

For the purposes of this research we developed a piece of equipment using standard apparatus, radio-engineering components, and measuring elements. A G5-2A pulse generator was used to shape the pulse, and the signal from this generator controlled the current in the anode circuit of the 6N5S triode.

Figure 1 shows the basic circuitry for the experiment.

In the absence of a pulse, no current passed through sensor R_s, since in the no-load position the C battery (B_C) blocked the triode. When a rectangular pulse of positive polarity is applied to the grid from the generator, the triode opens and a current is passed through the film heat sensor, the magnitude and duration of this pulse being governed by the parameters of the generator and the triode. In our experiments the duration of the pulse varied from 100-400 μsec. The magnitude of the current pulse in this case varied from 0.05 A $\leq$ i $\leq$ 0.1 A.

We know that when a voltage pulse is applied to the grid the anode current increases exponentially because of the capacitance charge C_{ac} (the anode—cathode system). The time for the increase in the exponent has a result of a low value for $R_a C_{ac}$ of ~1 μsec; the current pulse is therefore virtually rectangular in shape. Since the voltage to the film heat sensor is proportional to R_0 and $R_0 \alpha T$, in the recording of this voltage it is necessary to offset the constant component $i_{R_s} R_0$. We used a bridge circuit for this purpose, and the balancing of that circuit was accomplished with a potentiometer. The oscillograph was started with the G5-2A generator. Since the sweep proceeded the instant at which the pulse was applied by only 0.15 μsec, these instants were virtually coincident. The resistance R_3 was deliberately made small (~5 Ω) for the following reasons. On application of the pulse, at the initial instant of time, the resistance R_4 (~2 mΩ) is shunted by capacitance C_{gc} (grid-cathode), as a result of which a current varying exponentially passes through R_3. This current distorts the recorded changes in the potential difference. To reduce the charging time for capacitance C_{gc} the total resistance R_3 and the C battery B_C were made as small as possible.

In our experiments the signal flash resulting from the charge of capacitance C_{gc} in terms of time amounted to ~2 μsec, i.e., it virtually degenerated into a straight line.

The results from the measurement of the coefficient of thermal activity for the dielectric materials are presented in Table 1.

The quartz data are in good agreement with those published in [1]. The data for the BD-1 glass, from which the backing is usually made for thin-film thermometers, coincide within the limits of error (to 5-8%) with the results of [4].

To determine the values of ε for the substances applied to a system made up of the heat sensor and a backing, we used the BD-1 glass as a standard backing material. The value of ε in this case was calculated from formula (4).

In reference [5] the relative error in the determination of ε($\Delta\varepsilon/\varepsilon \approx 5\%$) is evaluated. The use of standard equipment to shape the pulse and the use of a bridge compensation circuit makes it possible, in this case as well, to take into consideration only those errors associated with the recording of the signal, and these amount to no more than 5%.

The use of a standard rectangular pulse shaper eliminates the need for the development of a special electronic circuit.

The method is distinguished by its simplicity and high sensitivity in the rapid determination of the coefficient of thermal activity for materials — insulators, crystals, dielectric coatings, and polymer films — which exhibit thicknesses of the order of $10\,\mu$m and higher, i.e., thicknesses which are used extensively in radio electronics and metrology.

NOTATION

λ	is the thermal conductivity;
c	is the specific heat capacity;
γ	is the density of the material;
$\varepsilon = \sqrt{\lambda c \gamma}$	is the coefficient of thermal activity;
a	is the thermal diffusivity;
q	is the heat flux;
τ	is the time;
T	is the temperature;
i_{R_s}	is the current pulse;
R_0	is the resistance of the film thermometer at the initial temperature;
α	is the temperature coefficient of resistance for the film sensor;
C	is the capacitance.

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