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## **Something about film devices controlled by an electric field and electromagnetic radiation**

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The paper provides information on some possible methods of controlling the properties of film devices using the actions of electromagnetic radiation, electric field and thermal action. Information is also provided on some such relevant devices and their possible applications. In this paper, first of all, those specified methods and devices that can be used for those or other transformations of thermal and electrical energy, as well as those properties on which the efficiency of the corresponding transformations of thermal and electrical energy depends, are considered. In particular, a combined device is considered, which combines the properties of electrocaloric and thermoelectric energy converters. A device with films sensitive to electromagnetic radiation, the control of the properties of which is carried out, in particular, by means of lateral electromagnetic radiation, is also considered. The information presented in this work can be used to study the influence of electromagnetic radiation, electric field and temperature on the properties of films, film devices or elements, to develop, create and use various controlled devices or elements (in particular, flexible ones), for example, photo-thermoelectric position-sensitive temperature sensors, thermoelectric and combined energy converters, electronic devices.

**Keywords:** electromagnetic radiation, electric field, film devices, thermoelectric elements, energy converters.

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### **Introduction**

It is well known that under the action of electromagnetic (e.g., optical) radiation, the properties of films sensitive to this radiation can change. It is also known that when the concentration of charge carriers changes (which can be caused, in particular, by the action of electromagnetic radiation), the Seebeck coefficient of the film can change [1 - 4]. And it is also known that under the action of an electric field, the properties of films can change [5].

The purpose of this work is a simplified (evaluative) consideration and analysis of some possible methods of controlling the properties of film devices using the actions of electromagnetic radiation, transverse electric field and thermal action. Also, the purpose of this work is a simplified (evaluative) consideration and analysis of such relevant devices and their possible applications. This work primarily considers those specified methods and devices that can be used for those or other transformations of

thermal and electrical energy, as well as those properties on which the efficiency of the relevant transformations of thermal and electrical energy depends.

Next, we will consider relevant examples.

### **I. Something about controlling the properties of films using electromagnetic radiation**

There are various formulas in the literature for calculating the Seebeck coefficient. For example, for a nondegenerate impurity semiconductor with a scalar effective mass and a parabolic dispersion law and with a power-law dependence of the relaxation time on energy for the differential Seebeck coefficient  $\alpha$  in [4], the formula is given:

$$\alpha = \frac{k}{e} \cdot \left( r + \frac{5}{2} \right) + \ln \frac{2(2\pi m^* kT)^{\frac{3}{2}}}{n \hbar^3}, \quad (1)$$

where  $e$  is a electron charge;  $T$  is a absolute temperature;  $\hbar$  is Planck constant;  $r$  is a parameter that depends on the scattering mechanism of charge carriers (for example,  $r = \frac{1}{2}$  for scattering by optical phonons, above the Debye temperature;  $r = 3/2$  for scattering by impurity ions);  $k$  is a Boltzmann constant;  $m^*$  is the effective mass of current carriers.

A feature of formula (1) is that the charge carrier concentration  $n$  is in the denominator of the logarithmic expression. Therefore, to obtain a practically significant change in the differential Seebeck coefficient, a rather significant change in the charge carrier concentration  $n$  is required. This correlates with the results of experiments given in [2, 3].

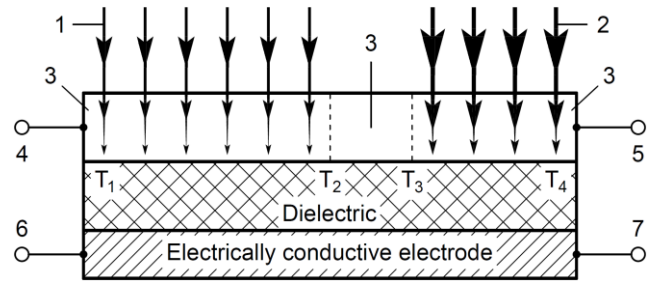
## II. Something about controlling the properties of films using electromagnetic radiation, electric field and thermal action

In works [2, 3, 6 - 8], the control of optical radiation over the properties of photosensitive elements is described. In this work, it is proposed to use electromagnetic (e.g., optical) radiation, electric field [9], and thermal action [10] to control the properties of film devices. Such control can be used to study the influence of electromagnetic radiation, electric field, and temperature on the properties of films, film devices, or elements. Also, the specified control can be used to develop, create, and use various controlled devices or elements (in particular, flexible ones), for example, photo-thermoelectric position-sensitive temperature sensors, thermoelectric and combined energy converters, and electronic devices.

### 2.1. Controlling the properties of a device with a film sensitive to electromagnetic radiation using electromagnetic radiation, an electric field, and thermal action

Let us consider an example of the implementation of the specified control, which is illustrated in Figure 1. In Figure 1: 1 and 2 – different electromagnetic radiation; 3 – photosensitive conductive film (sensitive to the action of the specified electromagnetic radiation);  $T_1 - T_4$  – device temperatures in the corresponding positions. Sources and loads of electrical energy, measuring devices, switching elements, etc. can be connected to contacts 4 - 7. The conductive electrode and dielectric are designed to create an electric field. In this example, short-term processes (pulse modes of operation of the device) can be used.

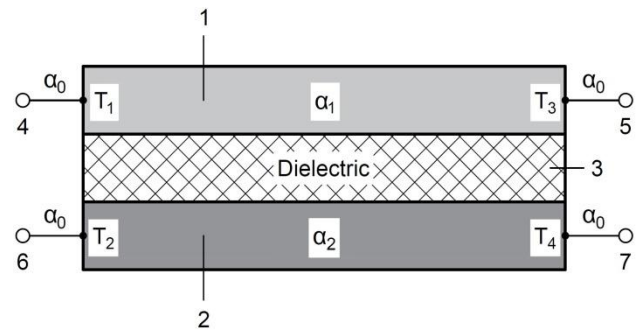
If an electric current flows through an electrically conductive electrode, then Joule heat will be released. This thermal action can be used to control the properties of the film 3. Also, using an electric current through an electrically conductive electrode, it is possible to create different voltage values along the electrode and, accordingly, different electric field values along the film 3. If necessary, the conductive electrode and film 3 may have a different number of terminals than shown in Fig. 1.



**Fig. 1.** Simplified scheme of an example implementation of controlling the properties of a device with a film sensitive to electromagnetic radiation using electromagnetic radiation, an electric field, and thermal action.

### 2.2. Device with films with different Seebeck coefficients

Consider the following example, which is illustrated in Figure 2. In Figure 2: 1 – electrically conductive film with the Seebeck coefficient  $\alpha_1$ ; 2 – electrically conductive film with the Seebeck coefficient  $\alpha_2$  (films 1 and 2 can be legs (branches) of a thermoelectric element); the leads from films 1 and 2 have the Seebeck coefficient  $\alpha_0$ ; 3 – one or another dielectric (for example, electrocaloric, piezoelectric or other);  $T_1 - T_4$  – temperatures of the device, which is shown in Fig. 2 (hereinafter referred to as device 2) in the corresponding positions. Sources of electrical energy, electrical loads, measuring instruments, switching elements, etc. can be connected to contacts 4 – 7. Using films 1, 2 and the dielectric (which form a capacitor [10]), an electric field can be created. In this example, short-term processes (pulse modes of operation of device 2) can be used.



**Fig. 2.** Simplified scheme of an example device with films with different Seebeck coefficients.

If an electrocaloric dielectric is used in device 2, then such a device will have the properties that are found in electrocaloric [11, 12] and thermoelectric elements. During the operation of such a device, thermal energy will be released or absorbed in the electrocaloric dielectric due to the electrocaloric effect. Also, Peltier energy will be released or absorbed (alternatively, divided in time) at the corresponding contacts. This Peltier energy  $E$  can be calculated using the well-known formulas:

$$E = \Pi I \Delta\tau = \Pi \frac{q}{\Delta\tau} \Delta\tau = \Pi q, \quad (2)$$

where  $\Pi$  is the Peltier coefficient of the junction;  $I$  is the current strength;  $\Delta\tau$  is the time interval;  $q$  is the charge.

Typical thermoelectric elements require the use of a

constant current in the direction to maintain a temperature gradient of constant sign. In contrast, device 2 can maintain a temperature gradient of constant sign using both a constant current in the direction and an alternating current in the direction. Also, for the operation of device 2, a constant current in the direction and an alternating current in the direction can be used (simultaneously). Using the electrocaloric effect, it is possible to change the temperature of device 2 and thus control its properties. It is also possible to control the properties of device 2 with an electric field. Device 2 combines the design features of an electrocaloric converter, a capacitor and a typical thermoelectric element. If device 2 has elements sensitive to electromagnetic radiation, then its properties can also be controlled by the corresponding electromagnetic radiation (this is not illustrated in Figure 2). Device 2 can also have transparent elements (this is not illustrated in Figure 2) [13, 14]. Device 2 may have more than two conductive films.

Alternatively, supercapacitors [13 - 15] with several leads from a single electrode (e.g., a film electrode) can also be used. In this case, the said leads and the single electrode can have different Seebeck coefficients (Peltier coefficients). Supercapacitors with more than two electrodes can also be used, at least one of which can be used to control the properties of the said supercapacitors. The supercapacitors can also have elements that are sensitive to the action of a particular electromagnetic radiation, which will allow controlling their properties using the said radiation. In this case, the supercapacitors can have transparent elements to implement the said control [13, 14].

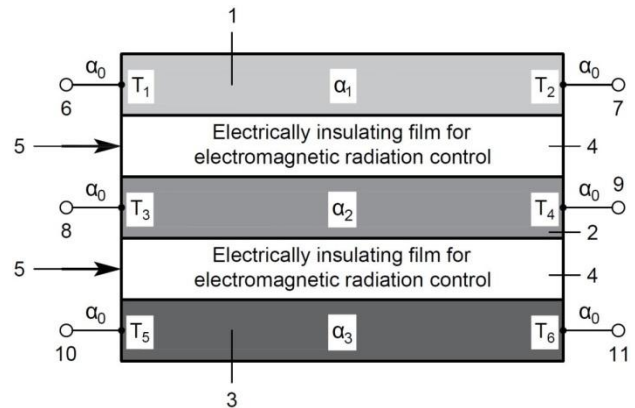
Combined devices that combine the properties of thermoelectric energy converters, electrocaloric elements, supercapacitors, possibly other capacitors, and elements sensitive to electromagnetic radiation can also be used.

### 2.3. Controlling the properties of a device with films sensitive to electromagnetic radiation using lateral electromagnetic radiation, an electric field, and thermal action

Consider the following example, which is illustrated in Figure 3. In Figure 3: 1 – electrically conductive film with Seebeck coefficient  $\alpha_1$ ; 2 – electrically conductive film with Seebeck coefficient  $\alpha_2$ ; 3 – electrically conductive film with Seebeck coefficient  $\alpha_3$  (films 1, 2 and 3 can be legs (branches) of a thermoelectric element); the leads from films 1, 2 and 3 have a Seebeck coefficient  $\alpha_0$ ; 4 – electrically insulating film for electromagnetic radiation control; 5 – electromagnetic radiation (for example, optical);  $T_1 - T_6$  – temperatures of the device shown in Fig. 3 (hereinafter referred to as device 3) in the corresponding positions. Sources of electrical energy, electrical loads, measuring instruments, switching elements, etc. can be connected to contacts 6 – 11. In this paper, the term "electrically insulating film for electromagnetic radiation control" refers to a film that provides waveguiding, directional control, and controlled formation of the required distribution of electromagnetic radiation while simultaneously serving as a dielectric. Examples of such films include dielectric light guide films used in edge-lit displays. Using films 1, 2, 3 and dielectrics (which form a capacitor [10]) it is possible to create an

electric field. In this example, short-term processes (pulsed modes of operation of device 3) can be used.

Device 3 can be considered as a multilayer film thermoelectric energy converter, the properties of which can be controlled by electromagnetic radiation, and which has the properties of a capacitor.



**Fig. 3.** Simplified scheme of an example implementation of controlling the properties of a device with films sensitive to electromagnetic radiation using lateral electromagnetic radiation, an electric field, and thermal action.

The devices shown in Fig. 1, 2 and 3 can be used to study the processes occurring in them, for energy conversions, and to obtain information regarding some questions, for example, the following. Will the moving of induced electric charges onto the surface of an electrically conductive film be accompanied by a thermal effect? How will the induced electric charges affect the effective Seebeck coefficient, effective Peltier coefficient and the electrical conductivity of the film?

Alternatively, for further research, it may be advisable to fabricate (and investigate) a controlled capacitive thermoelectric device (thermoelement) with three electrically conductive electrodes (films, plates) separated by dielectrics so that capacitors are formed [10]. In this case, dielectrics transparent to optical radiation or electrocaloric dielectrics can be used. Individual electrodes may have more than one electrical lead (contact). Alternatively, at least one electrode can change the conductivity type under the influence of one factor or another (for example, under the influence of a transverse electric field, change the n-type conductivity to the p-type conductivity [5]).

## Conclusions

The use the actions of electromagnetic radiation, electric field and thermal action, compared to the use of only one of the specified actions, expands the possibilities of controlling the properties of films and film devices. Devices that use more than one of the specified actions in their operation may have properties that are not available in devices that use only one of the specified actions in their operation. The information provided in this work can be used to study the processes occurring in the specified films and film devices, perform energy conversions, measurements, as well as to develop, create and use new

devices with the required properties.

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## **Дещо про плівкові пристрої, керовані електричним полем та електромагнітним випромінюванням**

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У роботі наведена інформація стосовно деяких можливих способів керування властивостями плівкових пристроїв з використанням дій електромагнітного випромінювання, електричного поля та теплової дії. Також наведена інформація стосовно деяких таких відповідних пристроїв та їх можливих застосувань. У цій роботі в першу чергу розглядаються ті вказані способи та пристрої, які можуть бути використані для тих чи інших перетворень теплової та електричної енергії, а також ті властивості від яких залежить ефективність відповідних перетворень теплової та електричної енергії. Зокрема, розглядається комбінований пристрій, який поєднує властивості електрокалоричних та термоелектричних перетворювачів енергії. Також розглядається пристрій з плівками, чутливими до електромагнітного випромінювання, керування властивостями якого здійснюється, зокрема, за допомогою бокового електромагнітного випромінювання. Наведена у цій роботі інформація може бути використана для вивчення впливу електромагнітного випромінювання, електричного поля та температури на властивості плівок, плівкових пристроїв чи елементів, для розробки, створення та використання різних керованих пристроїв чи елементів (зокрема, гнучких), наприклад, фото-термоелектричних позиційно-чутливих датчиків температури, термоелектричних та комбінованих перетворювачів енергії, електронних пристроїв.

**Ключові слова:** електромагнітне випромінювання, електричне поле, плівкові пристрої, термоелектричні елементи, перетворювачі енергії.