90 YEARS
NATIONAL ACADEMY OF SCIENCES OF UKRAINE 1918

ON THE TRANSFORMATION OF THERMAL ENERGY INTO ELECTRICAL ENERGY BY MEANS OF THERMIONIC EMISSION

Translated and reprinted from Ukr. Fiz. Zh. **2**, No. 4, pp. 379–380 (1957)

N.D. MORGULIS, P.M. MARCHUK

Institute of Physics, Academy of Sciences of the Ukrainian SSR
(Kyiv, Ukraine)

In one of his monographs [1], A.F. Ioffe paid attention to the interest which arose in connection with the creation of a "vacuum thermoelement". It is an electric energy generator which uses the kinetic energy of thermoelectrons emitted by two electrodes located in vacuum, provided that there is a certain temperature difference between the electrodes. In this case, an emphasis has been put on the importance of obtaining a thermionic current with significant density under the conditions discussed.

The issue concerning the energy of thermionic emission has already been considered in work [2] and, in more details, in [3].

Indeed, the energy efficiency coefficient for thermionic emission in this case is

$$\eta = J_e v_0 / W_c, \tag{1}$$

where J_e is the thermionic emission current density, W_c is the power spent by the cathode, and $v_0 = 2kT/e$ is the average energy per thermal electron. With modern efficient cathodes, one can rather easily obtain $J_e \approx 1$ A/cm^2 at $T \approx 900$°C and, accordingly, $v_0 \approx 0.2$ eV and $W_c \leq 3$ W/cm^2. In this case, a quite appreciable efficiency, $\eta \geq 5\%$, can be achieved. However, such an electron current is still almost impossible to be realized unless the anode voltage v_a is used as an extra power source [3]. To this end, the bulk charge of electrons should be compensated substantially, and there has been no idea of how this task can be solved.

On the other hand, a quite different approach to the problem was proposed in [4], namely, the use of the contact potential difference $v_c = \varphi_c - \varphi_a$ with such a polarity that accelerates thermal electrons. Here, φ_c and φ_a are the electron work functions for the cathode and anode ($\varphi_c > \varphi_a$). The energy φ_c, which is spent on the evaporation of an electron, is not lost entirely. It is only partially spent on heating the anode (φ_a), and the rest (φ_c) can be released at an external resistance R. In this case, the cathode work function φ_c should be as high as possible, and the anode work function φ_a should be as low as possible. So, we obtain the following relation instead of formula (1):

$$\eta = J_e(v_c + v_0)/W_c. \tag{2}$$

As an example, let us consider a cathode made of pure tungsten, and let $v_c = 3$ V (W–CsW). When the temperature of such a cathode is increased from $T =$ 2400°K to 2800°K, J_e changes from 0.1 to 3.5 A/cm^2, and W_c from 58 to 113 W/cm^2. Then the efficiency coefficient would range from 1 to 10%, according to formula (2). In this regard, we indicate two possible ways for the thermionic currents with such large densities to be obtained and for their large bulk charges to be compensated.

1. Let the vapor of cesium (or the vapor of some similar element) get into a tube. The atoms of this element (i) should cover the cold anode with a film that reduces the work function, e.g., down to $\varphi_a \approx 1.4$–1.9 eV and (ii) can be easily ionized at a very hot and, hence, pure cathode (e.g., made of tungsten, $\varphi_c = 4.5$ eV), so that the corresponding ion flow could totally compensate the bulk electron charge [5]. This procedure has already been realized experimentally by one of the authors in [4]. We obtained an emission current of about 24 mA at $T \approx 2500$°K, the corresponding current density being $J_e \approx 0.4$ A/cm^2 at $R \approx 100$ Ω. In this case, the net power was $W_c \approx 55$ mW. Whence it follows that $\eta \approx 1.2\%$ (without considering the energy spent on heating the tube, the energy necessary to obtain the required pressure of the cesium vapor, and so on). Such an estimate of η is in satisfactory agreement with the one given above. Moreover, there are grounds to expect that it can be increased further. In the above-discussed experiments, the "left"characteristic $v_c \approx 2.4$ V was obtained; the corresponding cesium vapor pressure was $p \approx 3 \times 10^{-3}$ mmHg and, naturally, we had $v_a = 0$. The pressure p was selected in correspondence with the

compensation coefficient, $k = J_e/J_p \approx \frac{1}{2}\sqrt{M/m}$. Some peculiarities of the bulk charge compensation and some issues related to controlling the current by an external magnetic field were discussed in [4] as well.

2. To obtain a higher J_e magnitude and, hence, a higher density of the ionic compensation current J_p, the cesium vapor pressure should be increased substantially. In this case, an anomalously low-voltage arc with potential drop $v_t \ll v_c$ is expected to be easily formed in the tube [6], where cesium ions will additionally be generated by the impact ionization. The corresponding efficiency

$$\eta = J_e(v_c + v_0 - v_t)/W_c \tag{3}$$

turns out to be somewhat lower than that given by expression (2). A similar case was realized in [7] in much the same manner, but under worse conditions, with an arc formed between a tantalum cathode and a barium–nickel anode in the xenon atmosphere. In this case, the efficiency $\eta \approx 0.3\%$ was obtained at $J_e = 0.5$ A and $v_c - v_t = 0.8$ V, and all positive ions were generated only by impact ionization.

Thus, a considerable electron current with appreciable energy efficiency coefficient can really be obtained, by using the contact-potential-difference technique described above. This result can be of interest in view of new opportunities in the application of thermionic emission, e.g., under the conditions specified in [1, 4, 5] (which are rather exotic, however).

1. A.F. Ioffe, *Semiconductor Thermoelements* (Izd. AN USSR, Moscow, 1956) (in Russian).
2. M. Strutt, Proc. JRE **40**, 601 (1952).
3. H. Moss, J. Electronics **2**, 305 (1957).
4. P.M. Marchuk, Trudy Inst. Fiz. Akad. Nauk Ukr. SSR, no. 7, 3 (1956).
5. M.E. Gurtovyi and G.I. Kovalenko, Fiz. Zapys. Akad. Nauk UkrSSR **9**, 240 (1941).
6. F. Newmann, Phil. Mag. **50**, 463 (1925); N.D. Morgulis and P.M. Marchuk, Ukr. Fiz. Zh. **1**, 59 (1956); **2**, 379 (1957).
7. G. Medicus and G. Wehner, J. Appl. Phys. **22**, 1389 (1951).

Received June 27, 1957

MORGULIS NAUM DAVYDOVYCH
(14.05.1904–01.09.1976)

Corresponding member of the Acad. of Sci. of UkrSSR N.D. Morgulis was the famous scientist in the field of physical electronics, surface physics, and plasma physics. He studied the mechanisms of electron and ion emissions from solids, as well as the processes running in electron emitters of various types; constructed the first ion microscope-projector; founded the Department of Physical Electronics at the Institute of Physics of the Acad. of Sci. of UkrSSR and the corresponding chair at Taras Shevchenko Kyiv National University. After the war, N.D. Morgulis initiated the studies of surface phenomena under superhigh vacuum, the development and mastering of new methods for the diagnostics of surfaces. Together with P.M. Marchuk, he proposed an efficient method for the direct transformation of heat energy to electric one with the use of thermoemission transducers filled with Ce vapor. A number of important works of N.D. Morgulis are devoted to the physics of low-temperature plasma.

N.D. Morgulis trained many highly qualified experts on physical electronics and founded the Kyiv school in this field recognized over the world. The National Academy of Sciences of Ukraine established the Morgulis' Prize awarded for the outstanding works on surface physics and physical and nano-electronics.