Emissions of electrons in metals due to ultrasonic effect

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Abstract. In the presented paper physical principles of thermoionic emissions phenomenon and principles of thermoemission converters' construction are presented. Also, ultrasonic electronic emission phenomenon and its application in thermoemission converters are justified. Ultrasonic electronic emission phenomenon is similar in nature to thermoionic emission, and ultrasonic effect allows to increase emissions current with a reduction of operating temperatures of a converter. Ultrasonic effect also would greatly increase efficiency of converter and its service life, because its elements will be able to work at lower temperatures.
[Trofimov A.I., Minin S.I., Trofimov M.A. **Emissions of electrons in metals due to ultrasonic effect** *Life Sci J* 2014;11(12):415-418] (ISSN:1097-8135). http://www.lifesciencesite.com. 80.

Keywords: emissions, ultrasonic, thermoionic emissions, ultrasonic emissions, nuclear reactors

Introduction

A physical phenomenon of thermoionic emissions was reveled in 1881 by T.A. Edison. Electron emissions phenomenon comprises electron emission by a surface of solid body (metal or semiconductor) due to an external influence. A role of external effects is to increase electrons energy up to values, which allow to overcome forces linking them with a solid body. The law of relationship between current density of thermoionic emissions and temperature was established Richardson in 1921. [1]. According to electron theory of metals, conduction electrons or free electrons in metals are able to freely move inside a crystal and inside a crystal conglomerate. Positive ions, which form metal lattice, create electrical field inside metal with a positive potential, which is changing periodically with a move of electrons through lattice points.

Main part

Free electron inside metal has a negative potential energy

$$U_0 = - qV_0, \quad (1)$$

where q – electron charge, V_0 – capacity of electric field, formed by positive metal ions.

In a case of electron transition into surrounding space, for example, vacuum, potential energy of an electron is equal to zero. Thus, metal for electrons is potential pit; in order to exit it, electron requires additional energy. Electron must conduct work, which is being referred to as photoelectric work. This phenomenon is clearly demonstrated by the model of potential pit proposed by Schottky (fig.1).

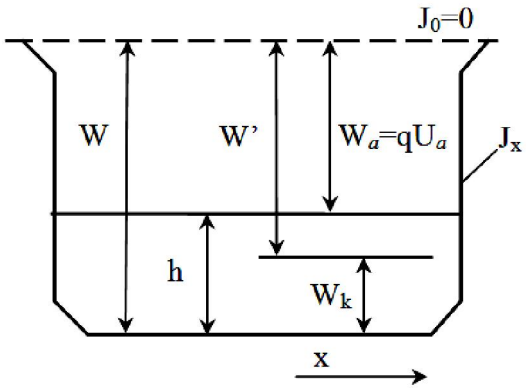

Fig.1. The model of potential distribution in metal (potential pit)

Electron gas, located in potential pit, can be considered as heavy liquid. The distance from the bottom of pit is a measure of kinetic energy of electrons. Outer space has zero potential. In a case of absolute zero kinetic energy of electrons W_k can fill a potential pit up to height, which is equal to Fermi energy μ. In a case of temperature increase, electrons will possesses energy, which is above Fermi level.

In order to conduct work for exiting metal, kinetic energy of electron must be higher than following energy:

$$W_a = qU_a = W - h, \quad (2)$$

where q – charge of electron, U_a – potential, equivalent to photoelectric work.

In a case of thermoionic emissions, electrons receive kinetic energy due to heating, which is sufficient to overcome forces that hinder their exit from metal. Electrons acquire V_{out} speed, which is determined from energy relationship:

$$\frac{mV_{out}^2}{2} = W_a .$$

(3)

If in a unit of volume dn electrons is contained, which speed in a direction of metal surface is $V_1 \geq V_{out}$, then emission current density is determined by following expression:

$I=qV_1dn$,

(4)

Maximum current density generated by cathode at temperature T, (saturation current density) is determined by the expression:

$$I = AT^2 \exp\left(-\frac{W_a}{kT}\right) ,$$

(5)

which is known as Richardson equation. Coefficient A – Richardson constant, k – Boltzmann constant.

During an assessment of current density it should be taken into account, that thermoionic emissions in metal is created only by electrons, which direction of movement is perpendicular to a surface of metal. With regard to a direction of electrons movement in the spatial coordinate system the expression (3) will have following form [2]:

$$W_a = \frac{m}{2}\left(V_x^2 + V_y^2 + V_z^2\right). \quad (6)$$

Electronic emission is provided only by the electrons, which speed direction is determined by component V_x.

Table 1. Values of emission current density of cathode, produced from tungsten [3].

T, K	2100	2200	2400	2600	2800	2900	3000
I, A/cm^2	3.9·10^{-3}	1.3·10^{-2}	1.2·10^{-1}	7.0·10^{-1}	3.5	7.3	14.0

As it can be seen, emission current takes place only in a zone of sufficiently high temperatures.

Physical phenomenon of ultrasonic electron emission of metals, which consists of the fact, that due to an influence of ultrasonics, metals emit electrons into surrounding space in a direction of ultrasonic wave. Ultrasonic waves create a directional movement of entire conglomerate of metal's conduction electrons.

That physical phenomenon has following mechanism. If ultrasonic wave in metal is presumed to be phonon flux, ultrasonic intensity will be determined by the expression [1]:

$I_x=n_f(x)\hbar c,$

(7)

where $n_f(x)$ – number of photons in a unit of volume in a point x; ħ[omega] - phonons energy ($\hbar$ – Planck's constant, [omega] – oscillation frequency), c – ultrasonics speed.

During an interaction of electron, phonon exchanges pulse and energy with it. If phonon passes its impulse to electron with an effective mass m^* momentum conservation law expression can be presented in the following form:

$$P_f = \frac{\hbar\omega}{c} = \Delta V_{el} \cdot m^* = P_{el} .$$

(8)

Therefore, electron increase speed in a direction of ultrasonic wave propagation.

$$\Delta V_{el} = \frac{\hbar\omega}{m^* c} .$$

(9)

Movement of electrons in a direction of ultrasonic wave propagation creates electric current, which is called acousto-electric current. Acouso-electric current density is determined using the equation:

$$I_{ae} = qn_e\Delta V_{el} = \frac{qn_e\hbar\omega}{m^* c} ,$$

(10)

where n_e – number of electrons, which are interacting with phonons.

At that, ultrasonic wave gives electrons power in a unit of volume:

$$Q_0 = \frac{\partial I_x}{\partial x} = a_{el} I_x ,$$

(11)

where a_{el} – electron attenuation (absorption) of ultrasonics in metal.

Theoretical justification of ultrasonic emission phenomenon is proved by the results of experimental studies.

On a basis of physical phenomenon of thermoionic emission thermoemission converters are created, which convert of thermal energy into electric energy for industrial applications [2, 4]. Thermoemission converter consists of emitter and collector with vacuum between them. Emitter is connected with a source of thermal energy. Emission current is created by heating of emitter. A gap between emitter and collector is 0.1-0.5 mm and that's why collector also heats up and becomes a source of emission current. In order to thermoemission converter become a source of electric energy, density of emission current of emitter

must be significantly higher than emission current density of collector:

$$I_{out} = I_e - I_k . \quad (18)$$

In order to do that, temperature of emitter is kept significantly higher than temperature of collector [5, 6].

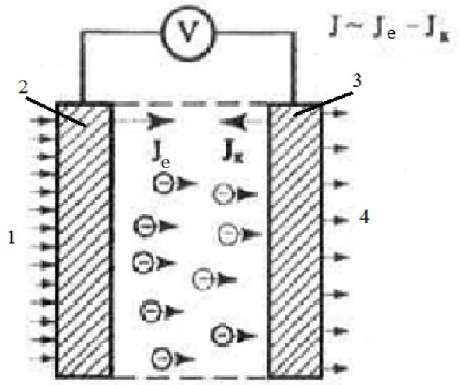

Fig.2. Scheme of thermoemission converter
1 – heat input; 2 – emitter; 3 – collector; 4 – heat output

An implementation of thermoemission converter as a source of electricity was proposed by Shlihter in 1915. In Russia experimental studies of thermoemission converters started to be conducted from 1940 on A.F.Ioffe initiative [7].

Thermoemission vacuum converters had low power, because of that with a transmission of emission current in vacuum gap a volumetric (spatial) charge of electrons is created, which hinders passage of current. Output power of vacuum thermoemission converters didn't exceed 1 W.

In 1947 N.D.Morgulis and P.M.Marchuk established, that an introduction of cesium vapor into an interelectrode space leads to an increase of current density of thermoemission converter, because cesium ions neutralize volumetric charge of electrons. That allowed to increase power of thermoelectric converter to tens of watt with following parameters: emitter temperature – 1800÷2000 K, collector temperature – 800÷1000 K, value of charge between collector and emitter – 0,2÷1,0 mm.

Systematic research and development of thermoemission converters started in 1960 in USSR and USA and were related with a program of a development of nuclear reactor with a direct conversion of heat energy in electricity with an implementation of thermoemission and thermoelectrical converter for space research programs [8]. Nuclear power units with a direct conversion of heat energy into electricity exclude transitional stage in energy conversion and allow to create small-sized power units with electric power from few to several hundred kilowatts.

In 1960 in USA a program had started for a development of nuclear power unit with thermoelectrical converter SNAP-10 with electric power of 100-200 W, which served as a trigger for Russian scientists, who developed thermoelectric nuclear power unit on fast neutrons and offset themoelectric system "Romashka" (chamomile) with electric power of 3 kW. Further development of nuclear energy system of "Romashka" type was conducted by means of replacing thermoelectric converters for thermoemission elements.

In 1969 in USSR a program for a development of space nuclear unit with thermoemission converters "Yenisei" (Topaz-2) had been started, the unit and electric power of 4.5-5.5 kW and service life was up to 3 years [8,9].

On fig.3 schematic diagram of a structure of thermoemission electrogenerating channel of nuclear energy unit "Topaz". Channel possesses five thermoemission converters. Emitter 2 of thermoemission converter is in a form cover made from tungsten alloy, inside of which there is high temperature nuclear fuel 1 based on uranium dioxide. Collector 3 is in a form of tube made from niobium alloy. Size of the gap 4 between electrodes is 0,4-0,5 mm. The gap is filled with cesium vapor. Outer cover 6 is made from stainless steel, between cover and converters there is an insulator 5. Thermoemission converters are connected serially.

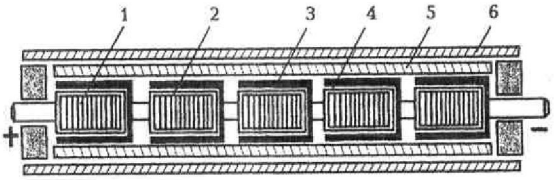

Fig.3. Schematic diagram of a structure of electrogenerating channel

Electric power of space emission nuclear energy units, kW: 11.7, 20.1, 35, 48.8, 68.7, 100, 134, 207. Output voltage – 120 V [9, 10].

Conclusions

It is proposed to introduce ultrasonic converter into a scheme of thermoemission converter in order to increase units overall power. An influence of ultrasonics on emitter of thermoemission converter leads to an increase of emission current density and, therefore, electric power and shift of temperature range of thermoemission converters in lower temperatures zone.

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8/15/2014