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USING OF CARBON-CARBON COMPOSITE MATERIALS FOR CREATION OF THERMAL-RESISTIVE CONVERTER OF THERMAL RADIATION

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The article presents the results of work aimed at research of electric-physical properties of carbon-carbon composite material (CCCM) under conditions of heat exchange by radiation in vacuum and creation of a thermal-resistive heat radiation converter for measuring temperatures up to 2500 °C.

Information about the thermal state of objects constitutes the basis of the automation of many technological processes which is the starting point for determining their performance, strength, wear resistance, reliability, residual resource and other properties and characteristics.

Strengthening of technical requirements for the reliability, durability of equipment and structural materials led to the creation of technological processes that use heating to high temperatures (up to 3000 °C) in a vacuum of $10^{-1}…10^{-2}$ mm of mercury. Such processes include degassing and recrystallization annealing, melting, fusing, soldering, welding, heating of metals for treatment under pressure, hardening, ceramics and glassware production, vacuum drying of materials, application of coatings and many others [1].

Such processes are carried out in the ranges of high temperatures, which are characterized by electromagnetic radiation in a wide spectral range starting from the short-wave area to the middle-wave area. Material medium is not needed to expand the electromagnetic waves; in a vacuum, they expand with the light speed and are characterized by wave length.

At a temperature of up to 1500 °C, the main part of the energy corresponds to infrared and partly to light radiation λ in the range of 0.7…80 μm [2]. To measure such temperatures, infrared radiation detectors are used, which are based on various measurement principles, including the use of thermal methods, in which the incident radiation is absorbed by the material, while its temperature increases, which in its turn, results in change of some physical properties of the material, for example, electrical resistance.

The spectral sensitivity of thermal radiation receivers is constant in a wide range of wavelengths, since the energy of photons is not converted into heat selectively, which makes it possible to determine the root-mean-square values of the temperature of thermal infrared radiation inside the vacuum facility in the temperature range of 500…2500 °C.

Each type of thermal-converters has its own fields of application, which are characterized by the range of measured temperatures, physical and chemical properties of the medium under investigation, needed measurement accuracy and a number of other special requirements also the differ on the materials used as sensitive elements.

Various metals are used for the production of sensitive elements, which must correspond to a number of requirements: they must not oxidize, have high reproducibility of electrical resistance values in the range of operating temperatures, have a monotonic dependence of resistance on temperature in the range of measured temperatures, and a sufficiently high value of the temperature coefficient of resistance.

Such metals include: platinum, indium, copper, tungsten, molybdenum, and tantalum. Rhodium, iridium, and rhenium are also used for production of high-temperature sensors, since they are inert to most reagents, except for oxygen, and have good physical and mechanical properties.

Table 1 demonstrates characteristics of the materials mostly used for production of sensitive elements of heat radiation converters and the ranges of measured temperatures [3].

The main disadvantage of sensitive elements made of these materials is the problem of not only in insufficient limit of temperature measurement, but also in the selection of wire material for placing the sensitive element directly in the measurement area with a temperature of up to 2500 °C.

Taking into account that thermal-resistive converters for high temperatures in a vacuum constitute the non-contact measuring devices, the possibilities of their application are determined, first of all, by the heat resistance of the material from which the resistive element is made. Resistive elements made of CCCM have such characteristics. Structurally, such thermal-resistive converter can be of almost any form: flat, rod, tubular, which is determined by the peculiarities of its application in the corresponding devices, taking into account the location of the source of thermal influence, the spatial-temporal integral characteristics of heat flows and the regularities of the stages of the thermal process.

The advantages of CCCM products include their low specific weight (1.35…1.85 g/cm^3), high mechanical properties in a wide temperature range, low heat capacity, high thermal conductivity, high resistance to thermal shocks, the ability to retain their shape and geometric dimensions during the process thermal-cycling.

Table 1

Characteristics of the materials

Mate-rial	Measu-rement limit, °C	Specific electrical resistance, Ω·m	Resistance temperature coefficient, K^{-1}
Pt	-260 + 1100	95.9 at 0 °C 0.029 at -263°C	0.0039 at 0 °C 0.00025 at -260°C
Cu	-260 + 180	15.5 at 0 °C 0.002 at -258°C	0.0042 at 0 °C 0.00006 at -260°C
In	-270 + 27	84 at 0 °C 0.0252 at -268°C	0.004 at 0 °C 0.0007 at -260°C
Ge	-271 + 263	89 at 0 °C	1.0 at -269 °C -2.8 at 271 °C
Coal	-273 + 190	25…63 at 0 °C	-0.1 at -263 °C -1.9 at -270 °C

The purpose of the work is to study the dependence of the specific resistance of CCCM on temperature and to create a thermal-resistive thermal radiation converter for a non-contact sensor that can be used in a wide range of infrared radiation in systems of automatic control and temperature regulation inside a vacuum installation in the temperature range of 500…2500 °C.

Thermal-resistive converters of tubular spiral shape were manufactured for conducting research with CCCM. Based on the design and technological requirements for the thermal-resistive converter, the width of the conductor of the resistive element is not less than 2 mm, the pitch of the spiral is 4 mm, the outer diameter of the spiral is 12 mm, and the inner diameter of the spiral is 8 mm. On both sides, two zones are foreseen for connecting of current-carrying conductors. Fig. 1 demonstrates a sketch of such design. Thermal calibration was performed using a high-temperature muffle furnace with a graphite electric heater by using a gauge pyrometer.

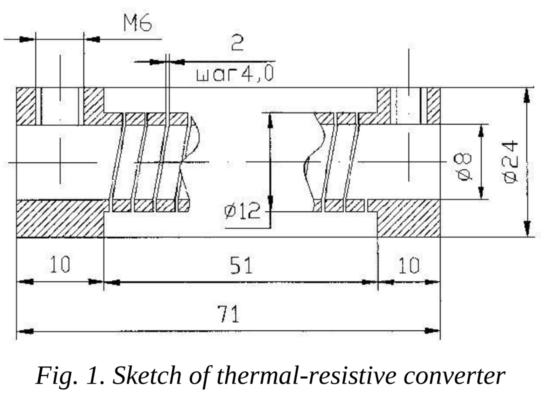

Fig. 1. Sketch of thermal-resistive converter

Fixing of the thermal-resistive converter in the vacuum furnace is made on two from CCCM, which simultaneously serve as conductive conductors for recording its electrical resistance. The range of measurements in vacuum can reach up to 2500 °C.

In order to calculate the heat flow from the furnace heater to the tubular shape thermal-resistive converter, located inside the furnace, it is possible to apply Kirchhoff's law, which establishes the relationship between the emissive and absorptive capacity of the subject, namely between the source and the thermal-resistive converter [4].

At this, it can be assumed that the absorption capacity and the degree of blackness of these bodies are equal to each other $\varepsilon_1 = \varepsilon_2$. Then the given absorptive capacity of the system can be replaced, for convenience, by the equivalent given degree of blackness of the system $\varepsilon_{(1-2)}$. In this case, in the stationary mode, the equations for determining the resulting amount of heat flow, which is transferred from the heater to the thermal-resistive converter and the presented degree of blackness, will be as follows:

$$Q_{(1-2)} = c_s \cdot \varepsilon_{(1-2)} \cdot \left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4 \right] \cdot F_1,$$

where F_i – calculated heat exchange surface; c_s – radiation coefficient of the absolutely black body; c_s = 5.67 W/(m^2·K^4); $\varepsilon_{(1-2)}$ – the indicated degree of blackness, which is determined:

$$\varepsilon_{(1-2)} = \frac{1}{\frac{1}{\varepsilon_1} + \frac{F_1}{F_2} \cdot \left(\frac{1}{\varepsilon_2} - 1\right)}.$$

The temperature of the thermal-resistive converter can be calculated using the formula:

$$T_2 = 100 \cdot \sqrt[4]{\left(\frac{T_1}{100}\right)^4 - \frac{Q_{(1-2)}}{c_S \cdot \varepsilon_{(1-2)} \cdot F_1}}.$$

Thermal-resistive sensor was calibrated in the course of the research. Resistance measurements were carried out in the following sequence:

– the electrical resistance of the thermal-resistive converter made from CCCM with installed current leads was measured when the furnace was turned off by the indirect counting method using the E7-8 RLC meter, which provides measurement of electrical resistance in the range $10^{-3}…10^{6}$ Ω;

– further, setting the required value of the current and voltage of the furnace on the stand, and connecting as close as possible to the frame of the four-leads clamps of the E7-8 RLC meter to two current leads, and controlling the temperature with the help of a pyrometer, the electrical resistance of the thermal-resistive converter was measured.

Results of measurements are shown in Table 2. The resistance value was calculated as the average arithmetic meaning based on the results of testing 10 samples.

Fig. 2 shows the dependence of the electrical resistance of the thermal-resistive converter manufactured from the researched CCCM sample on temperature.

Thus, in the temperature range from +500 to +2500 °C, the calculated specific electrical resistance of CCCM changes from $42 \cdot 10^{-6}$ to $13.4 \cdot 10^{-6}$ Ω·m and the calculated temperature coefficient of resistance at a temperature of 500 °C is equal to 0.0031 K^{-1} and at a temperature of 2500 °C it is equal to 0.0002 K^{-1}.

Table 2

Resistance meaning of thermal-resistive converter made from CCCM

T, °C	500	700	900	1100	1300	1500	1700	1900	2100	2300	2500
R, Ω	3.154	2.922	2.743	2.256	1.751	1.155	0.852	0.655	0.457	0.399	0.365

Fig.2. Dependence of resistance of the researched CCCM sample on the temperature

The sensitivity of the measurement decreases at the temperature above 2500 °C, but with the appropriate mathematical processing of the signal, it is possible to measure the temperature up to 3000 °C.

CONCLUSIONS

The possibility of measuring and controlling the temperature of thermal radiation in the infrared region of the spectrum at high temperatures up to 2500 °C at a pressure of 10^{-2} mm Hg was experimentally confirmed using the test sample of a thermal-resistive converter produced from CCCM. The recommended temperature measurement range with an error of 5% percent constitutes 500…2500 °C.

The advantages of the investigated thermal-resistive converter are the following: high reliability, correspondence of the radiative abilities of the source and receiver of radiation, which will ensure an increase of measurement accuracy.

Rather low values of the dispersion of test data for a batch of thermal-resistive converters manufactured at different times provide evidence on the satisfactory and stable quality of CCCM, which has significant practical value.

The thermal-resistive converter with CCCM allows performing of replacement of the expensive tungsten-aluminum and platinum-rhodium thermocouples and can be used in automatic temperature control systems.

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ВИКОРИСТАННЯ ВУГЛЕЦЬ-ВУГЛЕЦЕВОГО КОМПОЗИЦІЙНОГО МАТЕРІАЛУ ДЛЯ СТВОРЕННЯ ТЕРМОРЕЗИСТИВНОГО ПЕРЕТВОРЮВАЧА ТЕПЛОВОГО ВИПРОМІНЮВАННЯ

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Наведено результати роботи, спрямованої на дослідження електрофізичних властивостей вуглець-вуглецевого композиційного матеріалу (ВВКМ) в умовах теплообміну випромінюванням у вакуумі та створення терморезистивного перетворювача теплового випромінювання для вимірювання температур до 2500 °C.