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EXPERIMENTAL CRYOGENIC THERMISTORS BASED ON DISPERSED GERMANIUM

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Abstract. *The results of development and research of experimental samples of thermistors based on dispersed germanium are presented. The temperature dependence of electrical resistance in the temperature range of 4.2 - 300 K has been measured. High sensitivity of sensors in the cryogenic temperature range (at the level of 100 %/K) and high accuracy of measurement under the influence of magnetic fields are shown.*

Keywords*: sensors, temperature, thermistors, semiconductors, measurements.*

Introduction

Semiconductor thermistors are widely used in various fields of modern industry, process automation and scientific research [1,2]. Due to their high temperature sensitivity, such thermistors are also interesting for measurements in a wide range up to cryogenic temperatures. Such disadvantage as nonlinear character of temperature dependence of electrical resistance of semiconductor materials, and in this connection difficulties in calibration of sensors, is overcome by application of computer technologies in calibration of such sensors. To create sensors, new semiconductor materials and methods of their processing are constantly being developed to achieve optimal characteristics for certain application conditions [3-9].

Main text

Pure germanium is not used in thermometry because at low temperatures it has a very high resistance, low sensitivity. Often measurements must be carried out under conditions of various external influences (presence of magnetic fields, etc.), which, affecting the resistance of pure germanium, can lead to significant errors. Currently, to obtain suitable electrophysical properties of bulk germanium, various rather expensive and labor-intensive doping methods are used. They also use germanium in film form. In some works cryogenic thermistors based on germanium films on semi-insulating gallium arsenide have been investigated. At 4.2 K they can have a sensitivity of about 20%/K, some are resistant to neutron irradiation at 77 K to doses of the order of 10^{15} cm^{-2}.

Earlier we have already investigated some properties of experimental samples of thermistors [5,7-9] based on bulk dispersed germanium obtained by mechanical pressing at different temperatures and pressures of finely dispersed powder of monocrystalline germanium. The aim of the study was to create thermistors for the temperature range of 4.2-300 K resistant to extraneous external influences. The temperature dependence of electrical resistance in the above temperature range, magnetoresistance at T=4.2 K and the effect of neutron irradiation on electrical resistance at room temperatures were studied [9].

Figure 1 shows an image of the experimental thermistor sample.

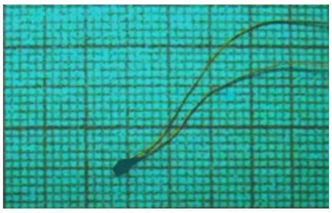

Figure 1. Experimental sample of thermistor on the basis of dispersed germanium

Source: built by the author.

Dispersed germanium was obtained from powder of monocrystalline germanium of *n*-type conductivity with a resistivity of 15 Ohm.cm,. Samples were produced by exposure to high pressures and temperatures. It was found that the pressure and temperature at which the powder was pressed determine the electrophysical properties of the obtained dispersed germanium. For creation of thermoresistors for cryogenic temperatures the most suitable samples were used. The obtained dispersed germanium had p-type conductivity, specific resistance at room temperature ρ = (1-4) Ohm.cm. It can be assumed that the acceptor levels are due to the peculiarities of the crystal structure of the obtained material. The peculiarities of the structure of dispersed (powder) germanium can also explain the increased radiation resistance of such material.

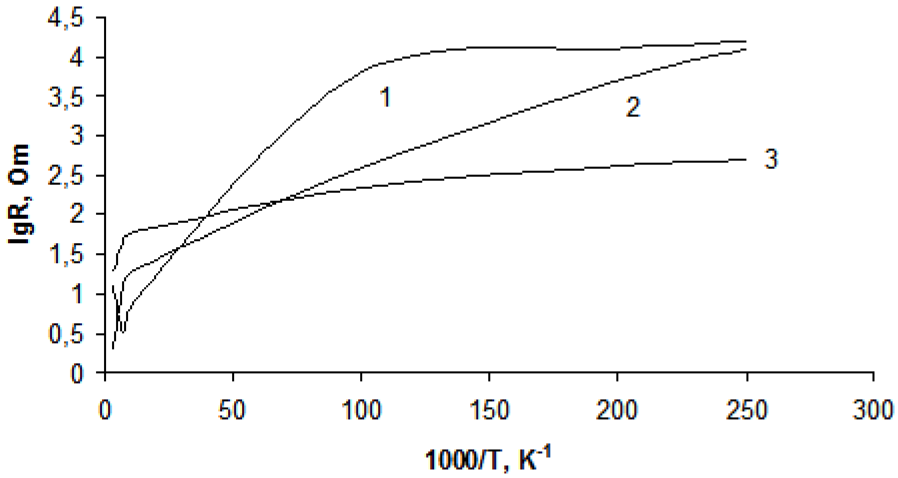

Figure 3. Temperature dependence of electrical resistance:

***1** - bulk initial monocrystalline germanium, **2** - thermistor based on dispersed germanium type A, **3** - thermistor based on dispersed germanium type B. Types A and B differ in temperature and pressure value when obtaining dispersed germanium - pressure 6 GPa and temperature 700 °C (type A) and 500 °C (type B).*

Source: built by the author.

The results of measurements of temperature dependence of electrical resistance are presented in Figure 3. It shows the temperature dependence of resistance of single-crystal bulk germanium of *n*-type conductivity (curve 1) and experimental thermistors from dispersed germanium (curves 2,3).

The temperature dependence of the electrical resistance of thermistors made of dispersed (powder) germanium type A (curve 2) at low temperatures is steeper than the dependence of monocrystalline original germanium and in the whole temperature range has a more monotonic character. The smooth character of the temperature dependence of the electrical resistance allows to approximate it with mathematical formulas quite simply and with good accuracy. For a sample of type A, for example, even for the temperature range 77-300 K using a polynomial of the form

$$\ln R = \sum_{i=0}^{n} A_i(\ln T) \quad (1),$$

(where Ai - constant coefficients determined by the least squares method, n - determined from the condition of the smallest approximation error) already for n =3 we obtain the dependence

lnR = 15.1077031+1.6552736*lnT - 1.7901811*(lnT)2 + 0.193233*(lnT)3

with correlation coefficient r2 = 0.9995 and an error of about 0.1K in the 77K region .

The sensitivity of type A thermistors in the liquid helium temperature region (4.2 K) reaches values of more than 100 %/K. Sensitivity of thermistors made of type B material is about 20 %/K and at 4.2 K they have electrical resistance as a rule not exceeding 500 Ohm.

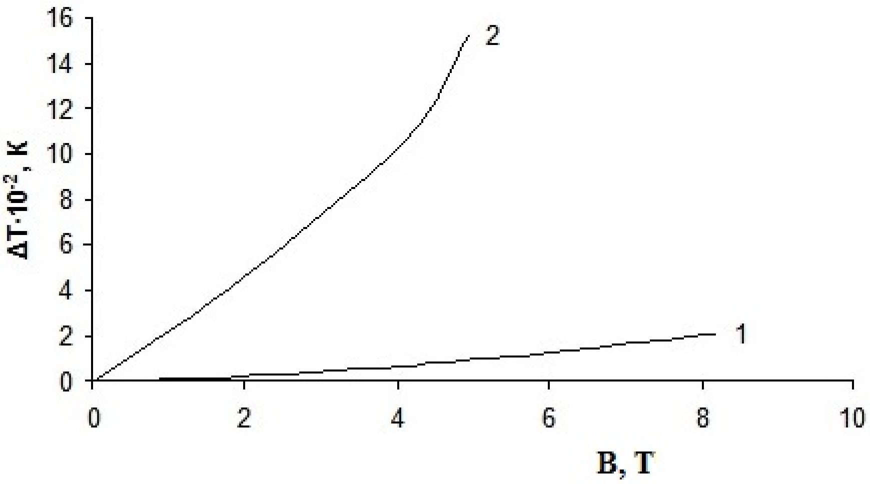

Figure 4. Dependence of the temperature measurement error ΔT in the region of 4.2 K on the magnetic field B for thermistors of type A (curve 1) and type B (curve 2).

Source: built by the author.

Figure 4 shows the dependence of the error ΔT of temperature measurement in the liquid helium region in the presence of magnetic fields on the magnitude of the magnetic field. The error of thermistors made of A-type material (curve 1) in the 8 Tesla field is approximately 0.02 K, and that of B-type thermistors in the 4 Tesla field reaches 0.15 K.

Conclusions

Thermometric properties of dispersed germanium in the range from room to cryogenic temperatures (4.2 - 300 K) are investigated. The characteristics of experimental thermistors in a wide range of temperatures and under the influence of external magnetic fields are given. High sensitivity of thermistors is shown, especially in the area of cryogenic temperatures - approximately at the level of 100 %/K. Magnetic fields up to 8 Tesla lead to an error of no more than 0.02 K.

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