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GERMANIUM-FILM RESISTANCE MICROTHERMOMETERS INTENDED FOR OPERATION WITHIN THE TEMPERATURE RANGE OF 0.03–300 K

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Germanium-film resistance microthermometers (∅1.2 × 1.0 mm) are worked out and manufactured to be used in a wide range of temperatures from superlow to room temperatures. The thermometer characteristics are investigated within the temperature range of 0.03–300 K.

At present a wide diversity of devices for measuring and monitoring temperature exists. Rapid development of new space technologies and of the experimental physics of low and superlow temperatures calls for the creation of new types of the devices characterized, first of all, by miniature dimensions and a wide range of working temperatures, capable of operating under extreme conditions of attack by strong magnetic fields and at high levels of radiation and possessing high reliability and low costs. These devices can be created by employing film semiconductor materials and using up-to-date microelectronic technologies in the manufacture of sensors.

As is known, a resistance thermometer must possess a monotonic temperature dependence of resistance, high heat sensitivity, resistance ratings convenient for measurement over the entire range of working temperatures, and also the required reliability and stability of its characteristics.

If a thermometer is intended for operation in a relatively narrow temperature range, then choosing heat sensitive material and the body's structure presents no particular difficulties for its manufacture. Nowadays there exist many methods of temperature measurement under these conditions [1, 2].

A substantially more complicated task is the creation of a device operating in a wide temperature range, especially at low and superlow (lower than 1 K) temperatures. For this, it is necessary to solve the following main problems. First, the choice of a heat sensitive material that provides the required thermometric characteristics in the range from superlow to room temperatures and development of the technology of its manufacture. Second, the development of the structure and technology of manufacture of a sensor and a body providing the required thermophysical properties and the high reliability and stability of its characteristics in multiple cooling and heating runs, in particular, in heat shocks.

The present investigation is devoted to the development and organization of the production of resistance microthermometers intended for operation within the temperature range from superlow to room ones. In the work, the structure of a microthermometer and its thermometric characteristics in the temperature range of 0.03–300 K are presented.

As heat sensitive material, we used Ge films on semiinsulating GaAs substrates. This was dictated by the fact that, first, Ge and GaAs make an ideal heterosystem. The difference in lattice constants of Ge and GaAs is extremely small and amounts to 0.08%, which provides relatively small internal mechanical stresses at the film-substrate interface. The linear expansion coefficients of both materials practically coincide within a wide temperature range. The absence of thermal stresses in the heterosystem is an important factor for the devices operating in a wide temperature range. Second, on Ge deposition onto the GaAs substrate a substantial

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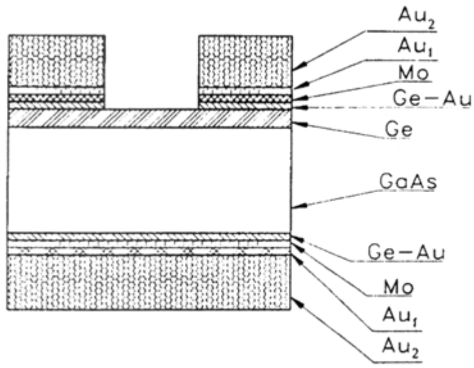

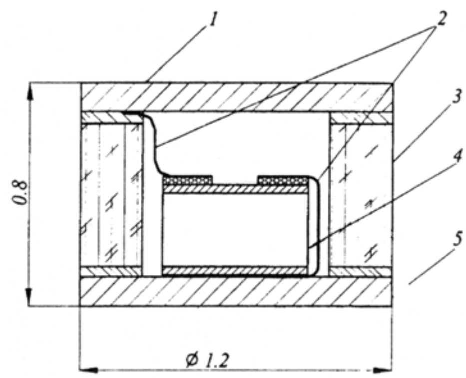

Fig. 1. Structure of the sensor of a thermometer.

Fig. 2. Structure of the thermometer body: 1 and 5) copper discs; 2) gold tape with a thickness of 6 μm and a width of 150–200 μm; 3) ruby cylinder; 4) sensor.

contribution to the formation of film properties is made by the diffusion of Ga and As atoms from the substrate. As is known, gallium in germanium is an acceptor impurity, while arsenic is a donor impurity. Therefore, the diffusion processes at the film-substrate interface exert a substantial influence on the electric properties of the Ge films.

The monotonic temperature dependence and good heat sensitivity in a superwide (0.03–300 K) temperature range can be implemented only by multicomponent doping and compensation of Ge when the continuous spectrum of impurity states exists in the forbidden gap of a semiconductor. Depending on the level of doping and the degree of Ge compensation, several different electric conduction mechanisms can be created, each of which will provide the required heat sensitivity in a certain temperature range.

In the GaAs-based Ge films, there are at least three sources of the levels in the forbidden gap which serve as suppliers of improper charge carriers: Ga (acceptor) and As (donor) impurities and structural defects manifesting themselves as acceptors. Their ratio depends on the conditions of preparation of the films. Varying the technological conditions, one can obtain Ge films with different level of doping and degree of compensation and create temperature sensors possessing different characteristics and capable of operating within different temperature ranges [3].

Consider the technology of manufacture of the sensor and the structure of the body of resistance thermometers denoted as TTR-1D model.

The films were produced by the method of Ge thermal evaporation in vacuum ($2 \cdot 10^{-4}$ Pa) onto semi-insulating GaAs substrates. The most suitable characteristics for the manufacture of low-temperature resistance thermometers were manifested by Ge films with a thickness of about 1.5 μm. The films had *p*-type conductivity. The concentration of free carriers in the films determined from the Hall effect at a temperature of 298 K was about $8.3 \cdot 10^{17}$ cm^{-3}, the mobility was 214 cm^2/(V· sec), and the specific resistance was $3.5 \cdot 10^{-2}$ Ω·cm.

To manufacture the sensor, we employed microelectronic technology. Figure 1 shows schematically the structure of the sensor of a resistance thermometer. The sensor dimensions are 0.3 × 0.3 × 0.2 mm. Its topology is formed by the photolithographic method. As is seen from the figure, the sensor represents a multilayer structure consisting of a heat sensitive Ge film and a semiinsulating GaAs substrate. To manufacture electric contact terminals to the Ge, we deposited in succession thin layers of AuGe (eutectics), Mo, and Au with a total thickness of about 0.3 μm. Such a multilayer metallic system was expected to provide a good electric contact terminal to the Ge within a wide range of temperatures from superlow to room temperature. The Mo layer was needed as a barrier for Au diffusion to Ge.

Contact terminals were manufactured by the method of thermocompression welding of a thin (6 μm) gold tape with a width of about 150–200 μm. To ensure reliable microwelding, an Au layer with a thickness of about 5 μm was additionally deposited by the electrochemical method.

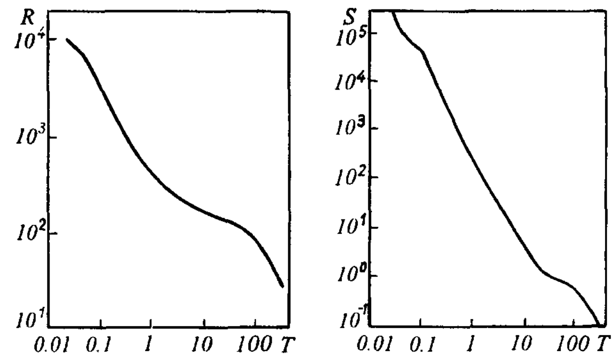

Fig. 3. Temperature dependence of the resistance R and the heat sensitivity S for the Ge film-on-GaAs thermometer (the TTR-1D model). R, Ω; S, Ω/K; T, K.

Figure 2 shows the structure of the thermometer body assembled from a ruby cylinder and two copper discs coated with a thin Au layer. The end faces of the cylinder were also coated with a thin Au layer. The discs were hermetically attached to the ruby cylinder by the method of thermodiffusive welding between the Au layers. The sensor was fastened to one of the discs by means of thermal diffusion welding. As the external electric leads, we used a copper wire with a diameter of 50 μm tin-welded to the discs. With allowance for the external electric leads and tin solder the overall dimensions of the thermometer were ∅1.2 × 1.0 mm.

Figure 3 shows the temperature dependences of the resistance R and the heat sensitivity $|S| = |dR/dT|$ for the thermometer in the temperature range of 0.03–300 K. The thermometer is characterized by a monotonic temperature dependence and good heat sensitivity in the entire temperature range investigated.

Thus, GaAs-based Ge films can be used as a sensitive material for wide-range cryogenic resistance thermometers encompassing the range of working temperatures from at least 0.03 to 300 K. The films are characterized by a monotonic temperature dependence of resistance in the entire temperature interval investigated and good heat sensitivity. A miniature thermometer body is developed and an industrial batch of resistance microthermometers (the TTR-10 model) is manufactured.

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