Influence of roughness parameters of surface on the emissivity of germanium single crystals

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Abstract. In this paper observed values of emissivity for germanium single crystals with various surfaces received by classical methods of processing (polishing, grinding by the powders F400, F800), and also for the raw surface after a cut. The received values will allow further thermovision researches of germanium single crystals by methods of active thermal control and IR-defectoscopy with minimization of measurement errors.

1. Introduction
At present, the use of germanium crystals in IR optics and photoelectronics is of a rather mass nature. A number of works have thoroughly studied the relationship between structural defects in germanium and optical inhomogeneities in these crystals. In particular, a correlation was found between the intensity of light scattering and the density of dislocations in germanium. Small-angle boundaries, as well as the spatial distribution of dislocations and resistivity along crystals, have been investigated [1-4]. For effective use, single crystals of germanium should have the highest possible optical transmission and the highest possible optical homogeneity, since the most important characteristics of the devices based on this crystal depend on them.

Most of the methods [5-7] used to control the quality of germanium crystals are contact, destructive (chemical etching, measurement of resistivity, etc.) or laborious and expensive (transmission electron microscopy, FIP, etc.). The method of active thermovision control differs favorably from the above, because due to the optical properties of germanium (the transparency range is 2-20 μm), it allows contactless obtaining information about on the defectiveness of the surface layers of the material and on uniformity throughout the volume, which reduces the number of technological Steps for the analysis of germanium samples (Figure 1 and Figure 2).

At thermovision measurements besides environment parameters (air temperature, humidity, temperature of the induced radiation), an important role is played by correctly particular emissivity which depends on material, a roughness of a surface and in a slight measure from sample temperature. However, in the modern literature there are no data on emissivity for germanium in the temperature range to 373K, which corresponds a method of the active thermovision control, or heating temperature of elements during the operation of devices on basis of germanium.
2. Features of thermovision measurements of germanium crystals

The main problem of thermal imaging of germanium crystals is the multiple reflection effect, a so-called optical resonator arises. The reflection of electromagnetic radiation from the germanium surface reaches about 36% (Figure 3), an increase in intensity occurs, and thus information about the temperature of the sample is distorted. This problem is solved either by shifting the sample into an area where the reflection from the lens of the thermal imager will not fall back on the sample, or by the creation of thermal imaging at an angle to the surface of the sample.

When measuring the emissivity, it should be taken into account the fact that germanium transparent IR radiation from the heating elements, so it is optimal to measure with the heater turned off during cooling by turning the sample with the warmest side to the thermal imaging camera.
Figure 3. Reflection of the thermal imaging camera from the germanium sample, leading to a distortion of the temperature values.

3. Preparation of germanium samples
The studies were carried out on germanium single crystals grown by the Czochralski method in the <111> direction doped with antimony (impurity concentration $1.4 \times 10^{14} \text{ cm}^{-3}$, n-type conductivity).

Surfaces of the samples were treated with grinding powders of different dimensions (grinding) and diamond pastes (polishing). Grinding was carried out with an aqueous suspension of electrocorundum powder: F200 powder on a glass substrate, F400 (intermediate grinding) on a glass substrate, powder F800 (fine grinding). Polishing of the samples was carried out in 4 stages: treatment with diamond pastes 5/3, 3/2, 2/1 and 1/0 on the felt (Figure 4). These powders and pastes are used for making optical elements from germanium.

Figure 4. A samples of germanium single crystals after treat F400(a), F800(b), polished(c) and cut (d).
Estimation of the parameters of the obtained surfaces was carried out on the optical profilometer NanoMap 1000WLI. A sample was also prepared, the surface of which was formed during the cutting of the crystal, it was not subjected to any additional processing and, because of the unevenness of the surface, was not subjected to analysis on the profilometer. The processing of the data was carried out using the SPIP program (The Scanning Probe Image Processor) (Figure 5). The surface irregularities are presented in Table 1 in accordance with ISO 25178.

![Figure 5. 3-D and 2-D profiles of surfaces of germanium single crystals after treat F400(a), F800(b), polished(c).](image)

| Table 1. Parameters of surface. |
|----------------------------------|
| Ra, nm  | Rz, nm  | Rmax, nm |
|--------|--------|---------|
| Powder F400 | 410 | 1340 | 1496 |
| Powder F800 | 206 | 850 | 960 |
| Polishing | 2.70 | 15.90 | 17.70 |
4. Experiment and results
The value of emissivity and other settings that characterize the environment was exposed on thermal imaging camera. The samples were heated, and then placed on a substrate and a thermocouple was connected to them. During the cooling, a table was made of the temperature values on the thermocouple and on the thermal imager at the points closest to each other. The results are presented in the form of graphs in the following form: the abscissa indicates the values on the thermocouple, along the ordinate the difference between the temperatures on the thermocouple and on the thermal imager (Figure 6).

![Graphs showing temperature differences](image)

**Figure 6.** Values of temperature on the thermocouple and the difference between temperature on the thermocouple and IR-camera: for a polished surface (a), for a surface treated with F800 powder (b), for a surface treated with F400 powder (c), cut surface (d).

5. Conclusions
Based on the results of the work done, we can draw conclusions:
- incorrectly set values of the emissivity for thermal imaging researchers of germanium single crystals can lead to a measurement error of temperature up to 10K or more.
- for germanium, the range of this coefficient lies in the range 0.74-0.84 for different types of surface and temperatures from 303K to 353K (Figure 7).
- the optimum temperature for IR-defectoscopy of germanium crystals is the range of 318-333K. At a lower temperature, problem occurs due to the reflection of heat radiated by the elements of the surrounding medium. At a greater temperature, cooling of the sample occurs rather quickly and it is difficult to set the correct value of the emissivity.
Figure 7. Dependence the emissivity of germanium single crystals on roughness surface and temperature.

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