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Radiation-resistant and Radiation-sensitive Sensors Based on Wide-gap Oxides

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Abstract: In order to expand the working area (50-2000 *nm*) and improve the spatial resolution of the detection system, we studied many crystals (with various impurities Cu, Fe, Ga, Ge Mg, Mn, Ni, Pb, Se, Si, Ti, V, Zn Sc and their concentrations, as well as their ratios). In the course of the work, the crystal samples were subjected to technological processing methods that made it possible to change the optical density of corundum in order to identify the mechanisms of energy transfer and the optimal use of crystals as sensors for VUV, UV, and IR radiation. As a result of the studies, those substances, their concentrations and ratios that have resonance absorption lines not only in the UV, but also in the spectral regions of the VUV were revealed. Thin sheets (50-200 *nm*) of corundum were obtained. Impurities were implanted into a thin crystal on both sides by a stream of high-energy ions of various chemical elements. We used those chemical elements that have good absorption in the radiation range of 50-2000 *nm*. Corundum fibers (0.2x0.2x2.5 *mm*) were obtained from these sheets using an ultrasonic unit, mechanical and chemical treatment. Two types of transducers were manufactured: a transducer for an integrated luminescence intensity detector and a fiber crystal matrix transducer to improve spatial resolution. The uniqueness of the work is that, based on the research, a corundum-based detector are developed and manufactured for use in a wide range of wavelengths (X-ray, VUV, UV, visible, infrared spectral ranges) using fiber optics.

Keywords: converter, fiber crystals, spatial resolution, corundum matrix, implant

1. Introduction

There are many fiber detectors based on various elements, various crystal beam technologies and fiber production technologies have been developed [1-10]. Our goal is to create a radiation-resistant and radiation-sensitive detector based on corundum. Corundum is a radiation-resistant material, has a complex of technically important properties and therefore is of particular interest both for radiation physics of a solid state and for applied purposes, for example, for the atomic and electron industry and for astronomical studies, where more sensitive receivers are required both in the UV and IR spectral regions (and radiation-resistant material). Fast particles with energies exceeding the threshold and high-temperature heat treatment can create both simplest and aggregate centers in corundum. The radiation resistance of corundum makes conversion of electronic excitations into ionic ones unlikely, which leads to purely electronic relaxation processes. This makes it possible to create radiation-resistant and radiation-sensitive sensors based on wide-gap oxides [3,4,5,9]. And therefore, impurities can be implanted into the crystal by a stream of high-energy ions of various chemical elements [11]. One of the advantages of the ion doping method is its versatility, due to which any impurity can be introduced into the crystal. One of the disadvantages of ion implantation and the method of radiation doping is the simultaneous doping with the formation in the irradiated crystals of radiation damage to the crystal lattice, which significantly changes the electro-physical properties of the material. Therefore, the necessary stage of the process in the preparation of ion-doped and radiation-doped crystals is the heat treatment (annealing) of the material after irradiation.

Annealing of the implanted layers was carried out to activate the implanted atoms, reduce the crystal structure defects formed during ion implantation and radiation doping, and ultimately, to create a region with a given distribution law of the dopant and a certain geometry.

2. Experimental part

In order to expand the working area $(50-2000nm)$ and improve the spatial resolution of the detecting system, we studied many crystals with different activators and, as a result, we selected several corundum crystals with interesting impurities (pieces 8), whose properties more or less correspond to our requirements [5].

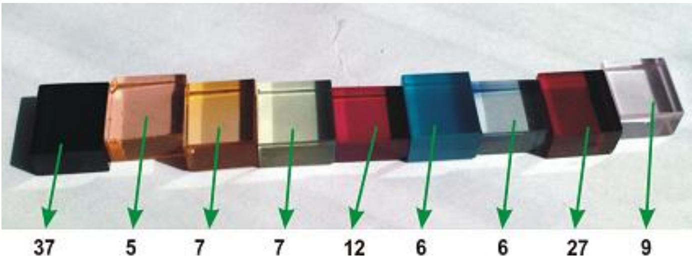


Fig. 1. The numbers below the crystals are the values of relative luminescence intensity in measured by a silicon solar cell.

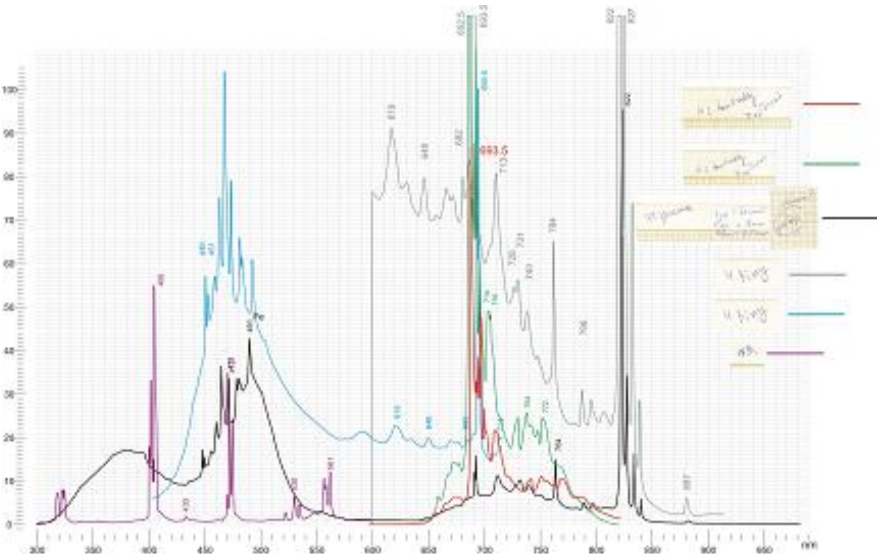


Fig. 2. The luminescence of these selected crystals.

It is possible to identify the main trends, patterns and ways of forming the necessary spectral characteristics including the methods of ion-beam implantation and thin fiber “bundles” of crystals. Spectroscopic measurements of absorption and luminescence depending on the composition of impurities and their concentrations showed that the sensitivity of the detectors (based on these crystals) increased by 30% (Figs. 3,4). All numerous measuring characteristics represent special interest for further research [4].

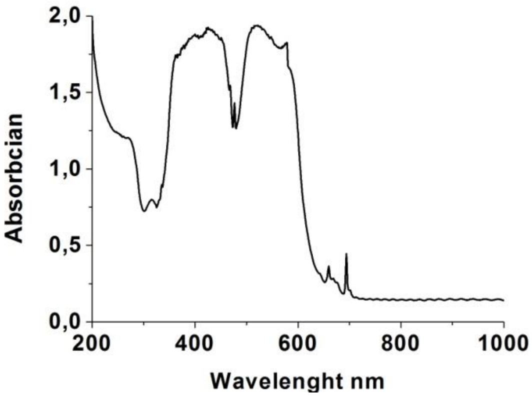


Fig. 3. Absorption crystal 27 in fig.1

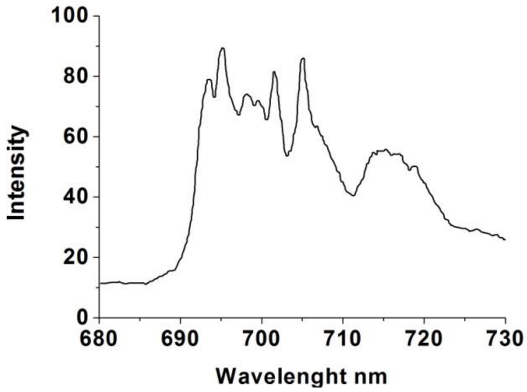


Fig. 4. Crystal intensity 27

Thin sheets $(50-2000nm)$ of corundum were obtained from these crystals and were additionally implanted into the thin crystal on both sides by a stream of high-energy ions of those elements that have resonance absorption lines in the radiation range of $50-2000nm$. These elements (lanthanum and lanthanides, scandium and etc.) have large atomic radius, they can create new excitation-photon interactions that lead to new transitions and energy conversions. Corundum fiber $(0.20\times 0.20\times 2.5mm)$ was obtained from these sheets.

When implementing our plans, the following methods, approaches and technical characteristics were used:

- comparative study of the “spectral sensitivity” of crystals and determination of their optimal compositions with an extended spectral range
- optical separation method - defect identification - concentration of bubbles in the crystal,
- annealing method for modifying the optical properties of a crystal
- *X*-ray fluorescence method for determining the elemental composition of the studied samples
- Spectroscopic method for determining absorption and luminescent spectra
- development of crystal beam technology
- development of a strapping system for crystalline fibers
- manufacture and testing of prototype detectors based on corundum in the spectral range of $50-2000nm$.

By thermal annealing, radiation exposure (the main methods for generating defects, in particular, color centers), it is possible to expand or improve these or other properties of crystals, so we decided to try to improve the characteristics of our samples by thermal annealing. Corundum samples with the same dopant concentrations and absorption properties were selected, and the process of annealing began. Annealing temperature of $500-1000^0C$ was selected [3].

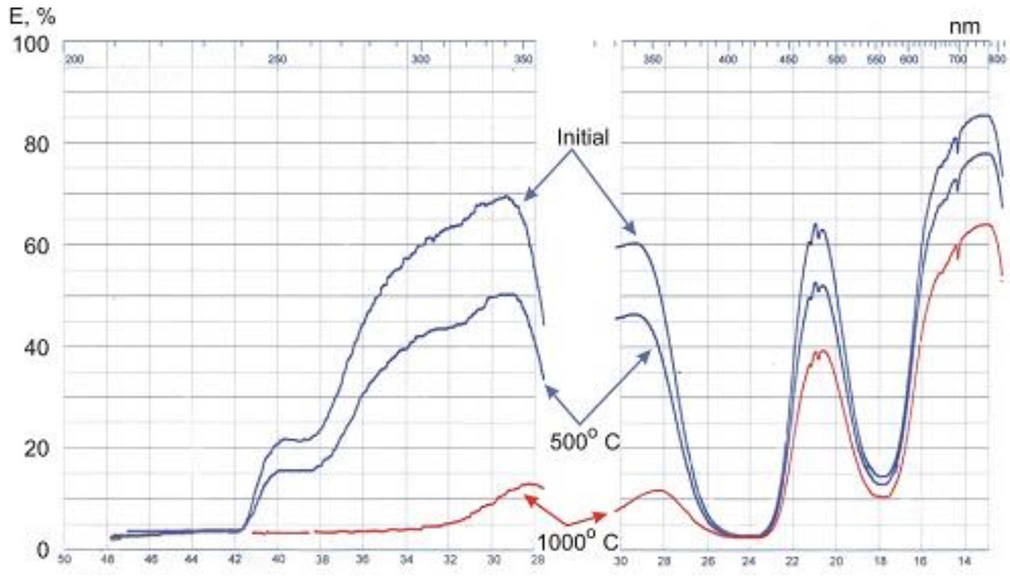


Fig. 5. UV-VIS spectrometer measurement graphs.

With increasing annealing temperature, the bandwidth begins to decrease not monotonously, therefore, there is a defect *F*; Centers of type *F* +, some of the anionic vacancies begin to annihilate or recombine (collapse), i.e. these sections of the defect are missing. Impurity defects are more stable; therefore, recharging or transferring of energy of the crystal lattice can occur, but a decrease in the absorption bands in the entire volume of the samples are observed at different speeds and kinetics (fig. 1). In any case, annealing of the selected crystals changes their optical properties. By varying the annealing parameters, one can destroy some and preserve other color centers. Usually, the longer the exposure to the operating temperature is, the more effective the refinement is, which is explained by the diffusion nature of the processes and the need for exposure to change the state of the impurities.

To modify the optical properties of the crystal, a new multifunctional annealing chamber was created to switch to the induction method of heating samples to a temperature of 1700^0C. The opportunity has been created to use a standard high-temperature device in equipment for *X*-ray studies, as camera device also allows heat treatment in various environments.

X-ray fluorescence (XRF) is the radiation of a characteristic “secondary” (or fluorescence) *X*-ray from a material that has been excited by a high-energy *X*-ray bombardment. This phenomenon is widely used for elemental analysis; it makes it possible to determine the concentration of dopand in a crystal. The measurements were performed on an AMPTEK *X*-ray fluorescence spectrometer (fig. 6,7).

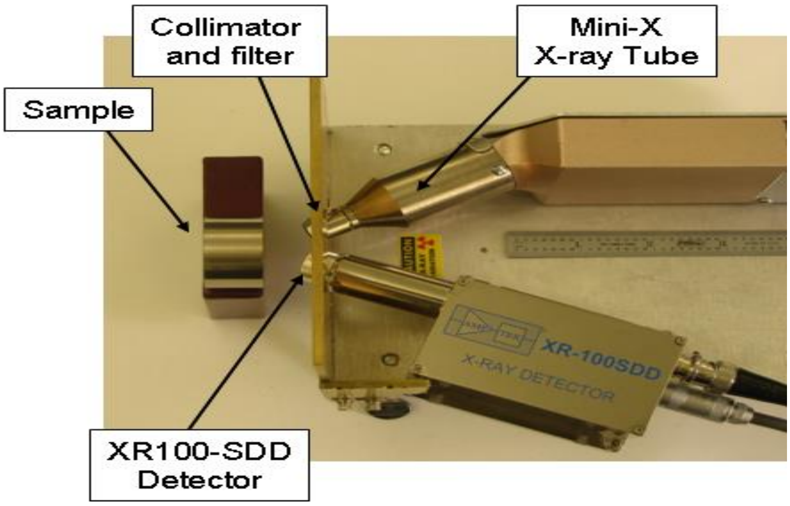


Fig. 6. X-ray fluorescent spectrometer.

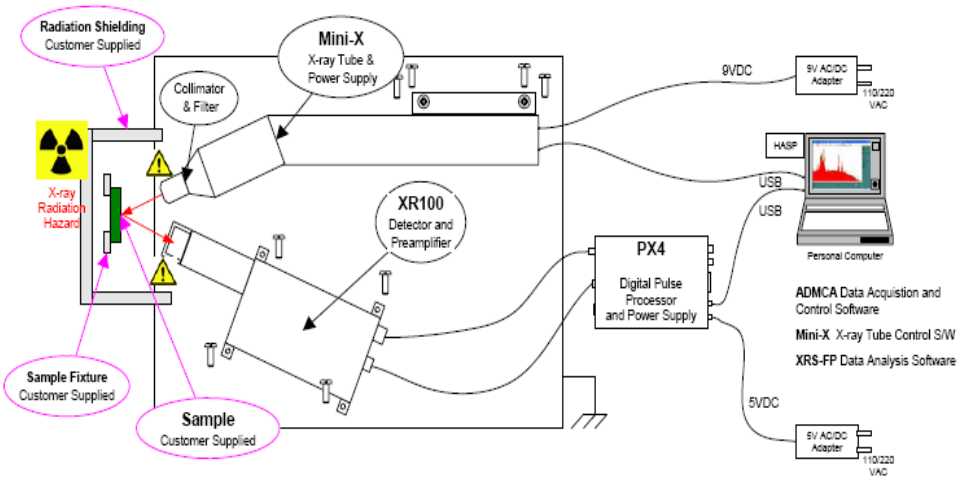


Fig. 7. Scheme and key components for the experimental setup.

Spectroscopic absorption measurements were performed on UV / VIS and M-400 and Specord UV and VUV spectrometers; luminescent ability was measured on a Perkin-Elmer Model Mpf-44B.

To expand the possibilities of experimental measurements, a multifunctional experimental setup (fig. 8) was developed and created that allows measurements of the absorption spectra and luminescence of samples, which allows to change the radiation sources, and by changing the width of the gap and passband.

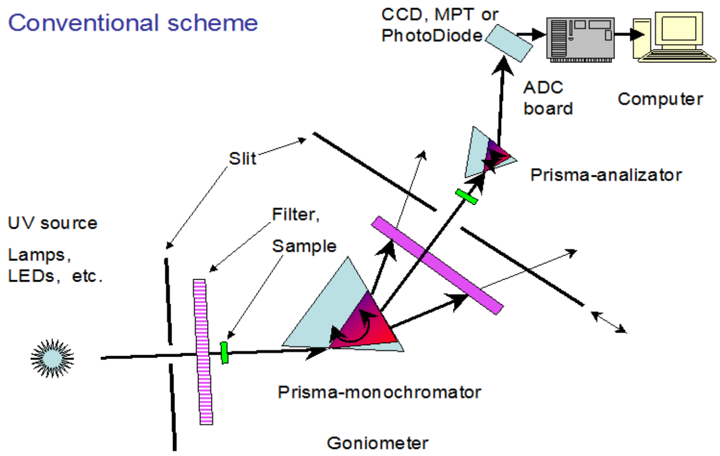


Fig. 8. Block scheme of the experimental device.

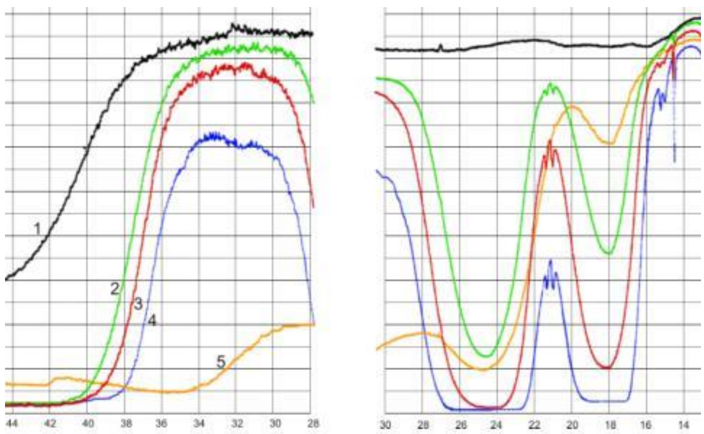


Fig. 9. Transmission curves measured by SPECORD UV VIS spectrometers

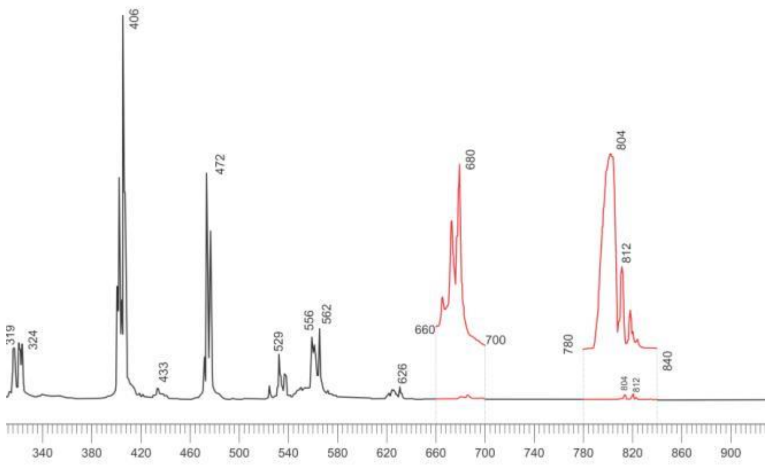
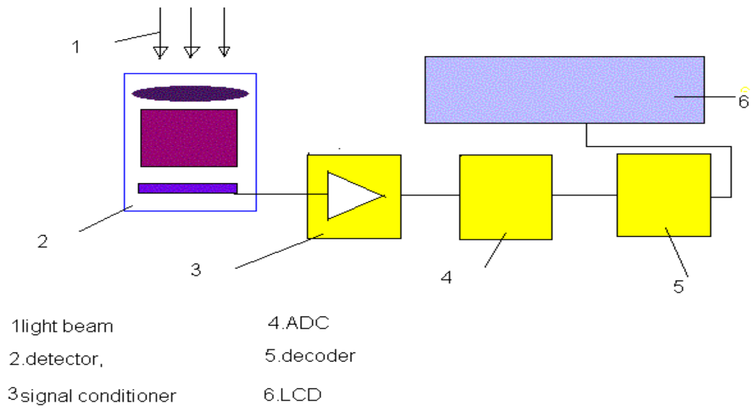


Fig. 10. At fixed frequency of the incident radiation 257 nm crystal luminescence is measured in 200-1000 nm range.

After all these studies, crystals were selected.

Two types of converters were made:
- converter for integrated luminescence intensity detector



Block diagram of the first detector

Converter

-fiber crystal converter matrix for improved spatial resolution.

Crystal beam technology was developed: To create a detector with spatial resolution (whose resolution is determined by the size of the element assembled into a mosaic), a crystal beam technology was developed. The sequence of operations is similar to FOP (fiber optic plate) or MCP (multi-channel plate) technology. The sequence of operations is described in Fig.11.

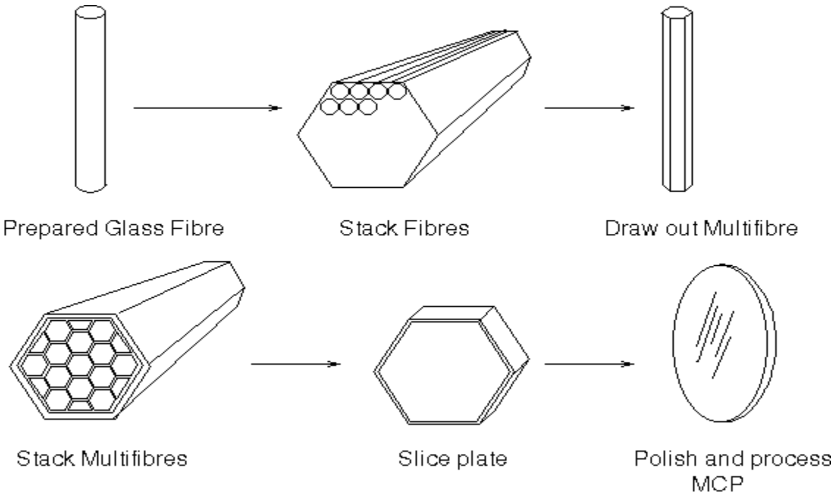


Fig. 11. The order and sequence of the operations for creation of fiber optic plates.

After one fiber element is ready, it is polished (both mechanical and chemical polishing), coated with a connecting material (nickel, copper, silver, platinum, etc.), “Binds”, cut into plates and, therefore, undergoing final processing.

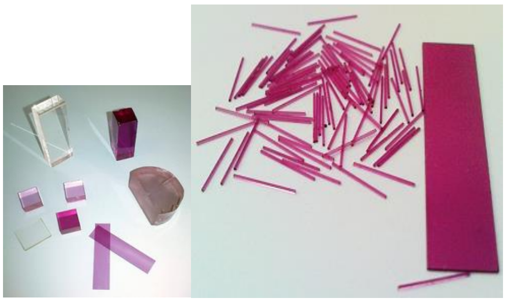


Fig.12. Pure corundum.

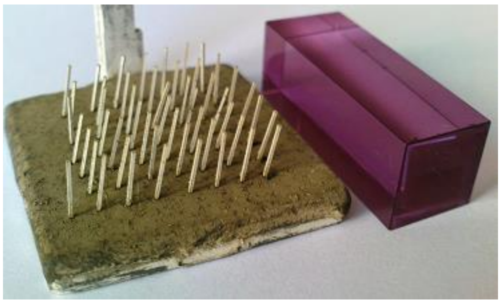


Fig.13. Corundum covered by silver

Fig.14. Pure corundum - 0.2x0.2x8.0 mm

Fig.15. Covered by silver 0.25x0.25x8.0 mm.

A “bunch” was made - a matrix of transducers from samples of corundum plates measuring $0.20\times0.20\times2.5mm$. About 100 samples were made, which made possible to assemble the matrix in the order of 6x7 and, accordingly $0.20\times0.20\times2.5mm$.

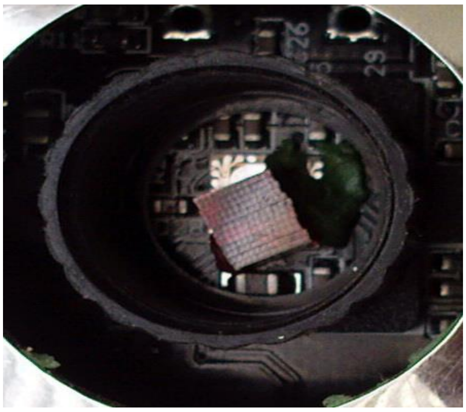


Fig. 16. Detector for imaging, where converter-mosaic from fiber crystals is located on the webcamera matrix.

3. Results

During the study, various methods were used to achieve our goal: the ion implantation method allows us to introduce any impurity into the crystal (one of the advantages of the ion doping method is its versatility, any impurity can be introduced into the crystal). A good result was recorded during annealing of the crystals. Annealing method for modifying the optical properties of the crystal, optical separation method - identification of defects - concentration of bubbles in the crystal, development of crystal beam technology, development of a strapping system for crystalline fibers, spectroscopic method for determining absorption and luminescent spectra, etc. gave us the opportunity not only to record VUV, UV and IR radiation, but also to obtain an image of the emitting object.

4. Conclusions

Single crystal samples with various dopants were studied, their optical properties were studied, and absorption and luminescence spectra were obtained. We developed a technology for producing fibers from corundum crystals of size $0.20\times0.20\times2.5mm$, assembled a matrix and obtained images. Single crystal samples with various dopants were studied, their optical properties were studied, and absorption and luminescence spectra were obtained. We developed a technology for producing fibers from corundum crystals of size $0.20\times0.20\times2.5mm$, assembled a matrix and obtained images. These measurements show that the differences between the spectra depending on the composition of the impurities and their concentrations are obvious. We can distinguish the main trends, patterns, and methods of forming the necessary spectral characteristics, including methods of ion-beam implantation and thin fiber "beams" of crystals. All the numerous measuring characteristics are of particular interest for further research, but all this work should be continued. The goal of the work is “one detector for the entire radiation region”.

Declarations

•Availability of data and material – Material data can be used freely.

• Funding – The work was done thanks to a grant (ISTC)

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