Research Square

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On the possibility of using corundum to create sensitive VUV, UV and IR detectors

J. G. Vardanyan
Institute of Applied Problems of Physics
R. Yu. Chilingaryan
Institute of Applied Problems of Physics
T. H. Sargsyan
tsargsyan380@gmail.com

Institute of Applied Problems of Physics
A. R. Mnatsakanyan
Institute of Applied Problems of Physics
J. P. Markosyan
Institute of Applied Problems of Physics
M. A. Hovhannisyan
Institute of Applied Problems of Physics

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Abstract

The energy, spectral and temporal characteristics of corundum (a-Al2O3) with various activators in different optical regions were studied. The elements that can be part of optically active crystals and those elements that can create new exciton-photon interactions leading to new transitions and energy transformation were determined. The percentage of impurities in these crystals and the percentage of this mixture at which the maximum conversion of optical radiation will occur were determined, absorption and luminescence spectra were obtained. Luminescence measurements were carried out at several constant frequencies of corundum irradiation and at different orientations of the crystal. Luminescence is the most important characteristic of crystals in the development of optical converters. The studies of these crystals led to the conclusion that corundum can be used as a photoconverter not only in the UV range, but also for creating sensitive detectors in the VUV and IR wavelength ranges. To modify the electrophysical properties of the single crystal, corundum was irradiated with accelerated ions of various elements to create active elements with precisely specified dimensions in the crystal.

1. Introduction

There are numerous detectors for registering ultraviolet (UV) and vacuum ultraviolet (VUV) radiation, based on various physical principles: charge-coupled devices (CCD), photomultiplier tubes (PMTs), hybrid photodiodes, microchannel plates, avalanche photodiodes, silicon photomultipliers, and others. Silicon-based detectors (such as PMTs) have limitations when used in open space; in particular, certain challenges arise during solar observations, where radiation flux and temperature are very high. These issues are discussed in [1]. The potential to solve these problems is the main argument for using diamond as a converter [1,2].

UV photodetectors of various types are developed based on AlGaN/GaN structures: photoconductors, Scotty photodiodes, metal–semiconductor–metal (MSM) structures, avalanche photodiodes, phototransistors, and p-n junctions [2,3]. A semiconductor AlGaN structure is fabricated and studied on a corundum substrate [4]. The quantum efficiencies for the 240–285 nm and 320–365 nm ranges are 0.53 and 0.82, respectively.

A microchannel plate (MCP) is an assembly of a large number (several million) of channel electron multipliers. MCPs can register gamma, VUV, UV, and optical radiation using the appropriate converter. The basic operating principle of an MCP is the conversion of an optical image into an electronic one. This electronic image is then transmitted to a phosphorescent screen. MCPs can only operate in a vacuum [5].

The accuracies of various fundamental studies largely depend on precise calibration and diagnostics of light intensity across different spectral regions. One needs high-performance photodetectors, as they serve as the key to accurate light radiation calibration. The most important requirements for optical sensors include compactness, sensitivity, durability, thermal and radiation resistance, and reliability. These factors depend on the properties of the corundum-based sensitive crystals employed in them.

Have been researched various photodetectors based on different detection media, including scintillation, luminescent, semiconductor, and silicon detectors, photomultipliers, semiconductors with an ultra-wide bandgap, gas detectors, diamond photodetectors, and GaN-based photodetectors. The converters used in these detectors have both advantages and disadvantages. Their radiation and thermal stability are generally low, their timing characteristics are suboptimal, and their lifespans are limited.

Optical sensors based on corundum crystals are well known and can be used under extreme conditions such as high temperatures, pressure, radiation, etc. Essentially, corundum is chemically inert and an excellent optical material. In particular, it has a high internal transmission coefficient across wavelengths from the far UV to the mid-infrared range (50 nm to 6000 nm). In the visible wavelength range, it exhibits a high refractive index (1.77), which leads to low radiation losses. Corundum is birefringent, with its refractive index depending on both the polarization and the direction of incoming light. It maintains structural integrity at temperatures up to 1600–1700°C. The use of corundum in radiation dosimetry improves the accuracy of ionizing radiation monitoring. New opportunities are emerging for using corundum as effective dosimeters for synchrotron, X-ray, VUV, UV, and IR radiation.

The aim ongoing work is to create photo converters based on a single crystal (as a matrix) taking into account the optical, radiation, thermal, temporal, and energy properties of corundum for the IR region of the spectrum with high sensitivity in addition to the UV and VUV ranges [6]. This allows to detect radiation in addition to obtaining images of the emitting object.

Overall, this work is dedicated to presenting these experimental studies and the results of corundum property research, as well as justifying their selection for the creation of various detectors. Based on the findings (8,9,10,11,12,13), we plan to develop and manufacture a family of detectors based on a single compound covering a wide range of wavelengths for use in various fields of science and technology.

2. Experimental Details

The percentage content of activation centers is determined for all available corundum crystals, and two types of luminescence detectors are developed: one with CCD matrix recording, and another based on a solar cell receiver. Absorption and transmission spectra were obtained for the dark-burgundy crystal in the infrared region. The crystal exhibits good absorption in the 500-1500 nm spectral range.

It is well known that many optical properties of crystals, including luminescence, largely depend on two factors: inclusions (dislocations) and impurities. Naturally, when developing such materials, it is crucial to accurately determine both the qualitative and quantitative composition of impurities, whose concentration in optical crystals may typically range from fractions of a percent to several percents. A key limitation of the methods used for this purpose is that these must be non-destructive.

During the experiments aimed at improving the sensitivity of the corundum-based converter and expanding its spectral range, the impurities in new corundum samples were identified, their concentrations and percentages were determined, and their spectral characteristics are studied.

Absorption spectra are obtained using a SHIMADZU UV-1800 spectrophotometer and SPEKWIN 32 software. Luminescence spectra are recorded using a modified DFS–24 spectrometer. The percentage composition of elements was determined using an "Amptek" X-ray fluorescence spectrometer.

After acquiring fluorescence intensity spectra with the ADMSA software on the X-ray fluorescence spectrometer, the relevant elements were selected, and their line intensities were converted into elemental concentrations using the XRS-FP software.

A number of corundum crystals (Figure. 2, 3, 4, 5, 6, 7) are examined for their optical properties (absorption, luminescence, etc.), as well as for the percentage of activation centers in their composition.

The analysis of experimental studies leads to a selection of a very dark-burgundy corundum crystal as the converter material. This particular crystal demonstrated the highest integral luminescence intensity in the VUV and UV [12] spectral regions. The color of the crystal is determined by its composition, which includes Cr2O#, TiO, and Fe2O3.

Table 1 presents the percentage composition of activation centers in the dark-burgundy corundum crystal. Notably, a high percentage of a given element does not necessarily mean it will dominate the absorption process; this is determined by the degree of beam conversion. For example, the chromium (Cr) content in ruby may be 0.3%, yet it provides a higher beam conversion than a concentration of 0.5%.

Table 1. Content of activation centers of dark-burgundy corundum crystal.

“Al”	“Ti”	“Cr”	“Man”	“Fe”	“Co”	‘Cu”	“Zn”
97.78322	0.021444	1.9715098	0.086921	0.005697	0.001276	0.003024	0.02662

Comparative measurements of the integral luminescence intensity of various corundum crystals are carried out. The ratio of input to output power is measured at different wavelengths. The measurement of the integral luminescence intensity is performed using a setup (see Figure. 1), where the sample served as the converter block for the detector. A laser with a pulse duration of ~100 fs and a frequency of 100 kHz at two wavelengths (400 nm and 266 nm) is used as the radiation source. Comparative measurements of the integral luminescence intensity of several corundum crystals are conducted at the RAGEA laboratory in DESY and the X-ray Optics Laboratory at CANDLE.

Prototypes (samples) of integral luminescence intensity detectors are developed and tested.

A critical criterion for certifying corundum crystals for design-related research is the determination of the presence and concentration of dopant impurities within the crystals. The presence and controlled introduction of dopants, as well as modifications to the crystal’s structural perfection (via annealing), are key factors that influence the luminescent properties of corundum crystals.

To create activation centers in corundum, the electrophysical properties of single-crystal corundum are altered through irradiation with accelerated ions of various elements (a method known as ion doping or

ion implantation) [1]. Using this technique, cobalt (Co) ions are implanted into the crystals. As a result, absorption at a wavelength of 300 nm increases by 30%. Additionally, implantation with scandium (Sc) ions leads to an increase in VUV emission intensity. As the ion energy increases, the number of radiation-induced defects (atomic displacements) within the crystal also increases. Therefore, the implantation energy is limited to ~150 keV. The doping depth does not exceed 0.5–0.7 μm, and the implantation process lasted several minutes.

However, after ion implantation, the samples should be annealed to eliminate radiation-induced defects caused by ion bombardment. This is done at temperatures ranging from 300 to 900°C for 30 minutes. The absorption and luminescence spectra of these annealed corundum crystals were obtained using optical spectrometers.

Depending on the impurity composition within the corundum crystals, the composition and number of emission lines in the luminescence spectrum change, and a redistribution of peak intensities occurs.

Analysis of experimental studies allowed us to select several crystals for the converter [Fig. 2,3,4,5,6,7].

3. Result Discussions

Figure 2,3,4,5,6 shows some of the crystals, the absorption spectra of which were measured in the IR range. All the crystals have absorption in the range of 400–1500 nm.

Crystal absorption graphs in the UV region of the spectrum were obtained. By extrapolation, it was determined that the crystal has absorption in the VUV range as well.

The extrapolation method allows for the theoretical proof that absorption extends beyond the UV region into the VUV region. Given a suitable experimental framework, these VUV absorption data can be verified empirically.

All other crystals also have absorption in the UV and VUV regions of the spectrum.

The chemical elements that make up optically active crystals have been identified, along with those that can create new exciton-photon bonds, leading to new transitions and energy transformation. The percentages of impurities in these corundum crystals have been determined, as well as the impurity concentration at which maximum conversion of ultraviolet radiation occurs. Absorption and luminescence spectra have been obtained. Luminescence measurements were carried out at different irradiation frequencies of corundum and at various crystal orientations. The maximum spectral sensitivity (quantum yield) varied over a wide range, with a tendency to shift into the vacuum ultraviolet part of the UV spectrum. Most of the crystals investigated have resonance absorption lines in the VUV, UV, and IR spectral ranges.

4. Conclusions

A comparative analysis of the experimental results and theoretical data makes it possible to conclude that:

- Research on these corundum crystals has led to the conclusion that not only corundum can be used as a photoconverter in the UV range but also it can be used fro creating sensitive detectors in the VUV and IR wavelength ranges.
- The obtained results showed that the dark burgundy crystal has the highest absorption concentration in the VUV, UV and IR radiation ranges (quantum yield ~ 1).
- Measurements show that the absorption spectra of corundum depend on the polarization of radiation.
- Studying the polarization characteristics of the receiver would provide additional information about the source and the propagation path of the radiation. This is particularly important in space research.
- Research on the temporal characteristics of luminescence radiation allows for the study of relaxation processes in the excited electron levels of impurity atoms, enabling the detection of pulse signals.
- After irradiating a corundum crystal in the low-frequency (240–250 nm) range of UV radiation, an increase in the permeability of the crystal was observed.
- This effect may be promising for creating “exit windows” when working with beams of charged particles and photons in the UV range, and it should be studied in the shorter wavelength range,

Declarations

Conflicts of Interest Disclosure

The authors declare no conflict of interest.

Declaration of Competing Interest

The authors declare that they have no known financial and other competing interests or personal relationships that could have influence the work reported in this paper.

Author Statement

The authors agree with submission of this article and that it is not published elsewhere.

Compliance with Ethical Standards

The authors confirm that all authors have read and approved the manuscript, and no ethical issues are involved.

Ethics approval and consent to participate:

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Consent to publish:

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Author Contribution

J.G.V. contributed to conceptualization, methodology, investigation, resources, writing the original draft, validation, and supervision. R.Yu.C. contributed to data curation, validation, and supervision. T.H.S. contributed to conceptualization, formal analysis, data curation, writing the original draft, and writing (review & editing). A.R.M. and J.P.M. contributed to writing (review & editing). M.A.H. contributed to formal analysis. All authors have read and approved the final manuscript.

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Data Availability Statement

Research data is available upon reasonable request to the corr. authors.

References

1. Hochedez J-F, Verwichte E, Bergonzo P, Guizard B, Mer C, Tromson D, Sacchi M, Dhez P, Hainaut O, Lemaire P, Vial J-C. Future Diamond UV Imagers for Solar Physics, *Physica Status Solidi (a)* 2000, Volume 181, Issue 1 pp. 141–149, 2000. https://doi.org/10.1002/1521-396X(200009)181:1%3C141::AID-PSSA141%3E3.0.CO;2-B., .
2. Shouleh Nikzad ME, Hoenk PJ, Grunthaner RW, Terhune, Frank J, Grunthaner R, Winzenread MM, Fattahi. Hsin-Fu Tseng, Delta-doped CCDs as stable, high-sensitivity, high-resolution UV imaging arrays, *Proceedings of SPIE*, 1994, Volume 2217, Aerial Surveillance Sensing Including Obscured and Underground Object Detection. https://doi.org/10.1117/12.179949, .
3. Mark Clampin. UV-Optical CCDs Space Telescope Science Institute, 3700 San Marhu Drive Baltimore, MD 21218, https://www.stsci.edu/stsci/meetings/space_detectors/clampin.htm, .
4. Malinowski PE, Duboz J-Y, De Moor P, Minoglou K, John J, Srivastava P, Semond F, Frayssinet E, BenMoussa A, Giordanengo B, Van Hoof C, Mertens R. EUV detectors based on AlGaN-on-Si

Schottky photodiodes, *Proceedings of SPIE*, 2011, Volume 8073, Optical Sensors 2011; and Photonic Crystal Fibers V; 807302. https://doi.org/10.1117/12.886682, .

5. Long JP, Varadaraajan S, Matthews J, Schetzina JF. UV detectors and focal plane array imagers based on AlGaN pin photodiodes. Opto-Electron Rev. 2002;0(4):251–60.
6. Graafsma H. Introduction to the Special Issue on Detectors. J Synchrotron Radiat. 2006;13(Pt 2):97–8. https://doi.org/10.1107/S0909049506004274. .
7. Monroy E, Palacios T, Hainaut O, Omnès F, Calle F, Hochedez J-F. Assessment of GaN metal-semiconductor-metal photodiodes for high-energy ultraviolet photodetection, *Applied Physics Letters*, 2002, Volume 80, Issue 17, id. 3198. https://doi.org/10.1063/1.1475362, .
8. Mkhitaryan SA, Vardanyan JG, Agadzhanyan GS, Nersisyan MN, Mnatsakanyan AR, Harutyunyan AP, Hovhannisyan MA. J Contemp Phys (Armenian Acad Sciences), 57 (3), 289–96, 10.1134/S1068337222030112.
9. Aslyan Z, Madatyan K, Vardanyan J, Tsakanov V, Mikaelyan R. Ruby based detector in UV and VUV spectral region. Brilliand Light life Mater Sci Yerevan. 2006;491–4. 10.1007/978-1-4020-5724-3_49. https://link.springer.com/chapter/.
10. Eurasian. patent 021017, 2017, https://old.eapo.org/ru/patents/reestr/patent.php?id=21017, .
11. J.Vardanyan G, Agajanyan M, Nersisyan. Corundum Detector Converter. Armen J Phys, 2019.
12. Vardanyan J*, Hovhannisyan M, Agajanyan H, Nersisyan M. Evolution Corundum Based Detector in UV and VUV Spectral Region. Phys Sci Biophys J ISSN: 2641–9165.
13. Vardanyan J*, Hovhannisyan M, Mkhitaryan C, Nersisyan M, Agajanyan H. Crystal Beam Technology with Special Resolution. Phys Sci Biophys J ISSN: 2641–9165.

Figures

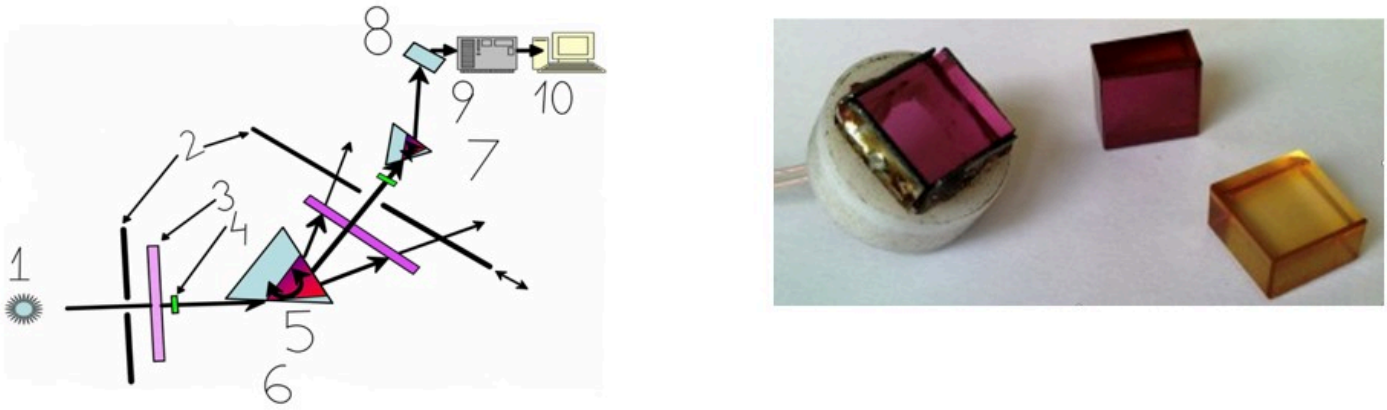


Figure 1

Schematic diagram of the setup for measuring the integral intensity of of corundum crystals: laser with a wavelength of 400 nm, power meter sample, corundum crystal.

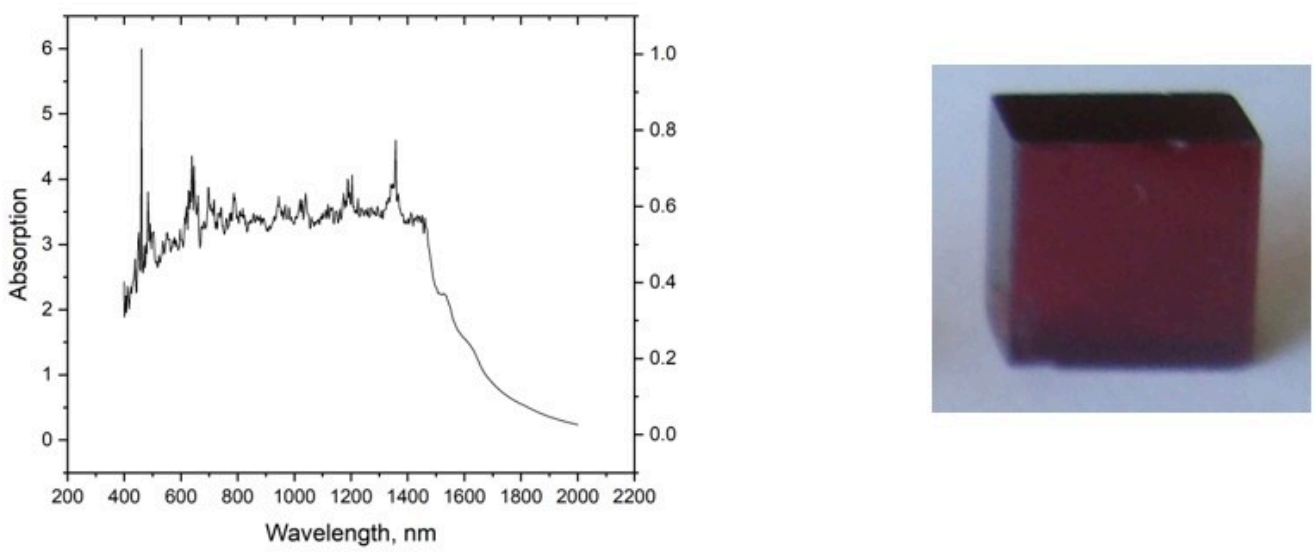


Figure 2

Absorption of a dark-burgundy corundum crystal.

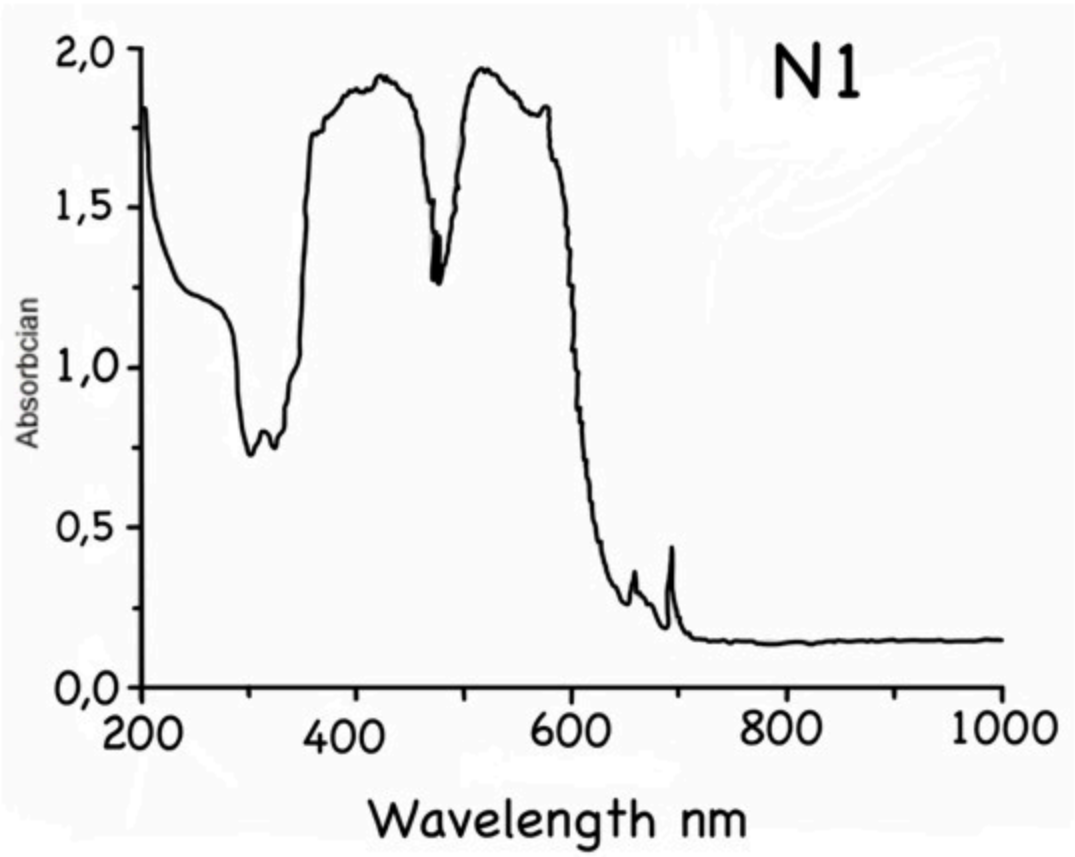
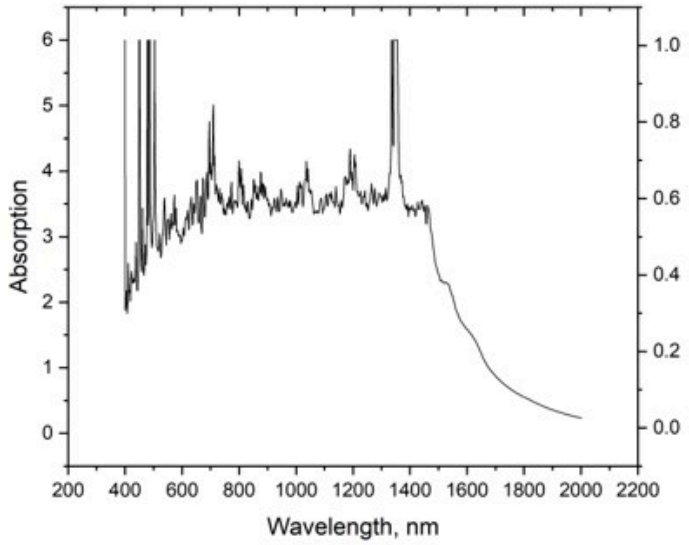


Figure 3

Figure 2/1. Absorption of a dark crystal in the UV range



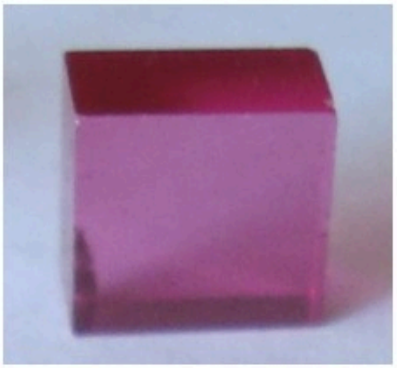
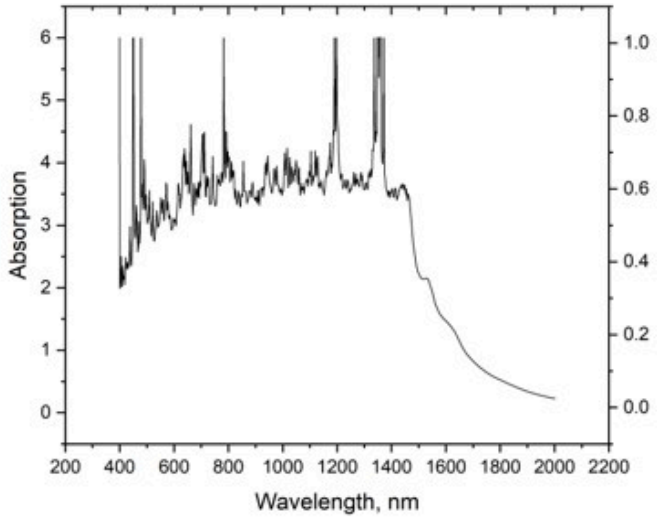


Figure 4

Figure. 3 Absorption of a red corundum crystal



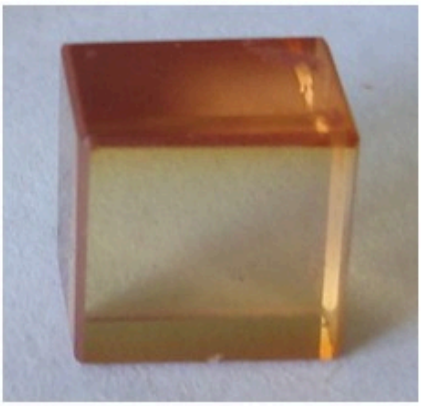
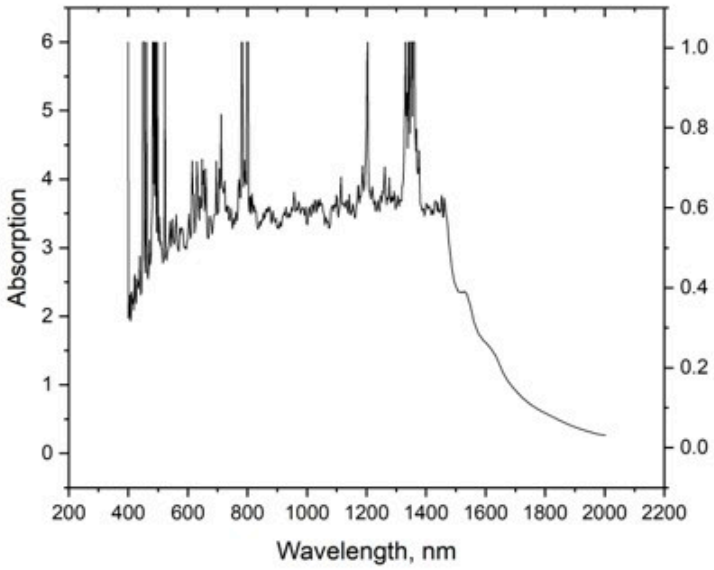


Figure 5

Figure. 4 Absorption of an orange corundum crystal



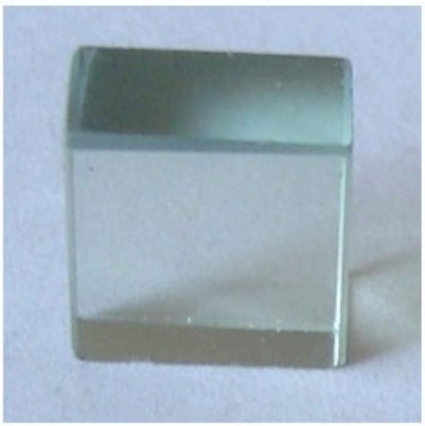
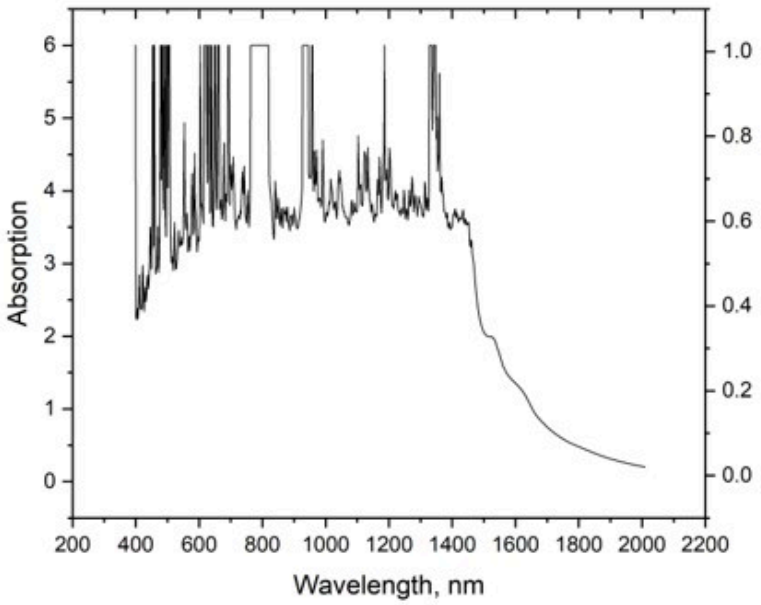


Figure 6

Figure. 5 Absorption of a green corundum crystal



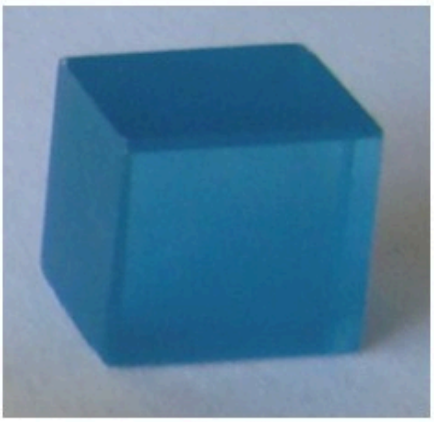


Figure 7

Figure. 6 Absorption of a blue corundum crystal

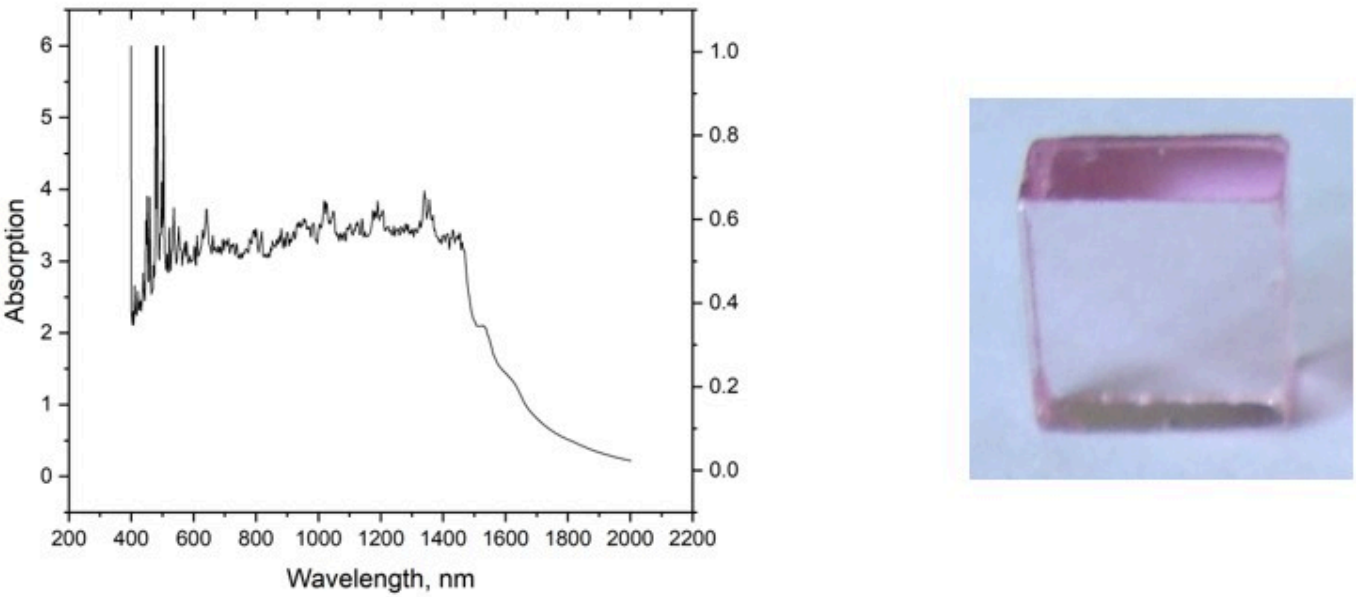


Figure 8

Figure. 7 Absorption of a light pink corundum crystal