PEROVSKITE MATERIALS AND THEIR USE IN IONIZING RADIATION DETECTION

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Perovskite materials are promising for the detection of radiation due to their unique electrical, optical, and structural properties. The article presents an overview of the main characteristics of perovskites, their structure, physical properties that determine their effectiveness as detectors, and methods for the synthesis of perovskite materials, including solution growth and the Bridgman method, which allow obtaining high-quality crystals with the required parameters. Special attention is paid to the use of perovskites as detectors of radiation, in particular their sensitivity to various types of radiation, such as X-rays, gamma radiation, and fast neutrons.

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INTRODUCTION

Perovskite is recognized as one of the most promising materials of the 21st century with a wide range of applications in renewable energy sources, energy storage and pollutant degradation due to its excellent catalytic and photovoltaic properties.

Perovskites (semiconductor materials with the structural formula ABX3) are a class of compounds that have found wide application in the fields of solar energy, quantum dots, LEDs, and, in particular, the registration of various types of ionizing radiation [1].

The first discovered perovskite is a mineral with the chemical formula $CaTiO_3$ (calcium titanate). Since then, all materials with the stoichiometric chemical formula AMX3, where X is an anion and A and M denote metal cations, that have the same or similar crystal structure to the original $CaTiO_3$ mineral, are called perovskite materials.

MATERIALS AND METHODS

Of particular interest is the use of perovskites as detectors of various types of ionizing radiation, including X-ray, gamma radiation and detection of fast neutrons. It is worth noting that the sensitivity of such materials is provided by both their structural properties and chemical composition. The mechanism of detection of fast neutrons, which is based on the interaction of neutrons with organic components of perovskites, which have a high hydrogen content. This makes them promising for the creation of new sensors for monitoring neutron radiation in various fields, including nuclear energy, medicine, applied and scientific research, and the security sector. Thus, perovskite materials offer new opportunities for the development of advanced detection technologies, which is of significant scientific and applied interest.

The ability to detect ionizing radiation was first demonstrated by the group of M. Kanatzidis in 2013, which gave a significant impetus to the development of this area of research [2]. The detector material used was $CsPbBr_3$, grown by the Bridgman method, which makes it possible to provide a large charge number Z for effective absorption of X-rays and gamma rays. The result obtained in 2013 was significantly improved in 2021, when a resolution of 1.4% was achieved for the same material at the 662 keV line of the Cs-137 isotope [3].

In 2015, Yakunin recorded X-rays from an Am-241 source with a single crystal of perovskite MAPbI3 (methylammonium-lead iodide) grown from solution by the inverse temperature crystallization (ITC) method. Growing organic-inorganic crystals from solution significantly reduces the cost (compared to the Bridgman method, which uses high-temperature furnaces) and increases the production speed [4, 5]. Another significant factor is the possibility of using organic cations, such as methylammonium or formamidinium, containing hydrogen. This opens the way to the potential use of organic-inorganic perovskite as a direct detector of fast neutrons.

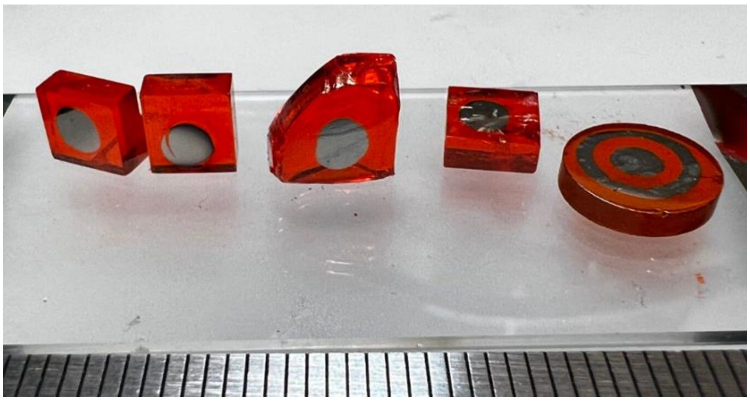

Fig. 1. Perovskite single crystals $MAPbBr_3$ grown from solution (1-4) and single crystal $CsPBr_3$ grown by the Bridgman method. The millimeter scale is given at the bottom of the image

Recent achievements include obtaining high energy resolution in gamma-ray detection using centimeter-sized mixed-cation perovskite single crystals $FACsPbBr_3$, which is close to the resolution achieved by commercial detectors made of CdTe and CdZnTe single crystals, as well as completely inorganic perovskites [6–8]. In addition, MAPbI3 crystals demonstrate the ability to detect alpha and gamma radiation [9], and the ability to select the composition of cations and halides in perovskite crystals Cs_x FA_(1-x) PbI_(3-y) Br_y improves stability [10].

Fig. 2. Perovskite single crystals of $MAPbBr_3$ grown from a DMF (dimethylformamide) solution, image from an optical microscope

CONCLUSIONS

As ongoing research continues to refine these materials and discover new compounds, organic-inorganic perovskite detectors have the potential to revolutionize the landscape of radiation detection and monitoring technologies. They have the potential to become a relatively cheap and effective solution for various applications in medical physics, national security, and scientific research.

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ПЕРОВСКІТНІ МАТЕРІАЛИ ТА ЇХ ВИКОРИСТАННЯ ДЛЯ ВИЯВЛЕННЯ ІОНІЗУЮЧОГО ВИПРОМІНЮВАННЯ

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Перовскітні матеріали є перспективними для виявлення випромінювання завдяки своїм унікальним електричним, оптичним та структурним властивостям. Представлено огляд основних характеристик перовскітів, їхньої структури, фізичних властивостей, що визначають їхню ефективність як детекторів, та методів синтезу перовскітних матеріалів, включаючи вирощування з розчину та метод Бріджмена, які дозволяють отримувати високоякісні кристали з необхідними параметрами. Особлива увага приділяється використанню перовскітів як детекторів випромінювання, зокрема їх чутливості до різних типів випромінювання, таких як рентгенівське випромінювання, гамма-випромінювання та швидкі нейтрони.