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**AUTOMATED LUMINESCENT UNIT FOR MEASURING THERMOSTIMULATED  
LUMINESCENCE OF ALKALI-HALIDE CRYSTALS**

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**Аннотация.** Создана автоматизированная люминесцентная установка по измерению термостимулированной люминесценции щелочногалогидных кристаллов. Люминесцентная установка состоит из двух каналов: спектральный и интегральный. Центральным узлом данной установки является металлический криостат с бериллиевым входным и литий-фторовыми выходными окошками. Облучение объектов и создание в них радиационных дефектов осуществляется с помощью рентгеновского аппарата РУП - 120. Интегральный канал установки позволяет в автоматическом режиме осуществлять сканирование от 95 К (температура жидкого азота) до 500 К и получение протоколов измерения термостимулированной люминесценции в программе Termo SCAN. Обработка экспериментальных данных производится с использованием программы Origin Pro. В данной работе в качестве примера описана методика сканирования спектров термостимулированной люминесценции кристаллов КВг.

**Ключевые слова:** щелочногалогидный кристалл, термостимулированная люминесценция, упругая деформация, температура, рентгеновское облучение.

**Аңдатпа.** Сілтілігалогидты кристалдарының термостимулденген люминесценциясын өлшеу бойынша автоматтандырылған люминесцентті қондырғы құрылды. Люминесцентті қондырғы екі арнадан тұрады: спектралды және интегралды. Осы қондырғының орталық торабы бериллий және литий-фтор шығатын терезелері бар металл криостат болып табылады. Объектілерді сәулелендіру және олардағы радиациялық ақаулар пайда болуы РУП-120 рентген аппараты көмегімен жүзеге асырылады. Қондырғының интегралды арнасы автоматты режимде 95 К-дан (сұйық азот температурасы) 500 К-ге дейін сканерлеуді және Termo SCAN бағдарламасында термостимулирленген люминесценцияны өлшеу хаттамаларын алуды жүзеге асыруға мүмкіндік береді. Эксперименттік деректерді өңдеу Origin Pro бағдарламасын пайдалана отырып жүргізіледі. Бұл жұмыста мысал ретінде КВг кристалдарының термостимулденген люминесценция спектрлерін сканерлеу әдістемесі сипатталған.

**Түйін сөздер:** сілтілігалогидты кристалл, термостимулденген люминесценция, серпімді деформация, температура, рентген сәулеленуі.

**Annotation.** An automated luminescent unit for measuring thermostimulated luminescence of alkali-halide crystals has been created. The luminescent installation consists of two channels: spectral and integral. The central node

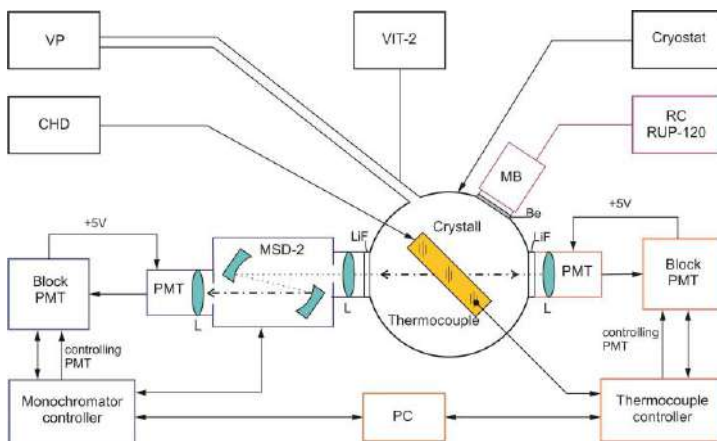
of this installation is a metal cryostat with beryllium output and lithium-fluorine output windows. Irradiation of objects and the creation of radiation defects in them is carried out using an x-ray device RUP-120. The integrated channel of the unit allows automatic scanning from 95 K (liquid nitrogen temperature) to 500 K and obtaining protocols for measuring thermostimulated luminescence in the Termo SCAN program. Experimental data is processed using the Origin Pro program. In this paper, as an example, a method for scanning the spectra of thermostimulated luminescence of KBr crystals is described.

**Key words:** alkaline halide crystal, thermostimulated luminescence, elastic deformation, temperature, x-ray irradiation.

The study of radiative relaxation of self-trapped excitons (STE) in alkali-halide crystals (AHCs) when the lattice symmetry is lowered by uniaxial deformation is possible if the following requirements for the experimental setup are met. Experimental methods should be luminescent and emission spectra of the STE must be registered at low temperatures (95 K); fluorescent installation shall provide spectra in the range of the spectrum from 6.0 to 2.0 eV; the crystals should have the cubic structure for a uniaxial strain in the crystallographic directions  $\langle 100 \rangle$  and  $\langle 110 \rangle$ , as well as cleaned from impurities, because the STE luminescence is luminescence of the crystal.

The luminescent installation can be divided into two channels. These are the spectral and integral channels for registering crystal radiation (Fig. 1). The spectral channel of the device allows registering X-ray luminescence, tunnel luminescence and thermostimulated luminescence (TSL) spectra. The integrated channel of the installation allows you to register the TSL and the total light sum of radiation. The spectral range of the installation is determined by the MSD-2 monochromator. Scanning of radiation spectra in the range of 200-800 nm was performed in automatic mode [1].

The central unit of the installation is a metal cryostat with beryllium output and lithium-fluorine output windows. The cryostat allows you to set the desired degree of deformation at 95 K in a vacuum. [2].



VP - vacuum post, CHD - cooling and heating devices, L - lens, PMT - photoelectric multiplier of the company "Hamamatsu", MSD-2 - monochromator, VIT-2 - vacuum meter, PC RUP-120 - control panel of the X-ray device, MB - monoblock, LiF - lithium-fluorine window, Be - beryllium window, PC - personal computer.

Figure 1. Flow diagram of the experimental installation

The cryostat is vacuumed by a vacuum post. The installation uses a PMT manufactured by Hamamatsu (Japan). Cooling of the crystal is achieved by pouring liquid nitrogen into the cryostat reservoir after it is evacuated to the level of  $10^{-4}$  Torr. The crystals were irradiated with the RUP-120 X-ray unit (W, 3 mA, 125 kV), which emits a hard X-ray spectrum that penetrates the entire thickness of the sample compared to the characteristic spectrum. The energy of the X-ray quantum when absorbed by the crystal is spent on the excitation of the electronic subsystem of the crystal, as a result of which high-energy electronic excitations are created in the AHC. In a very short time, they are converted into low-energy electronic excitations (excitons), the further relaxation of which ends in either the creation of radiation defects or the radiation of the crystal [3-4].

The experimental TSL method, which is an integral part of thermal activation spectroscopy, was introduced into physics by academician Lushchik C.B. [5], the order of measurement of which is as follows: the crystal is initially cooled to low temperatures (95 K) and at these fixed temperatures is irradiated for a long time with ionizing radiation (X-rays) in order to accumulate a sufficient concentration of oppositely charged radiation defects. Then the irradiation stops, and after these procedures, the crystal is heated at a constant rate to the temperature of thermal destruction of the  $F$ -centers (500 K). As a result of heating of such a crystal, as the thermal destruction of low-temperature hole centers of color ( $H_A$ ,  $V_K$ ,  $V_F$ ,  $V_{KA}$ ), their alternate delocalization occurs, followed by migration and recombination with the electronic  $F$ -center, which is accompanied by radiation of the crystal. Moreover the maximum peak of the TSL curve corresponds to the maximum breaking temperature of a specific center in a given crystal (for example,  $V_K$ -center in a crystal, KCl has a maximum TSL at 210 K).

The TSL measurement ends with a series of radiation bands whose maximum intensity corresponds to certain temperature values (Fig. 2).

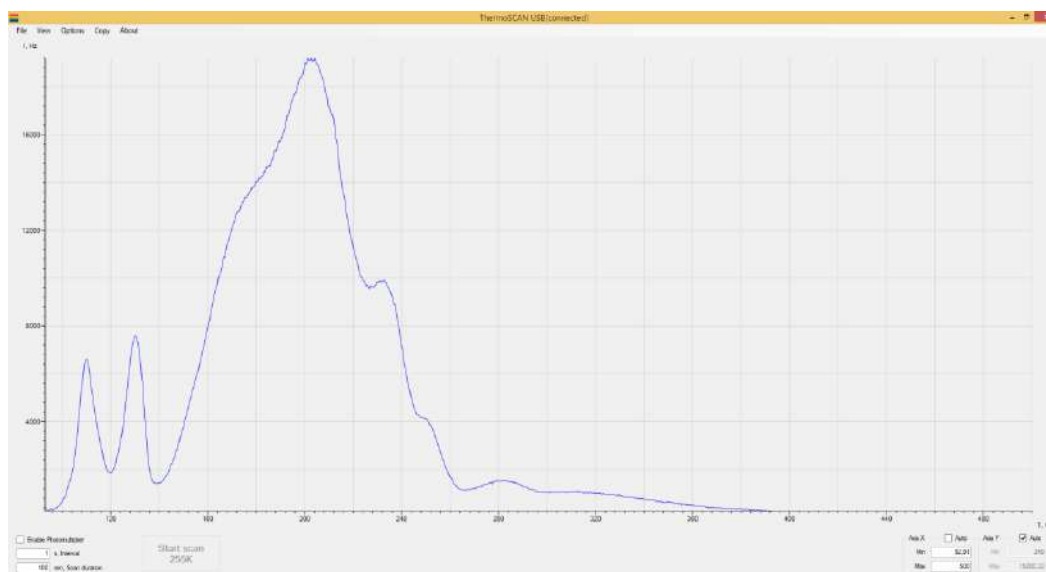


Figure 2. Graphic display area of the TSL of the KBr crystal

On the described luminescent installation, it is possible to implement a method of decomposition into spectral components in peaks of TSL of crystals in a wide temperature range (100÷400 K) during the ignition, the intensity of which changes in a narrow temperature range (5÷10 K). At the maximum peak of TSL, its maximum intensity becomes almost constant in a short time (independent of temperature), and a favorable situation is created for registering its spectrum. The maximum scanning speed of the equipment (50 nm/s) allows for a minimum temperature change (0.9 K) of the sample to register the spectrum in peaks of TSL in the range of 300 nm (for example, from 200 nm to 500 nm) for 6 seconds (Fig. 3). When the range of the recorded spectrum is narrowed to 100 nm, the scan is performed in 2 seconds, which corresponds to a change in the temperature of the crystal by 0.3 K.

It is experimentally established that the heating time of one peak of TSL of AHCs, depending on the half-width of the band at a temperature of 5 K and 10 K, is 33 and 66 seconds, respectively. During the heating of a single peak of TSL of the crystal, the equipment manages to repeatedly scan the specified range of the spectrum (from 6 to 10 times), since the scanning is performed in two directions without "dead time".

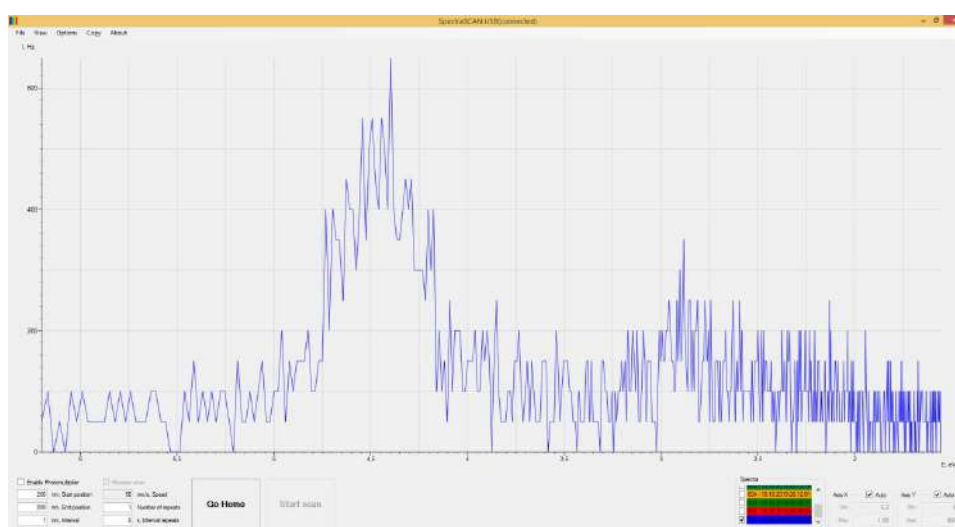


Figure 3. Graphic display area of the TSL spectrum of the KBr crystal at 110 K

According to the described method, we registered thermostimulated luminescence and TSL spectra of the KBr crystal before and after low-temperature deformation.

Thus, this paper describes a method for registering TSL and TSL AHCs spectra. TSL and the TSL spectrum of a KBr crystal under low-temperature deformation are demonstrated.

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## **МНОГОПЕРИОДИЧЕСКИЕ РЕШЕНИЯ ЛИНЕЙНЫХ СИСТЕМ С КВАЗИПЕРИОДИЧЕСКИМ ОПЕРАТОРОМ ДИФФЕРЕНЦИРОВАНИЯ**

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**Аңдатпа.** Зерттеуде квазипериодты дифференциалдау операторлы екі теңдеуден тұратын сызықты жүйе қарастырылды. Бір айнымалысы бойынша периоды, келесі айнымалысы бойынша квазипериодты және бірдей жиіліктер базисінен тұратын шешімнің бар және жалғыздығы есебін зерттеу нақты осьтің қандай да бір комплекс маңайында әрбір айнымалысы бойынша нақты аналитикалық жалғастырылатын көппериодты берілгендер бойынша анықталған жүйенің көппериодты шешімі теориясы әдісі негізінде жасалды. Айнымалылары бойынша нақты аналитикалық және квазипериодтылық және нормасы бойынша нақты осьтің маңайының енінен тәуелді шамамен жоғарыдан шектелген бағалау қасиеттері бар жалғыз шешімнің бар болуының жеткілікті шарты алынды. Берілген есепті сындық емес, сындық жағдайларда да шешуде қолданылатын жаңа зерттеу әдісі ұсынылды.

**Түйін сөздер.** Квазипериодическое решение, оператор дифференцирования, функция Грина, вещественно аналитическая функция, критический и некритический случаи.

**Аннотация.** В исследовании рассматривалась линейная система двух уравнений с квазипериодическим оператором дифференцирования. Исследование задачи существования и единственности решений периодических по одной переменной и квазипериодических по другой переменной с тем же частотным базисом разработана на основе методов теории многопериодических решений системы с многопериодическими входными данными, вещественно-аналитично продолжимыми по каждой переменной на некоторую комплексную окрестность действительной оси. Установлены достаточные условия существования единственного решения, обладающего свойствами вещественно-аналитичности и квазипериодичности по переменным и оценкой по норме сверху величиной, зависящей от ширины окрестности действительной оси.