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On the Possibility to Measure Solar Ultraviolet Emission using the Thermo Luminescence of Specific Crystals

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Abstract — A search for crystals capable to produce thermoluminescent glow curves after irradiation with ultraviolet (UV) light has been conducted. It has been found that ruthenium-doped crystal of $Bi_4Ge_3O_{12}$ (BGO:Ru) posseses suitable properties such as: long enough fading, good sensitivity towards UV emission, and hence could be a good candidate for direct measurement of the solar UV emission. A portable device for measuring the total and the UV solar light emission has been constructed in order to obtain quantitative values about the total and the partial UV energy absorbed by the crystals. Quantitative values for the principle thermoluminescent glow curves of BGO:Ru have been obtained for diurnal direct solar irradiation. It has been demonstrated that the intensity of the TL glow-curve peaks for exposures made at equal daytime intervals changes according Beer's law for the attenuation of UV in the Earth's atmosphere.

Keywords: Thermoluminescence, solar ultraviolet emission, actinometer, glow curve analysis

I. INTRODUCTION

Thermally stimulated luminescence (thermoluminescence) of exposed to radiation crystals is very interesting in view of possible practical applications. It is largely exploited at present in many applications: in dosimetry; in nuclear medicine; in environmental studies; in archaeology, etc [1-5]. Thermoluminescence (TL) emission of some crystals is caused also after irradiation with photons with "softer" than the X-rays' and gamma-rays' energy, say with the ultraviolet (UV) and even visible light [6, 7]. The latter brought us to an idea of a simple control of the diurnal ultraviolet solar emission. In this article we present some results from the search for appropriate crystals sensible to the UV light emission and to make use of their thermoluminescence in order to obtain quantitative values for the direct solar UV emission traversed Earth's atmosphere.

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II. SEARCH FOR APPROPRIATE CRYSTALS SENSIBLE TOTHE UV EMISSION

We have analyzed sets of crystals known to have a relatively high-statistics glow thermo-luminescent glow curves: crystals of Bi4Ge3O12 (referred to as BGO); crystals of Bi4Ge3O12 doped with Ru (BGO:Ru); crystals of Bi4Ge3O12 doped with V (BGO:V); crystals of Bi4Ge3O12 doped with Mo (BGO:Mo) and a crystal of Gd2SiO5 doped with Ce (GSO:Ce). ALl BGO crystals have been synthesized in the Institute of Solid State Physics, Bulgarian Academy of Sciences, with an automatic diameter-weight control system using the Czochralski technique. The GSO crystal was take from a scintillation part of a medical equipment for gamma-rays imaging (Hitachi Chemical Co.,Ltd). To obtain the physical parameters of the crystals we have used our thermoluminescence measuring setup developed for precise TL measurements on the basis of the accurately regulated linearly increase of the sample temperature up to 5000C [8]. The analysis of the glow-curves has been carried out using a computerized glow curve deconvolution method. A single peak of the TL spectrum is fitted by a general order kinetics formula described by the equation [9]:

$$I(T) = I_m b^{\frac{b}{b-1}} \exp\left[\frac{E}{kT}\cdot\frac{T-T_m}{T_m}\right]\cdot\left[(b-1)(1-\Delta)\frac{T^2}{T_m^2}\exp\left[\frac{E}{kT}\cdot\frac{T-T_m}{T_m}\right]+Z_m\right]^{-\frac{b}{b-1}} \tag{1}$$

where I(T) is the glow-peak intensity, I_m is the maximum glow-curve intensity, E (in electron-volts, eV) is the activation energy, k is the Boltzmann constant, T is the temperature (expressed in Kelvin degrees, K), T_m is the value of the temperature at the peak maximum (in K), $\Delta = 2kT/E$ and $\Delta_m = 2kT_m/E$, $Z_m = 1+(b-1)/\Delta_m$. In this formula the parameter b is the so-called kinetic order.

When the glow peak is a composite peak, compounded of m overlapping glow peaks, the method consists of a minimization of the χ^2-function

$$\chi^2 = \sum_{i=1}^{n}\left(I_i - \sum_{j=1}^{m} I_j(T_i)\right)^2 \tag{2}$$

where I_i are the measured glow-curve intensity values, $I_j(T_i)$ are the values of each partial glow curve at the temperature T_i, n is the number of the experimental points and m is the number of the partial glow peaks compounding the observed peak.

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For the analyses of the TL glow curves we used a multi-component glow-curve deconvolution program GCFIT implementing multivariate conjugated-gradients algorithm developed at the Laboratory for nuclear physics and radioecology at the University of Shumen "K. Preslavsky" [8]. From the set of crystals we have revealed that the crystal of BGO:Ru and BGO:V as well as the GSO crystal have a good sensitivity to the UV light.

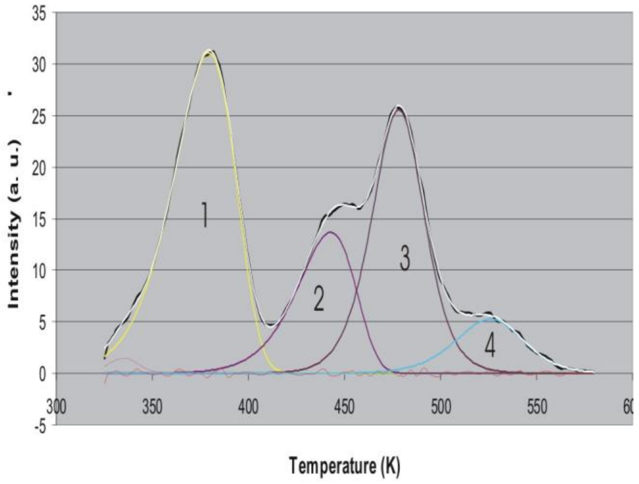

Fig. 1 Glow curve of BGO:Ru

However the fading measured for the GSO crystal showed very short values which would inevitably introduce large errors in further quantitative measurements. On the other hand the BGO:V crystal was found to be sensible to the visible light as well and its eventual use would require employment of filters to cut the interfering visible light. It turned out that the BGO:Ru possessed the most appropriate properties such as long enough fading, good sensitivity towards UV emission, and it could be a good candidate for direct measurement of the solar UV. The glow curve of the BGO:Ru crystal obtained immediately after 5 minutes of irradiation with XBO lamp (no annealing) is shown in Fig 1. The temperature rate of TL reader was kept at 0,6 *deg/s*. In the figure the fitted experimental data are in black, the fit is in white and the deconvoluted peaks are numbered.

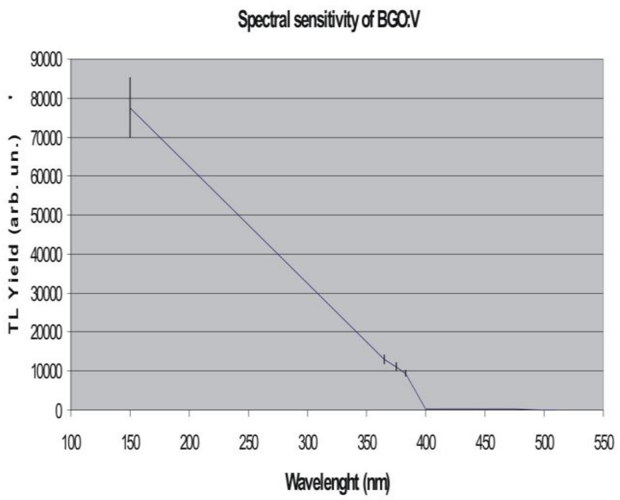

Fig. 2 Spectral sensitivity of BGO:Ru

A diagram about the spectral sensitivity of BGO:Ru is shown in Fig. 2. From the diagram it is clearly seen that the crystal has a good sensitivity to the UV light up to 380nm and does not show sensitivity to the visible light which in turn means that the crystal could be used for direct solar exposure (no filters in front). The surface area dependence on the time of storage in dark at constant temperature of 20^0C (the fading) is shown in Fig. 3. It is seen that peaks II and III are well preserved at least up to a week.

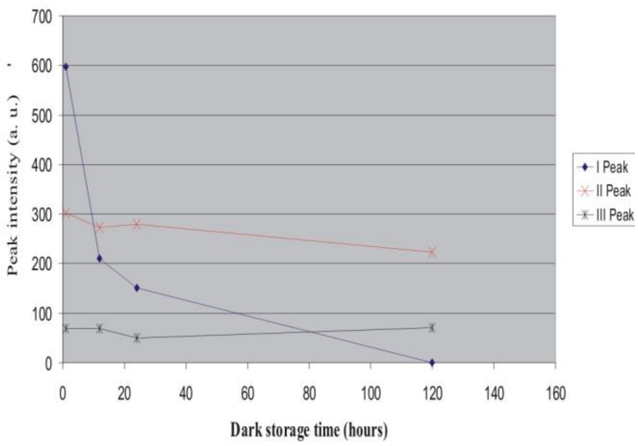

Fig. 3 Fading of BGO:Ru

III. A SETUP FOR MEASURING THE SOLAR LIGHT EMISSION

To measure the solar UV emission we have developed and realized a portable experimental setup shown in Fig. 4. It has compartments for crystal deposition and an electronic sensor, connected to a portable computer to measure the total visible light emitted during the measurement. The latter is used in order to normalize the UV light collected by the crystals during the measurement versus the total solar energy during the measurement. In such a case, since the time of the crystal irradiation takes about 5 to 10 minutes, corrections can be made for the random changes in the solar light intensity caused by eventual clouds appeared during the measurement. The device consists of three tubes T_1, T_2 and T_3. The internal walls of the tubes are painted black in order to avoid light reflections and to change the total amount of light collected by the crystals in T_1 and T_3 and by the LVC sensor in T_2.

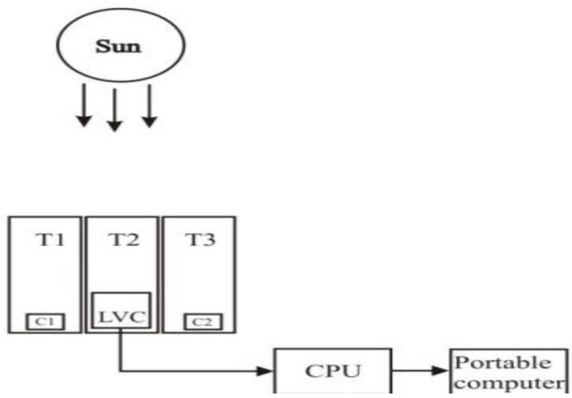

Fig.4. Block-diagram of the experimental setup

The sensor LVC is based on TLS257 photodiode, which has a high sensitivity to the full visible light spectrum and converts the light into a bias voltage in the interval from 0 to 5V. The sensor output is connected to the analog-to-digital device (ADC) in the CPU block in Fig. 4.

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Then the signal is recorded as dependence of the bias versus the time of measure and is transmitted to a portable computer. To transmit the recorded signal a RS 232 interface is incorporated in the CPU block as well, since as a rule such an interface is not incorporated in the great part of the commercially available portable computers. The whole measuring system (the actinometer) is compact and lightweight and together with the portable computer could be used to conduct remote-spots open-air solar-intensity measurements.

IV. MEASUREMENTS OF THE UV SOLAR EMISSION

We have already shown that the BGO:Ru crystal is sensible to the UV emission. Our further intention was to certify whether the crystal could be successfully applied as a UV sensor towards the solar light emission, and in particular whether it could "feel" the differences in the intensity caused by the attenuation of the UV light passing through the atmosphere. As it is seen from Fig. 5 the thickness of the atmosphere layer traversed by the light is d/cos(θ), where θ is the angle between the position of the Sun in its highest diurnal elevation point (zenith) and the particular position at the moment of measurement.

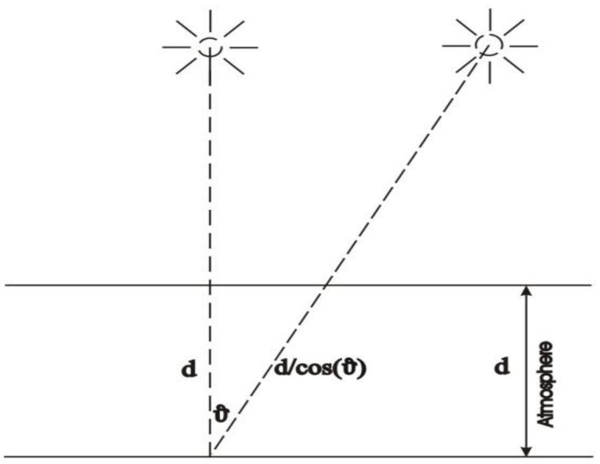

Fig. 5. Angular dependence of the atmospheric layer thickness passed by the solar light

Following Beer's law for the attenuation of the light passing a media with some thickness x, it would be expected that the intensity of the UV light I at the Earth surface is

$$I = I_0 \exp(-\alpha x)\,, \tag{3}$$

where I_0 is the initial light intensity just before entering the atmosphere and α is a linear attenuation coefficient. Substituting x in (3) with d/cos(θ) after simple transformations the following formula can be deduced:

Fig. 6 and 7 represent the (ln(S), 1/cos(θ) plots from the normalized peak areas of peak I and peak II for BGO:Ru. It can be concluded from the same figures that the experimental points are fairly linear with both linear correlation coefficients close to 1.

$$\ln(I) = A\left(\frac{1}{\cos(\vartheta)}\right) + B\,, \tag{4}$$

where A and B are constants. Since in our case the intensity of the UV light is directly proportional to the intensity of the glow curve and respectively to the peak areas there, the relation (4) could be transformed in:

$$\ln(S_i) = A_i\left(\frac{1}{\cos(\vartheta)}\right) + B_i\,, \tag{5}$$

where S_i is the peak area of the *i*-th peak obtained from the deconvolution procedure and A_i and B_i are constants. From equation (5) it follows that a linear dependence between the logarithm of the peak area and 1/cos(θ) exists.

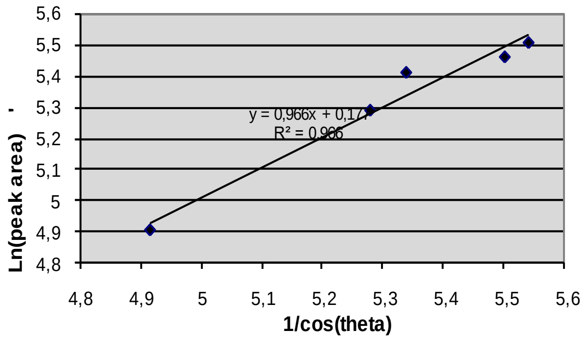

Fig. 6. (ln(S), 1/cos(θ)) dependence measured from the first peak in the glow curve of BGO:Ru

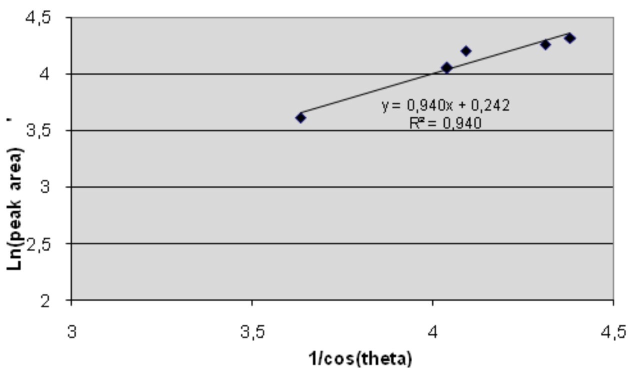

Fig. 7. (ln(S), 1/cos(θ)) dependence measured from the second peak in the glow curve of BGO:Ru

Measurements of the solar emission were conducted during two measuring days: on 2nd July 2008 and on 13th August 2008. The irradiation time of the crystal for the first measuring day was 5 minutes and for the second one – two (3)
minutes. Glow curves have been obtained immediately after each measurement without annealing. The values for the glow curve peaks areas obtained from the deconvolution procedure of the data from 13th August 2008 are given in Table 1.

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Table 1. Normalized values of the glow-curve peaks of BGO_Ru

Time of measurement (h)	Normalized peak areas (arb. un.)	
	Peak I	Peak II
9	136.35	37.87
11	208.26	59.74
13	254.96	79.81
15	245.12	74.56
16.5	196.22	56.81

V. CONCLUSION

Measurements for the UV emission of the Sun conducted with the crystal of BGO:Ru show that the crystal is sensible enough to the UV emission. Moreover, since it has been shown [8] that the crystal does not change (deteriorate) its thermoluminescence parameters with the number of annealing procedures it could be used for diurnal quantitative control of that emission. The actinometer built initially as an auxiliary device turns out to be a very useful tool also with respect to the future measurements for the total diurnal solar energy emitted. Its connection with a portable computer and the possibility to register also the prompt solar intensity makes this device very valuable for our future measurements. One very important conclusion is that the whole device could be used for some other applications such as measuring the optical thickness of the aerosol layer in the atmosphere, the penetration depth of the solar UV emission in lakes and rivers, etc.

ACKNOWLEDGMENT

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