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Analysis of Electrical Response of Conventional Graphite Rod at UV Radiation

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Abstract—**UV radiation causes harmful effects on living beings and outdoor materials alike. To detect UV light different strategies were investigated and applied. One of them is the use of photoelectric systems, which take advantage of the possibility of semiconductive materials to produce electrical current under different sources of radiation, including UV. The study's main objective was to assess the possibility of using graphite as a UV light detector. To achieve the objective two materials with different concentrations of graphite were exposed to a UV source and the photovoltaic effect was measured. Under UV light the electrical current with an amplitude of 149 and 187 mV was produced. FFT evidenced that the frequencies of the obtained signals were near 20 and 40 Hz. The results suggest that graphite materials can be used for photoelectrical systems for UV light detection.**

Index Terms—**UV radiation, current production.**

I. INTRODUCTION

Graphite, an allotrope of carbon, is prominent in both scientific and industrial realms due to its distinctive abundance, unique structure, and diverse applications [1]. Abundantly found in nature, graphite is primarily sourced from metamorphic rocks and acts as a fundamental carbon reservoir. Its layered hexagonal structure consists of planar sheets of carbon atoms densely packed in a two-dimensional honeycomb lattice. The weak π-π interactions between these layers give graphite its characteristic lubricity and cleavage, allowing individual layers to slide past each other easily [2].

Due to its abundance and unique properties like semiconductor nature, high thermal conductivity, and relative chemical stability, graphite is used in different areas. Some of them are common, such as pencils, for example, and some are elaborate and more specific, like energy storage, as an anode in alkaline batteries, and thermo-isolation, as a part of polymeric composites [3,4]. The last one was the object of extensive studies, including its damage by sunlight radiation.

Han et al. have simulated a low earth orbit space environment and investigated its effects on epoxy composites doped with graphite [5]. Particular emphasis was placed on the effects of UV radiation combined with other factors. It was shown that the synergistic effects of the factors cause significant and potentially dangerous changes in the properties of the composites. In another study, the impact of solar radiation on graphite polystyrene was assessed [6]. Similarly, to Han´s work, significant damage to the composite was observed. Both studies report damage caused by UV radiation on graphite mixtures, however, the observed effects can´t be extrapolated to graphite nor the direct quantification of received UV radiation was performed.

To date, there are different approaches to detecting UV light, which can be classified into photochromic and photoelectric systems [7]. The last one is based on the fact that semiconductive materials convert UV radiation into an electrical output due to the changes in their band gap values. Different semiconductive materials were used to this purpose: ZnO [8], TiO_2 [9], Zn_2SnO_4 [10], etc. Carbon nanomaterials such as graphene and carbon nanotubes also were used in photoelectric UV detection systems with encouraging results [11, 12]. Although the semiconductive materials mentioned above presented acceptable capacity to detect UV radiation, their synthesis can by time and resource consuming, which may impede their practical application. On the other hand, graphite is abundant in nature and do not require additional chemical treatment, nevertheless, its use in photoelectric systems was not reported previously.

In the present work, we describe a novel approach to detect UV radiation using changes in electrical current produced in the graphite, which can be detected by a simple electrical system. Additionally, we provide the analysis of the resulting electrical signal in order to understand the underlying process.

II. MATERIALS AND METHODS

Graphite. Hexagons-shaped tablets were made from the three graphite rods (84%, and 93% of graphite, LYRA, Germany). The surface of the tablets was smoothed to a mirror-like appearance by sanding.

Experimental procedure. Each graphite sample was placed into the UV-light chamber (365 nm, 68 W) and directly connected to an oscilloscope (GW Instek, USA). The data was recorded at a 0.01 s sampling interval for 10 seconds. After this period of time, the UV-light source was turned on and the oscilloscope data was recorded for 10 seconds. The procedure was performed 3 times for each graphite sample separately.

Data analysis. Each data set was divided into two zones: before UV and during UV, and each one was analyzed separately. As the first step, the Kolmogorov-Smirnov test was performed. Each dataset evidenced a normal distribution, so, the data was presented as mean ± SD. Average of maximum and minimum voltages were obtained for each signal and peak-peak voltage (Vp-p) was determined. Root mean square (RMS) of electrical signal during UV exposure was obtained from the formula (1):

$$RMS = \frac{1}{2*\sqrt{2}} \times Vp - p. \tag{1}$$

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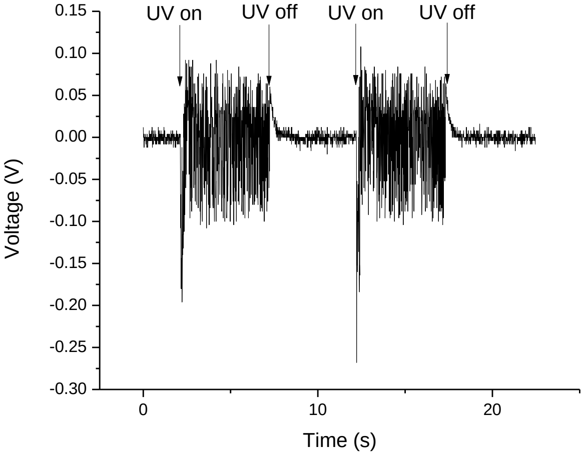

Fig. 1. Typical electrical trace obtained with and without UV radiation of the graphite material (arrows indicate when the UV lamp was turned on and off)

TABLE I
DATA FORM THE ANALYSIS OF VOLTAGE CHANGES FOR THE STUDIED MATERIALS

		84% of graphite			94% of graphite		
	# of sample	Max (mV)	Min (mV)	Vp-p (mV)	Max (mV)	Min (mV)	Vp-p (mV)
Without UV light	1	16	-12	28	2	-4	6
	2	8	-12	20	12	-12	24
	3	12	-12	24	8	-12	20
	Mean ± SD	12 ± 4	-12	24 ± 4	7 ± 5	-9 ± 5	17 ± 9
	RMS (mV)			8.5			6
UV light	1	72	-80	152	92	-100	192
	2	64	-76	140	84	-88	172
	3	72	-84	156	84	-112	196
	Mean ± SD	69 ± 5	-80 ± 4	149 ± 8	87 ± 5	-100 ± 12	187 ± 13
	RMS (mV)			57			66

FFT spectra were obtained for each set of data using Python software.

III. RESULTS AND DISCUSSION

The present study aims to introduce the possibility of detecting UV radiation by means of current production in semiconductive materials. Graphite is a semiconductive material with a relatively low band gap [13]. It is possible that interlayer electrons may acquire movement due to applied external energy, such as UV radiation, resulting in electrical current production, detectable by modern electronics. In order to prove the concept, we used 2 graphite materials exposed separately to UV radiation and detected changes in electrical current by oscilloscope.

Figure 1 shows a typical signal obtained for the material with 93% of graphite during two consecutive cycles of UV light on/off. It can be observed that before UV light was turned on, oscilloscope record the usual noise of electric system (approximately 20 mV peak-peak amplitude). At first second of the UV light prominent peaks of 200-250 mV can be observed. In preliminary experiment it was confirmed that observed changes were not produced by the line noise. The UV light source used in this study was of the fluorescent nature, so, it is possible that initial flickering of the lamp causes rapid electron movement in the graphite, causing strong voltage change. After that brief transition period, the UV light is steady and a production of the current with the stable amplitude can be observed. It worth mentioning that the same behavior was observed for 84% graphite samples, which indicates that the graphite material shouldn´t be 100% pure and 84% is sufficient to produce the visible changes in electrical voltage.

Data form the experiments was processed in order to obtain in depth understanding of the voltage changes caused by graphite under UV radiation. Table 1 shows the voltage changes with and without UV radiation. It can be observed that in all cases the static noise before UV radiation did not exceed 24 mv peak-peak amplitude. RMS of the noise produced by oscilloscope is of 6-8 mV, approximately. This value is a somewhat greater than the commonly reported values of 1-5 mV [14], probably, due to internal differences of the equipment.

During UV radiation, the electrical current appears, probably due to oscillation of the electrodes in the graphite caused by energy provided by the light. UV lamp energy can be calculated from the Planck-Einstein equation as follows:

$$E = \frac{h \times c}{\lambda}, \qquad (2)$$

there h is the Planck constant ($4*10^{-15}$ eV*s), c is speed of light ($3*10^{8}$ m/s), and λ is wavelength.

Since wavelength of the UV source was 365 nm, the equation is solved as:

$$E = \frac{4 \times 10^{-15} \times 3 \times 10^{8}}{365 \times 10^{-9}} = 3.3eV.$$

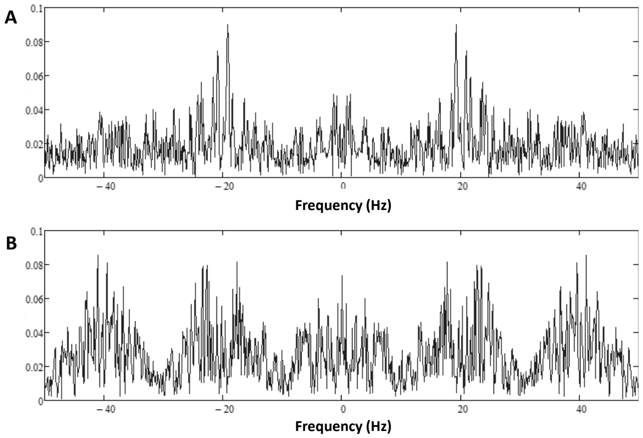

Fig. 2. FFT spectra of the signals during UV light obtained for A) 84% and B) 94% of graphite

The reported band gap of graphite varies from study to study, but it is the general agreement that semiconductive materials such as graphite, band gap is 1-2 eV, approximately [15]. Thus 3.3 eV energy provided by UV lamp is sufficient to cause the displacement of the electrodes inside the materials from valence to conductive band, which is registered as voltage variations by oscilloscope.

From the table 1 it also can be observed that RMS of the observed electrical current depend on graphite concentration in the sample: 57 mV and 66 mV for 84 and 94% of graphite, respectively. Graphite is the only semiconductive component in the used rods, since clay and wax are insulators [16,17], so, the larger sinus amplitude can be explained by the higher number of electrons which are transgressing the materials´ bandgap. However, more detailed study should be performed in order to establish clear correlation between graphite concentration and the output voltage amplitude.

FFT was performed for better understanding of the produced electrical current. As it was mentioned earlier, without UV radiation a small-amplitude signal appears due to intrinsic noise of the system. For that reason, FFT analysis of the initial signal did not evidence any characteristic frequency, and therefore FFT graphs for the signals before UV-light were not shown. Figure 2 presents the FFT spectra obtained during UV radiation of both materials.

Signals from both materials present strong peaks at frequencies near 20 Hz and 40 Hz, however, the presence of other frequencies indicates that more than one underlying process may take place in the material. The power energy of the signal obtained for 94% of graphite is than the one obtained for 84%. This fact supports the claim that the electrical response to UV light depends on the graphite concentration in the material. The more extensive study should be performed in order to confirm dose dependent appearance of electrical current and to explain in detail its origin.

IV. CONCLUSIONS

Graphite is a viable option to be used in photoelectric systems, because under UV radiation, it produces an electrical current with amplitude greater than 100 mV at frequencies near 20 and 40 Hz. The behavior seems to positively correlate with the graphite concentration in the material.

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DATA AVAILABILITY STATEMENT

Data will be made available on reasonable request.

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