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COMPARATIVE TESTS OF TEMPERATURE EFFECTS ON THE PERFORMANCE OF GaN AND SiC PHOTODIODES

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Abstract

The paper presents a study of the performance of some selected UV detectors. Unlike many similar works, the obtained data refer to commercial photodiodes (not only to detector materials). The main task of the research was to determine the influence of the operating temperature and annealing on the detector spectral responsiveness. A comparison of the results obtained for the photodiodes made of GaN and SiC was also performed. Although both kinds of detectors can work at high temperatures for a long time, some modification of their properties was observed. However, for GaN and SiC photodiodes, this modification has a substantially different nature. It is very important for some applications, e.g. fire alarms and a military equipment.

Keywords: optical detectors, UV radiation, photodiode, GaN detector, SiC detector.

1. Introduction

Analysing or monitoring chemical, environmental and biological objects, the flame and radiation detection, astronomical studies, and optical communications are a wide range of applications in which detectors of the UV radiation are very important [1, 2]. They are used in e.g. the UV dosimetry and imaging (solar UV measurements), the fire alarm systems, the missile plume combustion engine control, the intra- and inter-satellite secured communications, the ozone and pollution detection in the air, the detection of biological agents, etc. UV detectors are more widely applied in a military equipment, e.g. the construction of smart weapons, the protection systems against chemical and biological threats, the ballistic missiles and the artillery fire-control. A high-performance photodetector should be characterized by a high sensitivity, a high signal-to-noise ratio, a high spectral selectivity, a high speed, and a high stability [3].

Due to the used semiconductor materials, the UV detectors can be divided into the modified silicon-based semiconductor materials and the wide gap ones [4]. Selecting UV detectors for a dedicated application mainly takes into account the catalogue data provided by their manufacturers. However, it should be considered that their presented optical and electrical characteristics can vary significantly during their operation [5]. The most common sources of these processes are the long-term thermal and optical excitations, far exceeding the nominal operating conditions. This effect is a result of various processes in their construction, e.g. the electrical and optical behaviour of their contacts [6–7].

Consequently, special tests for examining an impact of the thermal annealing on the spectral characteristics of the detectors should be carried out. These investigations should be made at the elevated temperature corresponding to the operating conditions. Such studies also allow to determine the long-term reliability of a detector.

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However, for such a situation the detector manufacturers do not show the relevant data. This is due to long-time measurements, significantly increasing the production cost of detectors. In a contrast, the information on the high temperature operation defines only the properties of the detector housing, but not the stability of its parameters. Also, the analysed literature does not contain the detailed information on this issue. The reported data relate to annealing procedures, optionally only in the case of semiconductor structures. The main task of these procedures is e.g. improving the sensitivity. However, no information relates directly to the final detectors, such as photodiodes, photoresistors, etc. Therefore, the presented work is an attempt to assess changes in the UV detector parameters caused by different thermal treatments. These changes are illustrated by the results of the comparative tests of two groups of commercially available photodiodes made of GaN and SiC structures.

2. Measurement setup

The aim of the tests was to record changes of the detector spectral characteristics caused by the operating temperature as well as the long-time thermal annealing. The temperature range was widened beyond the operation limits defined by the manufacturer. The measurement setup consists of two systems. For registering the spectral characteristics, two monochromators are used (Cornestone 260 type-Oriel 74100 and M250/1800/UV-Optel). During a measurement cycle, two photocurrents are registered for a specific spectral range. The first one comes from the investigated photodiode, whereas the other - from the reference one (Thorlabs company, silicon photodiode S120VC). A view of this setup is shown in Fig. 1.

a) b)

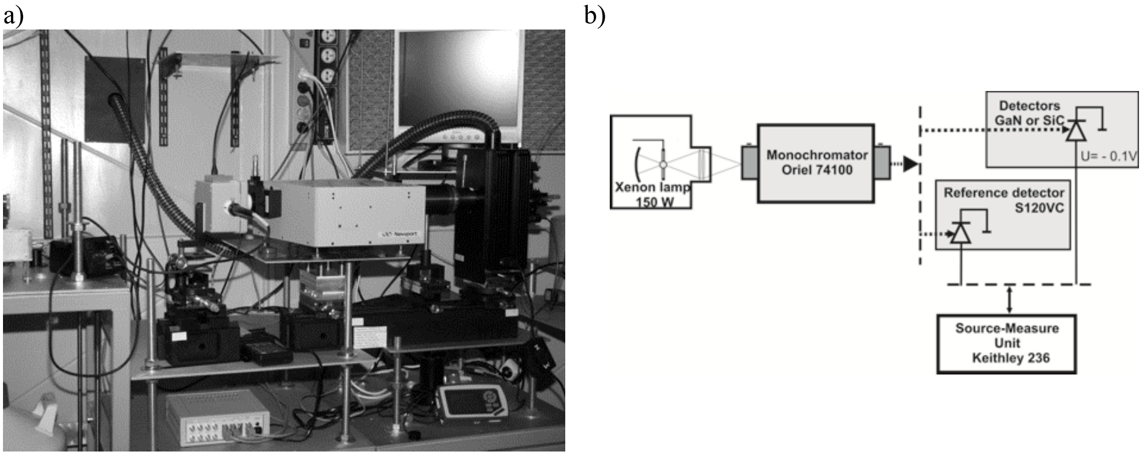

Fig. 1. A photograph (a) and a block diagram (b) of the lab setup for measuring the detector spectral characteristics.

As the radiation source, a xenon lamp is used. The lamp enables to measure the spectral characteristics of detectors in the range of 230 nm - 800 nm. Additional elements of the system are: a temperature controller and a Keithley type 236 current source. Using this source, the output current of reverse-biased detectors (with the 0.1 V voltage) has been measured.

The main part of the system is a set of thermal holders for heating detectors. Their construction stimulates the detector housing temperature (without a direct contact with its optic structure). The system enabling the simultaneous thermal stimulation of four photodetectors is presented in Figure 2. Each set is thermally isolated from the others. The temperature change of the detector housing is possible owing to special heating plates. These plates contain an 80 W heater and a temperature sensor. The maximum value of the obtained temperature was 450°C. Due to the detector datasheets (operating thermal limits), the studied temperature of 200°C was generally not exceeded.

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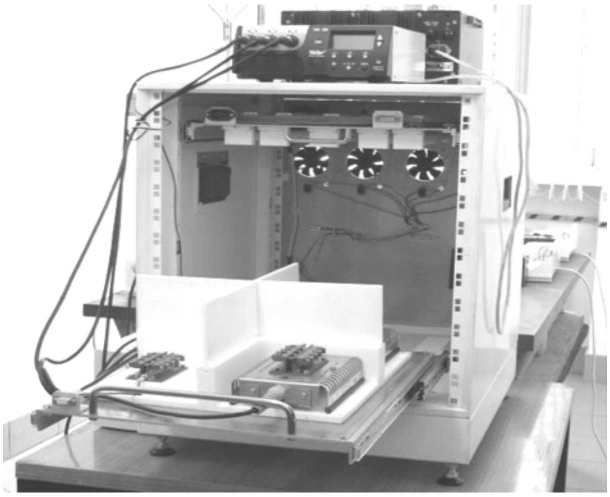

Fig. 2. A photograph of the lab setup for measuring the long-term annealing of UV detectors.

The system is also equipped with a special module to test UV detectors during the long-term optical irradiation. During the tests, two xenon lamps: a 450 W lamp and a 150 W one were used. Additionally, it is possible to use also fluorescent lamps. The system configuration enables optional or simultaneous examining changes of the detector responsiveness caused by stimulating the thermal and optical excitations.

3. Experimental results

The commercial market offers many types of semiconductor detectors for the UV spectral range. For testing, two commercial detectors made of different materials: GaN (detector # 1) and SiC (detector # 2) were selected. The described study does not concern only two specific pieces but groups of these elements. Although the results are directly related only to few detectors, they can be extended on the whole groups. Gallium nitride is a classic material that has been used in the construction of UV detectors for many years. It is considered to be a strategic technology for the development of high-performance detectors. GaN have many advantages, such as the ideal spectral selectivity with wide direct band gaps, a high breakdown field, a high thermal stability, the radiation hardness, and an expected high responsiveness. Silicon carbide has emerged as the most mature wide band gap (2.0 eV $\leq E_g \leq$ 7.0 eV) semiconductor since the release of commercial 6H-SiC bulk substrates in 1991 and 4H-SiC substrates in 1994 [8]. It is a material long known to have a potential sufficient for high-temperature, high-power, high-frequency, and radiation hardened applications.

3.1. Operating temperature vs. spectral responsiveness

The spectral characteristics of the selected detectors were determined for several temperatures within the range of 22°C - 200°C. The highest temperature value was limited directly by the catalogue data of these detectors (resistance of housing and mounting). In the first stage of the research, the spectral characteristics of # 1 group detectors were measured (Fig. 3). It can be seen that, within the range of 22°C - 110°C, the detector responsiveness slightly increases and its maximum position does not change. For the temperatures exceeding 110°C, the responsiveness decreases to its smallest value (75% of the nominal one) reached at the temperature of 200°C. Small changes in the spectral position of the responsiveness maximum are also observed.

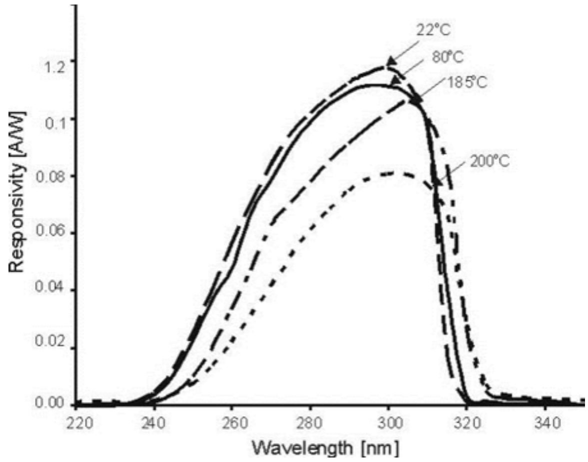

Fig. 3. The spectral responsiveness vs. operating temperature characteristics for an GaN detector.

The similar tests were performed for SiC photodiodes. Figure 4 shows the spectral characteristics of these detectors for different operating temperatures.

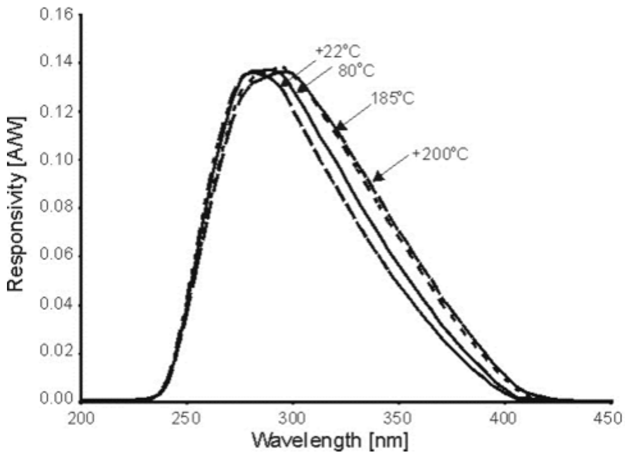

Fig. 4. The spectral responsiveness vs. working temperature characteristics for an SiC photodiode.

The performed research has shown that the responsiveness of an SiC photodiode has not changed. A slight tuning of its maximum towards longer wavelengths can be noticed. The results indicate that the detectors from #2 group (SiC) are preferred in high-temperature applications. However, it should be mentioned that during the tests only a few pieces of commercial detectors were examined. The technology of detector processing and housing can vary considerably and modify the presented results.

3.2. Long-term annealing vs. detector responsiveness

Long-term investigations of detectors have lasted for two months. This period takes into account both the duration of measuring the spectral characteristics at the room temperature and the duration of installing detectors in the heating setup. During the tests, photodiodes were divided into four sets. The first group was treated as the reference level, the second, the third and the fourth ones were annealed at the temperatures of 80°C, 150°C, and 200°C, respectively.

Measurements of the detector spectral responsiveness were performed for different time intervals - up to 1008 hours of annealing. After each interval, the spectral characteristics of a tested photodiode was measured at the room temperature. Using that procedure, the registered results present the effects caused by the annealing process. Figure 5 shows the spectral responsiveness of GaN photodiodes after annealing in different temperatures.

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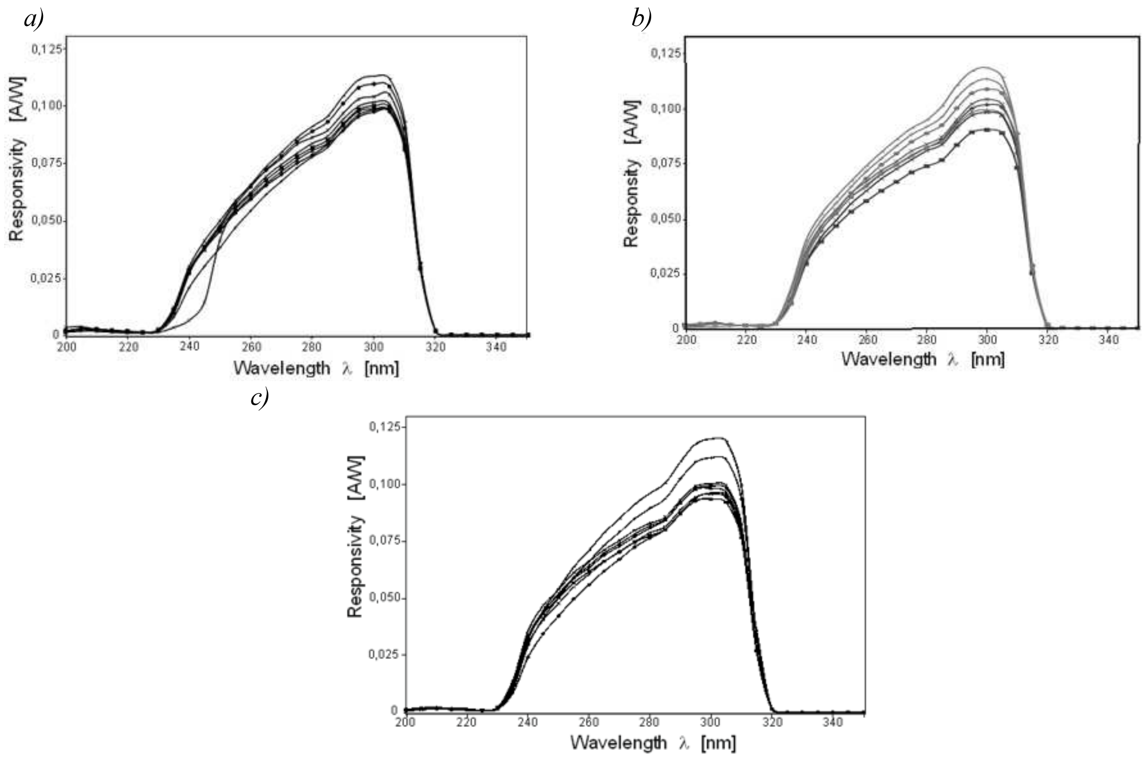

Fig. 5. Temporal changes of the spectral responsiveness of GaN photodiodes registered after annealing in the temperature of 80°C (a), 150°C (b) and 200°C (c).

The characteristics of the maximum detector responsiveness for three different temperatures and annealing times are compared in Fig. 6.

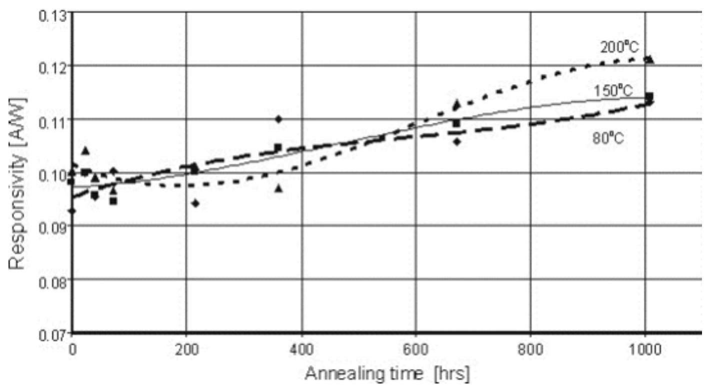

Fig. 6. Time changes of the maximum GaN photodiode responsiveness obtained after annealing in different temperatures.

In the case of GaN detectors, long-term annealing has no effect on the spectral position of the maximum responsiveness (300 nm). But this process influences the responsiveness values. For the annealing time exceeding one month, an increase of the detector responsiveness is observed. Additionally, the largest changes are noticed for the highest annealing temperatures (200°C). The same measurement procedure was applied to test some photodiodes made of SiC. Figure 7 shows changes of the spectral responsiveness for different temperatures of annealing.

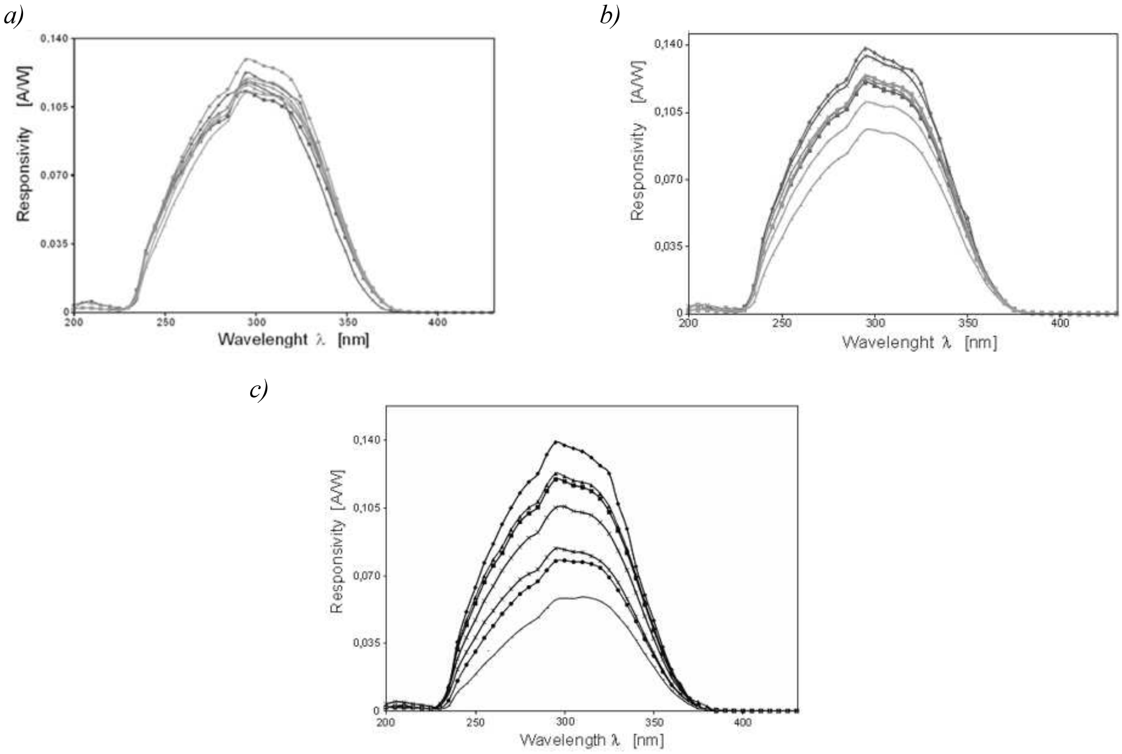

Fig. 7. Temporal changes of the spectral responsiveness of SiC photodiodes registered after annealing in the temperature of 80°C (a), 150°C (b) and 200°C (c).

The characteristics of changes in the SiC maximum responsiveness for different annealing times and temperatures were also determined (Fig. 8). For SiC detectors, a small impact of annealing on the spectral characteristics was expected. Such semiconductor devices are theoretically dedicated to high-temperature applications. As can be seen from the presented results, long-term annealing did not affect the spectral position of the maximum responsiveness of the detectors.

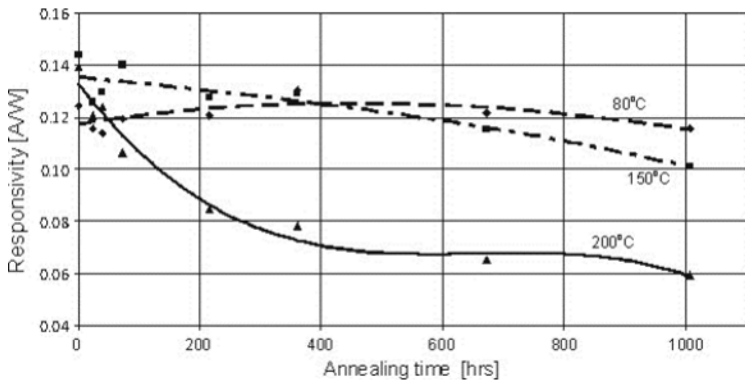

Fig. 8. Time changes of the maximum SiC photodiode responsiveness obtained after annealing in different temperatures.

Unfortunately, the current responsiveness decreases significantly as a function of the annealing time and temperature. It is most significant for higher temperatures, e.g. 150°C and 200°C. When annealing is performed in temperatures below 100°C, the changes are smaller (a few percent). Also, a few deviations from this rule are observed. It can be seen such durations of annealing, that the detector responsiveness increases by several percent. This effect is probably related to the existence of defects in an SiC crystal. Short annealing eliminates some of these defects.

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3.3. Long-time irradiation

Preliminary measurements of the spectral responsiveness changes of an SiC detector irradiated by optical signals were also carried out. As a radiation source, a xenon 450 W lamp was used. The total duration of this experiment was 880 hrs. During that period, twelve measurements were taken at different time intervals. Figure 9 shows the registered spectral responsiveness for two selected time intervals (560 hrs. and 880 hrs.).

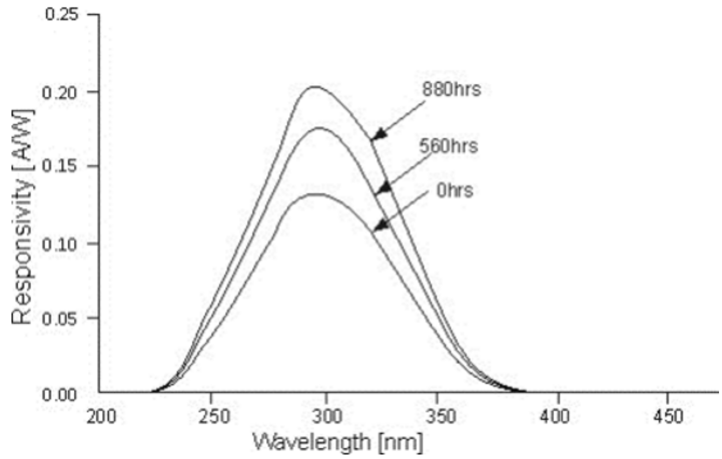

Fig. 9. The spectral responsiveness of an SiC photodiode for different times of the optical irradiation.

For the tested SiC photodiode, a long-term optical stimulation increases its responsiveness by about 30%. The irradiation procedure can be seen as a method of improving its properties.

4. Summary

The paper describes some comparative tests of selected commercial UV detectors. For the investigations, GaN and SiC photodiodes were used. The influence of the operating temperature on the spectral characteristics of detectors is determined. Additionally, some effects of the long-term annealing and optical irradiation are also found. For an GaN photodiode, the operating temperature changes both the maximum responsiveness and its spectral position. In the case of an SiC detector, only a low spectral tuning was observed. During the annealing process, the obtained results for both kinds of photo-detectors are different. This process is adverse for the SiC detector. With an increase of the annealing temperature, the responsiveness of the SiC decreases. For GaN photodiodes, this process has not such a strong influence.

It is shown that the temperature and the time of light exposure can significantly modify the detector properties. Comparing the investigation results of commercial detectors with the data of GaN and SiC materials, some differences are noticed. But these detectors are complex instruments – their features are defined not only by parameters of the applied detecting structures. The electrical connection technology, the thermal properties of their housing, and applied optical components are also very important in their construction. That is why, although these detectors are designed to work in harsh conditions, periodic monitoring of their properties is also required.

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