

---

## MEASUREMENT SYSTEM FOR TESTING THE OPTICAL RADIATION DETECTORS IN A BROAD TEMPERATURE RANGE

**Robert Ćwirko, Joanna Ćwirko, Zbigniew Bielecki**

*Military University of Technology, Faculty of Electronics, Institute of Electronic Systems, Gen. Sylwestra Kaliskiego 2, 00-908 Warszawa, Poland (✉ rcwirko@wel.wat.edu.pl, +48 22 683 7123, jcwirko@wel.wat.edu.pl, zbielecki@wat.edu.pl)*

---

### Abstract

IR, VIS and UV detectors are used in scientific research and industrial or military applications. An integrated system used for spectral characteristic measurements of UV, VIS and IR semiconductor detectors is presented in the paper. The system was developed in the Military University of Technology (MUT). Measurements, including noise measurements, can be carried out in a broad temperature range – from 10 K to 450 K. Selected measurement results for UV detectors are presented in the paper, too.

Keywords: UV, VIS and IR detectors, integrated measurement system, lock-in detection, cryogenic measurements and spectral response of photodetectors.

© 2009 Polish Academy of Sciences. All rights reserved

---

### 1. Introduction

Recently the interest in optical radiation applications in optoelectronics has increased considerably not only in the visible (VIS) or infrared (IR) spectra but also in the ultraviolet (UV) [1]. Photodetector is the basic element of each photoreceiver and is responsible for photoreceiver parameters. VIS and IR detectors have been used for years in many fields of life: industry, automation, AVT applications, medicine, *etc.*

Semiconductor UV photodetectors were not commercially used before 1996. In 1996 the American firm Cree Research Inc. started production of photodiodes based on SiC compound. Other semiconductors based on materials with large forbidden gaps like GaN, AlGaIn, and TiO<sub>2</sub> were used as UV range detectors [2]. UV semiconductor detectors are used in the biological and chemical recognition systems, medical applications, intelligent weapon systems or individual soldier's protection [3].

Semiconductor producers of photodetectors implemented a lot of technological solutions to increase sensitivity and improve spectral characteristics. In order to obtain high detector sensitivity it is necessary to simultaneously minimize the noise and maximize a signal to noise ratio [4].

For example, a lifetime of detectors used in accelerators is highly dependent on degradation speed of their crystal structure. Sensitivity of these detectors decreases with time because of increasing noise level in detectors [5].

Tests of optical detectors carried out in a broad temperature range allow estimation of change in their sensitivity of as well as a position of their absorption edge.

## 2. Measurement system

In the Military University of Technology the integrated test system for spectral and noise characteristics measurements of optical radiation semiconductor detectors was developed (Fig.1). Test system ensures measurements in temperature range from 10 K up to 450 K.

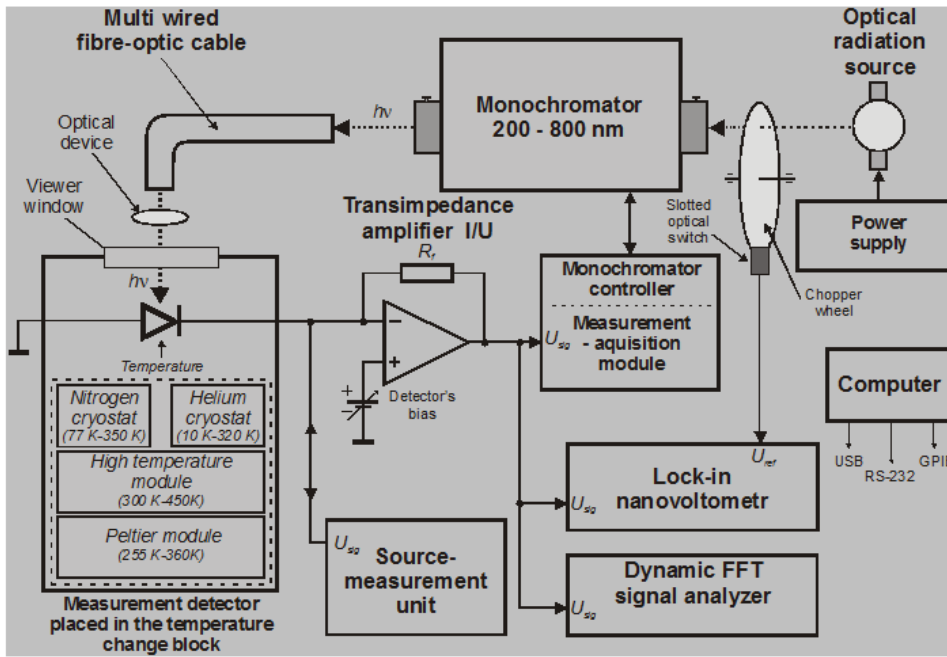


Fig. 1. Functional scheme of the test system.

A current signal from detector output is amplified in the transimpedance low noise Keithley 428 type amplifier for most measurements configurations. This device has a built-in voltage polarization system for measurement detector. If the current signal from detector is directly connected to the internal input of the built-in amplifier (example: lock-in SR830 nanovoltmeter of the Stanford Research Co), the detector is polarized from external voltage source. In case of measurements with a lock-in nanovoltmeters, elimination of an external transimpedance amplifier decreases error level related to additional phase shifts. Basic measuring devices in the system are the lock-in nanovoltmeter, the dynamic FFT signal analyzer and the source-measurement unit.

Measurements of characteristics are carried out as phase-sensitive measurements. This is because that even if a big power illuminator is used, the current signal from tested detector has, in general, less amplitude than the background noise. The noise components are generated both by the monochromator, illuminator, the optical interface plugged-in to the monochromator output, as well as the detector itself, its polarization system, technological devices providing thermal environment of the measurement *e.g.* preamplifier, *etc.* In measurements with lock-in nanovoltmeters modulation of the light radiation flux is necessary.

The modulation is performed using the rotating disk of the mechanical SR549 type chopper by the Stanford Research firm. The reference signal of the fixed frequency and phase is generated at the slotted transoptor output of this modulator and is used for analysis of the signal from tested detector. The frequency of the light flux modulation is chosen in a way that for specified frequency and its close proximity the maximal noise values are much lower than

usable signal of the detector. The FFT dynamic signal analyzer is used to detect this specific frequency.

Basic measurement device used for determination of the photodetector noise characteristic is the FFT HP35665 type signal analyzer by Hewlett Packard. When noise measurement is carried out, a current signal from detector output is preamplified in the low noise transimpedance 428 type amplifier. The current-voltage characteristics measurements are carried out using force-measurement Keithley 236 type source.

The measurements in the full temperature range are long-lasting (several dozen hours), thus the entire control process of the measurement and data acquisition are fully automated. Majority of measuring and technological devices are connected to the PC computer using *GPIB* bus. The control software was written using *TestPoint* environment which ensures solutions to be carried out in real time. In the next parts of the paper the instrumentation for spectral characteristic measurements and the temperature change block are described.

### **2.1. The temperature change block**

Tested photodetector is placed in one of technological devices in the temperature change block. This block consists of a flow nitrogen cryostat, helium compressor cryostat, test module for high temperature measurements, and the Peltier cell module. In order to ensure a broad range of temperature changes in nitrogen and helium cryostats, all measurements of detector characteristics have to be carried out in vacuum which minimizes thermal energy losses in a sample measurement volume. Moreover, when semiconductor structure is not closed in hermetic casing the effect of surface structure degradation caused by gases included in residual atmosphere can occur. As an example, SiC used in UV detectors very strongly reacts with oxygen. In both cryostats the set of the two pumps (oil pump and turbo-molecular one) assures vacuum at the level of  $10^{-6}$  Tr. The vacuum level is measured using IONIVAC ITR090 sensor which is a combination of the Pirani and the Bayard Alpert heads with hot cathode. The ITR 090 sensor cooperates with a microprocessor pressure meter IT23 which allows remote monitoring of meter indications and alarm levels signalization as well. Tested detector is mounted using special handle on operation table equipped with a heating system and temperature sensor.

A calibrated silicon diode D type working at temperatures between 4 K and 450 K is used as a temperature sensor. This sensor is connected to microprocessor temperature controller of the LTC60 type by Leybold which, executes a PID digital algorithm for temperature control. The quality of the temperature control and the time necessary for temperature stabilization depends on the PID parameters optimization. The second sensor is placed as close as possible to the tested sample which minimizes the temperature reading error during measurement.

The heads of both cryostats are equipped with the viewer window based on special Suprasil glass of light transmission from ultraviolet up to near infrared and enable optical excitation of the measured detector. The choice of the cryostat in the measurements is a compromise between required minimal measurement temperature and a noise level generated by cryostat head. The compressing helium cryostat of the RDK 10 – 320 type by Leybold enables measurements to be carried out at the temperature range from 10 K up to 320 K. The serious disadvantage of this cryostat are significant mechanical strokes generated by compressor placed in the cryostat head. These strokes are transformed on tested sample and are a source of considerable piezo- and triboelectric interference. Thus the helium cryostat compressor is not the best solution for measurements of very small signals since they can be masked by extensive distortions. Much lower level of distortions appears in the flow nitrogen

cryostat, but its minimal working temperature (77 K) is higher than that in helium cryostat (10 K).

The high temperature stand permits to test photodetectors up to 450 K. A test module with the Peltier cell is used for preliminary detector measurements (limited temperature range 255 K – 360 K). This cell is controlled via bipolar current source of the 06DLT320 type by Melles Griot Co. Even though measurements conducted in high temperature stand using Peltier cell do not need vacuum, special hubcaps with viewer windows are mounted on testing modules thus enabling removal of atmospheric gas and filling the facility with a gas neutral for detector structures – for example nitrogen.

## 2.2. The instrumentation for measurements of spectral characteristics

During measurements of spectral characteristics of photodetectors a wavelength of exciting optical radiation should be automatically retuned. In our system a monochromator of the M250/1800/UV type by Optel is used for this purpose (Fig. 2).

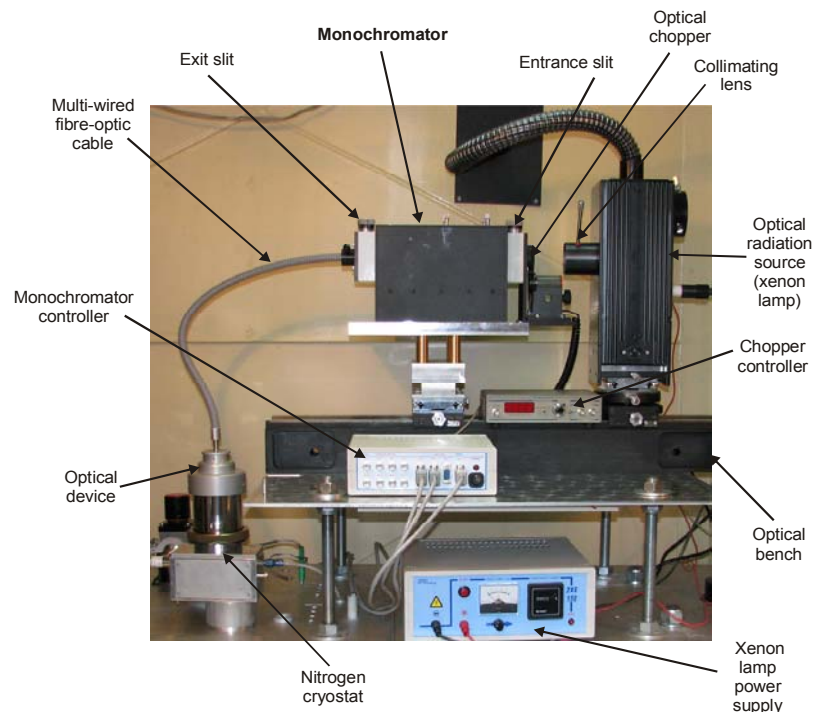


Fig. 2. The overall view of the optical system.

An optical interface in form of a multi-wired fibre-optic cable [6] with focusing lens connects the monochromator output with a technological device ensuring proper thermal parameters of a measurement. The monochromator used in tests is built according to Czerny-Turner configuration (focal length  $\frac{1}{4}$  m) and measurements can be carried out in the range from 200 up to 800 nm if a proper illuminator is used. The monochromator works with two types of illuminators. The first illuminator uses a 150W xenon lamp of the XBO150 W/Cr OFR type with a very small ozone emission level, an average luminance of  $1800\text{cd/cm}^2$ , and a lifetime of about 3000 h. Spectral characteristic of the lamp allows measurements from about 200 nm to 800 nm, so detectors working from UV to near infrared range can be tested using this illuminator. The maximum light flux is observed in the flat part of the spectral characteristic, *i.e.* between 400 and 800 nm. However, the intensity of a light flux for 230 nm is about 100 times lower. The intensity of a light flux in the 230 nm region can be increased

five-fold if the XBO150 W/CR OFR lamp is replaced by a XBO 150/W1 lamp which, however, is a lamp with a high ozone emission level. If a low ozone emission is required a 30W deuter lamp 63161 equipped with a power supply of the 68942 type by Oriel can be used.

A course of a spectrum characteristic measured with a lock-in nanovoltmeter does not render a real shape of a spectral characteristic of tested detector because it is deformed by illuminator spectral components, monochromator, optical interface, and so on. However, on the base of spectral characteristic obtained for a standard detector in the same experimental conditions, a special correction table can be elaborated. These correction table can be used for correction of spectral characteristic of the tested detector.

The photodiode S120VC with optical power meter of the PM100D type by Thorlabs is used as a standard detector in the 200 – 1100 nm range. The spectral characteristic of this photodiode is built-in into the EEPROM memory during supplier calibration process. The memory is placed in the interface used for connection of the photodetector with the power meter.

### **3. The measurements**

Below are presented the most representative measurement results of the UV detectors made out of AlGa<sub>N</sub> compound. The UV detectors of this type are called “solar blind” detectors which means that they do not require additional optical filters against visible radiation that might disturb their operation. Due to their optical characteristics they are the most perspective group of detectors but with regard to the material used – AlGa<sub>N</sub> – their noise characteristics can be pretty complex. AlGa<sub>N</sub> is characterized by relatively high concentration of deep defect centers in forbidden gaps. In consequence a large amount of generation-recombination noise component in the whole detector noise can be expected.

Measurements of current-voltage, spectral, and noise characteristics were performed to obtain detector characterization. During measurements of these characteristics the nitrogen cryostat was used to stabilize thermal conditions in the experiment. The choice of the nitrogen cryostat resulted from the necessity of the interference minimization in measurements of noise characteristics.

#### ***3.1. The current-voltage characteristics measurements***

The I/V characteristics measurements were carried out for temperatures from 80 K up to 300 K. The force-measurement source of the 236 type by Keithley was used in measurements.

In Fig. 3 the current-voltage characteristic for AlGa<sub>N</sub> diode No 1 is presented in a function of temperature.

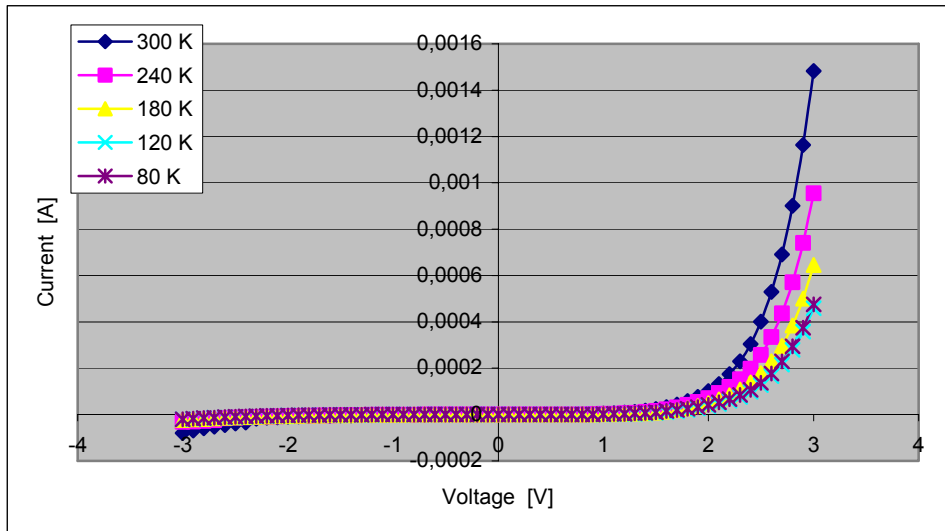


Fig. 3. Diode No. 1 characteristic for selected temperature values (1V polarization).

This curve and the curve in Fig. 4 present the shape of a dark current for the diode and both curves were determined for 80 K – 300 K temperature range with the 10 K step.

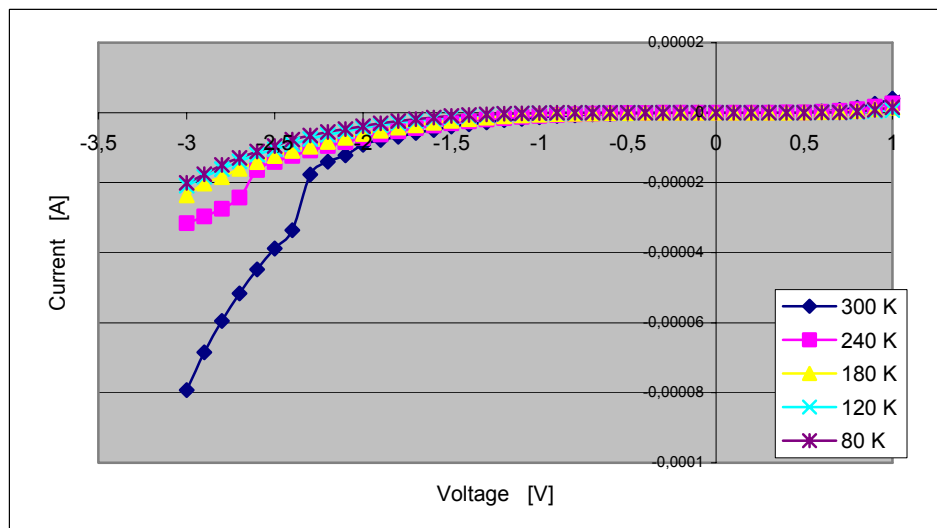


Fig. 4. Dark current for diode No. 1 for selected temperature values (1V polarization).

### 3.2. The spectrum characteristic measurements

The photodetectors spectral characteristics were determined using 150W xenon lamp of the XBO150 W/CR OFR type. The characteristic of this lamp allow measurements in the range of 200 nm – 800 nm. The 140 Hz modulation of a light flux was applied. Direct measurements were carried out using phase-sensitive nanovoltmeter, without any signal preamplifying. In Fig. 5 the spectral characteristic versus temperature is shown for AlGaIn diode No. 1 (0V polarization).

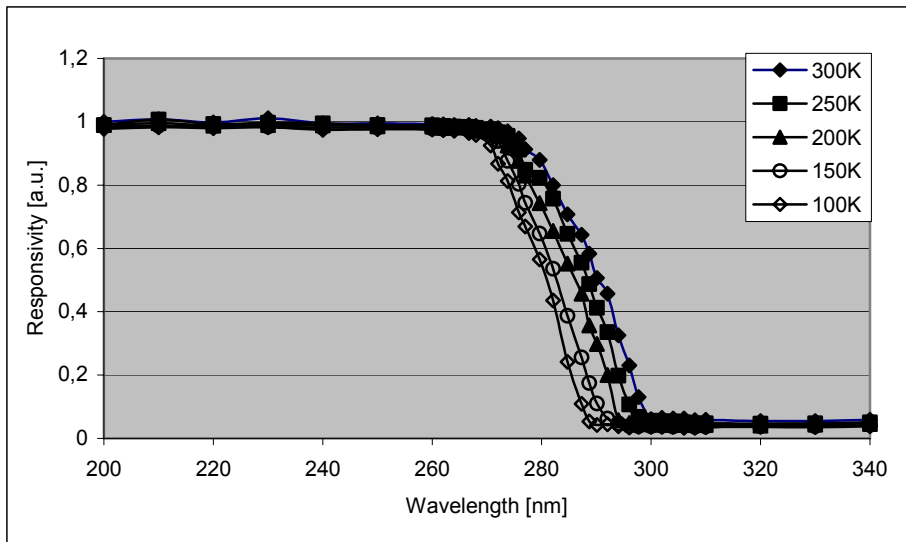


Fig. 5. Spectral response of AlGaIn photodiode for selected temperature values.

This spectral characteristic and the next characteristic (Fig. 6) obtained for SiC photodiode were made in temperature range between 100 K and 360 K.

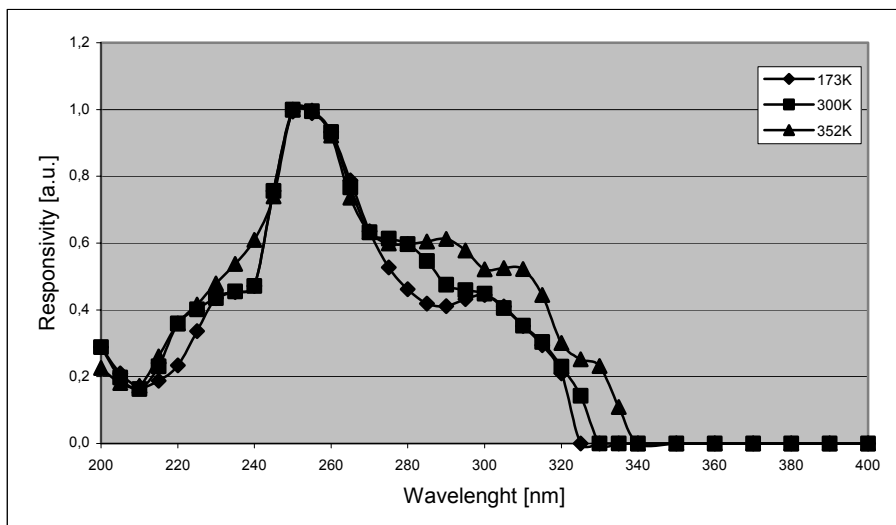


Fig. 6. Spectral response of SiC photodiode for selected temperature values.

### 3.3. The noise characteristic measurements

Typical characterization of tested detector is based on determination of power spectral density of noise in 2000 measurement points in the frequency range from 1Hz up to 102 kHz. The measurements were carried out with FFT signal analyzer of the HP35665A type. The current signal from detector output was preamplified in the low noise transimpedance Keithley 428 type amplifier. The measurements were carried out at the temperature range from 80 K up to 350 K. In Figs 7 – 10 selected results for two AlGaIn detectors are presented.

In Figs 7 and 9 power spectral density (PSD) of noise was calculated for each photodiode at 6 different polarizations in fixed temperature. In other figures – 8 and 10 – the PSD were calculated for selected temperature in fixed polarizations.

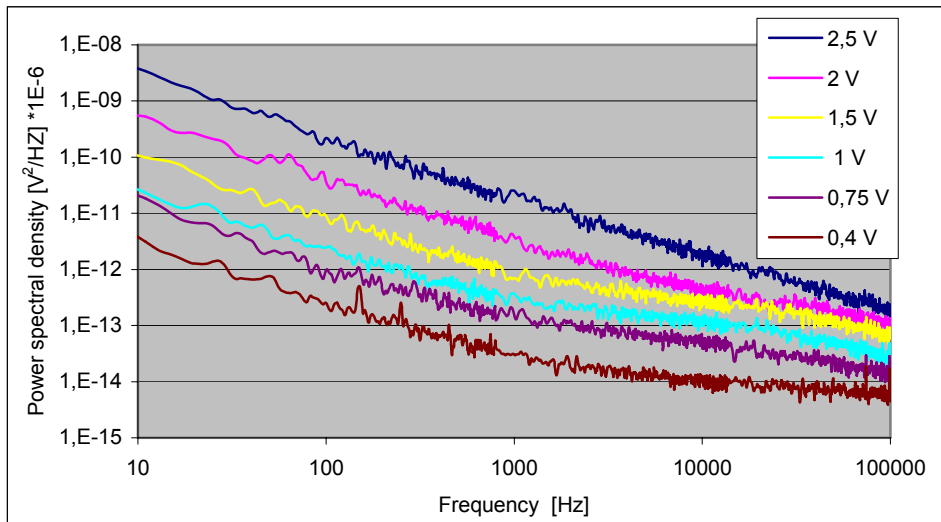


Fig. 7. Noise characteristics of the diode No. 1 for selected polarizations at 292 K.

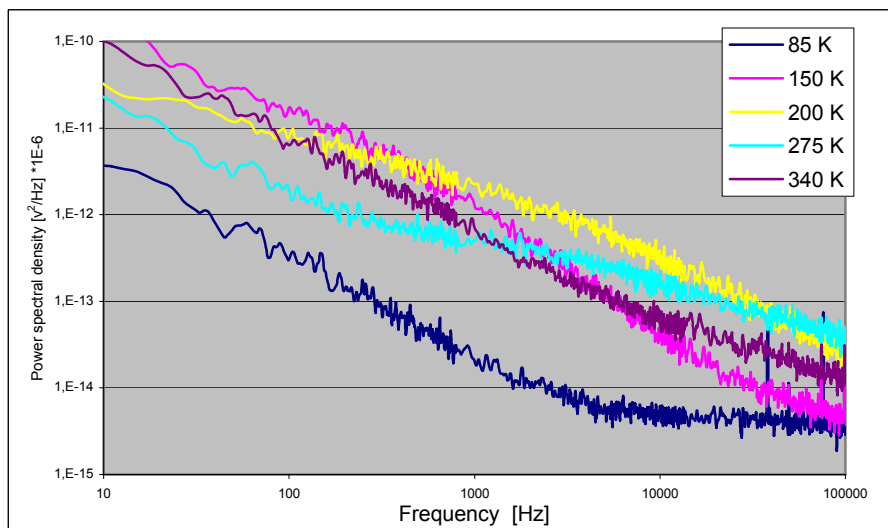


Fig. 8. Noise characteristics of the diode No. 1 for selected temperature values (1V polarization).

As we can see in presented Figs, for UV detector tests with noise methods it is possible to determine in which frequency ranges detector is characterized with non-accepted noise level, how a noise characteristic of detector is changing with electrical polarization, and how noise characteristic of detector is changing with temperature. When analyzing the course of detectors noise characteristics for various temperatures it is possible to obtain information how to optimize conditions of detector operation.



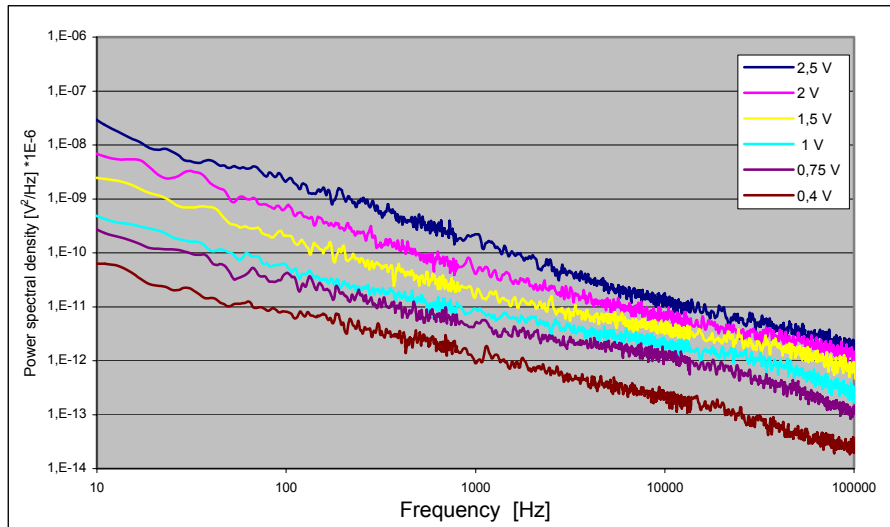


Fig. 9. Noise characteristics of diode No. 2 for selected polarizations at 300 K.

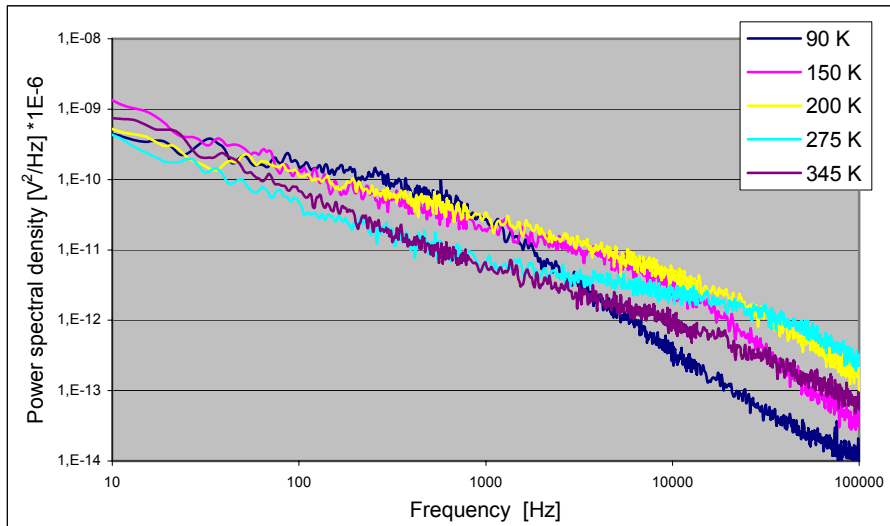


Fig. 10. Noise characteristics of diode No. 2 for selected temperature values (1V polarization).

#### 4. Conclusion

The integrated measurement system developed at the Military University of Technology (MUT) allows determination of current-voltage, spectral, and noise characteristics of detectors in the 10 K – 450 K temperature range. In Fig. 11 a general view of the testing system is shown. Investigation results show that the integrated measurement system developed at the MUT was constructed correctly. Optical measurements of detectors carried out in a broad temperature range assure definition of changes of absorption edges of materials used in detector structures, responsivity dependencies with temperature, as well as a character of interaction of individual noise components which has an essential influence on correct estimation of signal-to-noise ratio (SNR).

For hybrid photodetectors having built-in detector and transimpedance I/V amplifier (in one chip), it is possible also to determine an influence of temperature on amplification module

and its external elements (external coupling resistors, frequency compensation sub-assemblies, etc.).



Fig. 11. The overall view of the test stand.

## References

- [1] A. Rogalski: "Advanced Technologies in Development of Optical Detectors". *Elektronika*, no.12, 2004, pp. 2-19. (in Polish)
- [2] N. Biyakli, T. Kartaloglu, O. Aytur, L. Kimukin, E. Ozbay: "High-speed Visible-blind GaN-based Indium-tin-oxide Schottky Photodiodes". *Applied Physics Letters*, vol. 79, no. 17, 2001, pp. 2838-2840.
- [3] A. Bednarkiewicz, P. Gacek, J. Jaroński: „Wykorzystanie światła niebieskiego do diagnostyki nowotworów i stanów przednowotworowych”. *Elektronika*, no. 3, 2006, pp. 1-13. (in Polish)
- [4] R. Ćwirko, Z. Bielecki, J. Ćwirko: "Low-frequency Noises as a Tool for UV Detector Characterisation". *Opto-Electronics Review*, vol. 14, no 2, 2006, pp. 155-160.
- [5] N. B. Lukyanchikova: *Noise Research in Semiconductor Physics*. Gordon and Breach Science Publishers, ISBN 90-5699-006-3.
- [6] H. S. Nalva: *Photodetectors and Fiber Optics*. Academic Press. ISBN 0-12-513908-X.