Abstract. In this work the characteristics of aluminum oxide/zinc oxide heterostructures based sensors used for UV radiation detection were investigated. The UV response dependent on the distance of the UV source versus sample and relative humidity changes was studied. The dependency between the response time and the distance to the UV source was determined.

Keywords: heterostructures, aluminum oxide, zinc oxide, UV sensor, humidity.

Introduction
Zinc oxide (ZnO) is a $n$-type semiconductor that has a bandgap of between 3.1 and 3.3 eV [1-4]. In order to modify the bandgap, various impurities such as titanium oxide, palladium [2], cadmium, europium, silver as well as functionalization with noble metals such as Au and Pt can be used. All these changes are performed to develop gas sensors or ultraviolet (UV) radiation detectors, which can be incorporated into various portable devices for the detection of gases such as ammonia, methane, ethanol, hydrogen, carbon dioxide, butanol, propanol as well as for UV radiation detection in different ambient.

Experimental
In order to obtain zinc oxide, one of the most effective and inexpensive methods of manufacturing a sensor based on semiconductor oxide was chosen, namely the synthesis from chemical solutions (SCS) method [10]. This is a straightforward method that also allows impurity doping during the zinc oxide production. The substrate glass, on which the zinc oxide is deposited, is cleaned preventively and then sensitized in a SnCl$_2$·2H$_2$O/HCl solution. Zinc sulphate is used as a cationic precursor and sodium hydroxide is used as an initial reagent to form a complex solution. All solutions of chemical reagents were of purity higher than 99.9% with no further purification [5]. The ZnSO$_4$ solution was gradually added to the NaOH solution which was continuously stirred with a magnetic stirrer until the solution became transparent. The impurity doping can be achieved by introducing impurity ions into the complex solution [6].

Low temperature thermal atomic layer deposition (ALD) of Al$_2$O$_3$ deposition was carried out using Picosun’s R-200. Trimethylaluminum (TMA) was used as aluminum source and H$_2$O to oxidize chemisorbed TMA. Alternating pulses of aforesaid precursors pulsed into reactor chamber for 0.1 s per pulse to grow monolayers of Al$_2$O$_3$. Nitrogen was used to transport the precursor vapors into the reaction chamber and to purge byproducts from the reactor.
Cleaning of the glass substrate surface was performed by a successive washing in acids HCl 2% with decontamination in distilled water. This cleaning method is widely described in previous papers. [10]. After the deposition of the films by the SCS method, rinsing in deionized water and drying in a hot air stream for 1 min at $t \approx 150 \, ^{\circ}\mathrm{C}$ was carried out. Rapid thermal annealing (RTA) or post-growth heat treatment is mandatory for SCS materials in order to improve the structural, chemical, optical properties and to diversify the scope of the respective nanomaterials.

In this paper all experiments were performed at room temperature. The current-voltage characteristics were investigated under different conditions: in Figure 1.a the curve (1) indicates the characteristic without the application of UV radiation, while the curve (2) shows the characteristic with the application of UV during the measurement. As can be observed, there is a greater increase of current under UV illumination, which demonstrates that the developed sensor can be used for UV detection. In Figure 1.b curves (1) and (2) indicate the sensor's response depending on the humidity. Curve (3) shows the volt-ampere characteristic at the humidity level of 89% and with UV illumination. The analysis of the curve (3) shows that this structure senses UV light at the humidity levels higher than the medium room humidity level.

Figure 2 shows the response to UV measured at humidity level of 89%, depending on the distance from the UV source. It is observed that together with the change of distance, the change of answer takes place. The response at the distances of 1 cm and 2 cm does not differ too much, but at the distance of 13 cm the response to UV is much smaller. To determine the response to UV radiation the following equation was used: Eq (1):
$S = \frac{G_{UV} - G_{dark}}{G_{dark}} \times 100\% \quad (1)$

where

$G = \frac{1}{R} \quad (2)$

In order to demonstrate that the developed sensor, being mounted at a distance of 13 cm to the UV source, has a high response, it was tested in ambient air with a relative humidity (RH) level of 16%. The result of this measurement is shown in Figure 2.b. It can be concluded that the humidity level has an influence on the sensor’s response to UV light.

The response time $\tau_r$ and the recovery time $\tau_d$ of the Al$_2$O$_3$/ZnO heterostructure at different distances from the UV source are shown in Figure 2.a. For calculation purposes, the response time $\tau_r$ was defined as time which is needed to reach 90% of the complete response, while the recuperation time $\tau_d$ was defined as the time to reach the value of 10% of the initial response [8]. From the figure it can be determined that the response times at the distance of 1 cm and 2 cm to the UV source are $\tau_r = 4.35s$ and $\tau_r = 5.07s$ while for the distance of 13 cm the response time is $\tau_r = 8.24s$. In all cases a partial recovery takes place.

![Figure 3. SEM image of sensible surface of Al$_2$O$_3$/ZnO heterostructure](image)

The UV sensing mechanism that describes the response to ultraviolet radiation can be explained on the basis of a depletion region forming at the surface of Al$_2$O$_3$ and can be described by the “Eq.(3)”. Thus, the dark conductivity appears in the inner layers which have low resistance. Under UV illumination the excess of photo generated charge carriers is formed [7].

$$h\nu = h^+ + e^- \quad (3)$$

Further, electrons and holes are separate and electrons migrate through the inside of the film, while holes remain on the surface and migrate to the surface forming a depletion region. At the same time, the oxygen photo-desorption takes place, which is described by the Eq.(4) [7].

$$h^+ + O_2^- \rightarrow O_2 \quad (4)$$

leads to a narrowing of the depletion region and to the increasing of through the inner layer current. As a consequence, the current gets saturated due to the reaction described in equations (3) and (4) taking place.

**Conclusion**

Measurement results showed that presented Al$_2$O$_3$/ZnO heterostructure has a high potential as a sensor for the UV radiation detection of at both, normal and high humidity levels. It was observed that at the humidity level of 89% the response is dependent on the distance to the UV source: the response changes from 825% at 1 cm distance to 78% at 13 cm distance. At the humidity level of 16% and at 13 cm distance, the value of the UV response was 525%. It can be concluded that the sensor is able to detect UV at different distances from the UV source. Sensing properties might be further enhanced by increasing the surface area of Al$_2$O$_3$/ZnO structure, e.g. by using a highly porous network made of tetrapodal shaped ZnO particles as a substrate material [9].
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