Materials and Energy Research Center
MERC

Contents lists available at ACERP

Advanced Ceramics Progress

Journal Homepage: www.acerp.ir

Original Research Article

Design and Study of the Photodetection Performance of Photodetector Based on $CH_3NH_3PbBr_3$ Organic-Inorganic Hybrid

Elmira Sadeghilar [a], Soghra Mirershadi [b, *], Farhad Sattari [c]

[a] *MSc, Department of Physics, Faculty of Sciences, University of Mohaghegh Ardabili, Ardabil, Ardail, Iran*

[b] *Associate Professor, Department of Engineering Sciences, Faculty of Advanced Technologies, University of Mohaghegh Ardabili, Namin, Ardail, Iran*

[c] *Associate Professor, Department of Physics, Faculty of Sciences, University of Mohaghegh Ardabili, Ardabil, Ardabil, Iran*

* Corresponding Author Email: s.mirershadi@uma.ac.ir (S. Mirershadi)

URL: https://www.acerp.ir/article_159417.html

ARTICLE INFO

Article History:

Received 5 October 2022
Received in revised form 24 October 2022
Accepted 24 October 2022

Keywords:

Photodetector
Optoelectronic Device
Perovskite
Response

ABSTRACT

In this paper, the performance of photodetectors based on $CH_3NH_3PbBr_3$ organic-inorganic hybrid was evaluated, given their wide applications in different industries. This structure an appropriate for the active layer of photodetector device. Impressive results are concluded by changing the halogen atom and the energy gap of the hybrid structures. The obtained results reveal that the investigation of the appropriate organic cation and suitable halogen atom, as well as the concentration of the hybrids in the photodetectors, are necessary to find a suitable condition for an effective photodetectors. Exciting results are achieved by considering the Current-voltage (I-V) curves of darkness and light. The I-V curve with 1.8 wt. % concentration of $CH_3NH_3PbBr_3$ organic-inorganic hybrid shows the Isc of 1 µA and response of 0.027 µA/W. The device with 1.2 wt. % concentration showed Isc of 0.25 µA and response of 0.006 µA/W. Perovskites are optically configurable so that they acquire proper band gaps with high slope absorption edge and considerable efficiencies in collecting the charges produced by the light.

https://doi.org/10.30501/acp.2022.364509.1105

1. INTRODUCTION

Photodetectors are among the most interesting optical communication components that play a significant role in many fields such as spectroscopy and ultraviolet detection, to name a few [1]. These components convert optical signals into electrical signals. A photodetector consists of an optically active region connected to two metal electrodes. In order for the active region to absorb more radiant light, the thickness of this area should be low. When light with adequate energy shines on the surface of the intended semiconductor which acts as an active layer, the electron pairs-generated holes are collected and generate an electric current [2].

The function of photodetectors depends on several important factors, one of which is the current response rate obtained through Equation (1).

$$R_i = {I_{out}}/{P_{in}} \tag{1}$$

Please cite this article as: Sadeghilar E., Mirershadi, S., Sattari, F., "Design and Study of the Photodetection Performance of Photodetector Based on $CH_3NH_3PbBr_3$ Organic-Inorganic Hybrid", ***Advanced Ceramics Progress***, Vol. 8, No. 3, (2022), 13-17. https://doi.org/10.30501/acp.2022.364509.1105

The response of a photodetector determines how much light current is produced due to light radiation with a certain wavelength [3]. In other words, responsiveness could be defined as the ratio of the output electrical signal (output current or I_{out}) to the radiant optical power (P_{in}).

Another important factor for photodetectors is the external quantum efficiency. The ratio of the electron pairs- generated holes by the photodetector to the number of photons irradiated on the photosensitive region is called quantum efficiency [4].

Dark current is an important parameter in the study of photodetectors. It is a small current that occurs without radiation falling on the photodetector in it. Most photodetectors need a secondary power source in order to detect light better that in turn incurs high costs. To solve this problem, a new kind of photodetectors which function without a secondary source of power was employed [5].

Although the concept of photovoltaic has been of interest to the researchers in recent years, it still has an inherent potential for constructing new detectors. These types of detectors are one of the most common electronic tools in optoelectronics due to the high speed of responsiveness [6]. Since one of the connections contains reverse bias, these tools have lower dark current than other photodetectors [7].

Figure 1 shows a schematic of photodetectors based on organic-inorganic perovskite which consists of two electrodes, a substrate, and a light-sensitive layer. This configuration is formed by layering perovskite with the thickness of 200 nanometers on the indium tin oxide substrate and also a conjunction of aluminum metal on the organic-inorganic perovskite.

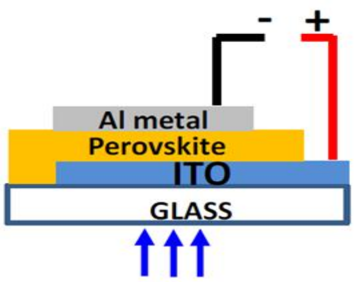

Figure 1. Schematic of photodetectors [8]

A great deal of efforts have been made in conducting ultraviolet detection with semiconductors that contain big energy gaps until now [9]. In recent years, two-dimensional substances have been widely utilized among which, graphene and black phosphorus are two of the best examples [10]. One-dimensional substances, such as carbon nanotubes, and one-dimensional metals have been widely used in recent years for conducting photodetectors owing to their mechanical and optoelectronic properties [11]. These substances include features like a weak interlayer covalent bond, high mechanical resistance, high luminescence, strong quantum confinement, and adjustable band gap [12]. Commonly used electrodes in making photodetectors are gold (Au), silver (Ag), and indium tin oxide [13]. In practical applications, heat, light radiation, and humidity are the main factors that have a destructive effect on the performance of photodetectors. In order to prevent these uncalled-for effects, the encapsulation method in the photovoltaic industry is commonly used [14]. Modern photodetectors are mainly based on semiconductor materials with an adequate band gap that converts photons with different energies into electrical signals for the procession, reconstruction, and storage of images [13].

In the last few decades, organic substances have been used in many optoelectronic tools such as photodetectors owing to their cheapness and easy processability. However, in order to conduct organic-based optoelectronic tools, some other obstacles such as low mobility of charge carriers and chemical interactions should be taken into consideration. One of the suggested solutions to this problem is to use organic-inorganic hybrid materials which enjoy the benefits of both organic and inorganic compartments while overcoming either one's limitations. In recent years, there has been a significant interest surge in studies on conducting organic-inorganic hybrid perovskite structures in the solar cells field. In addition to this filed, more research projects focused on the photodetectors based on organic-inorganic hybrids during the past two years due to the extraordinary optoelectronic features of these structures. Owing to such an exclusive function, optoelectronic tools based on these materials, such as photodetectors and optical transistors, have been developed and reviewed in recent years [15].

Three-dimensional organic-inorganic halogen hybrids are another common structure of hybrids. These hybrids contain the general formula AMX_3, where A is a monovalent cation and commonly Li, Na, K, Rb, Cs or an organic amine cation of proper size, and M the bivalent metals of the periodic table such as (Cu^{2+}, Ni^{2+}, Co^{2+}, Fe^{2+}, Mn^{2+}, Pd^{2+}, Cd^{2+}, Ge^{2+}, Sn^{2+}, Eu^{2+}, and Pb^{2+}), and X a halogen element [16].

2. MATERIALS AND METHODS

2.1. Synthesis of Perovskite Structures

Synthesis of hybrid structures is the most primary and essential requirement in their examination, and they are usually synthesized through simple chemical methods. Organic-inorganic hybrid structures is generally synthesized in two steps namely the synthesis of amino salt and preparation of perovskite solution.

Lead dibromide salt ($PbBr_2$, sigma aldrich) with high purity as the mineral part and methylamine (CH_3NH_2, 40 % solution in water, Merck) as the supplier of the organic part are used for the synthesis of $CH_3NH_3PbBr_3$ organic-inorganic hybrid, as used in this research. In the first step, an amine salt is extracted by the reaction of stoichiometric amount of CH_3NH_2 with hydrobromic acid (HBr, 47 %, Merck). Given that this reaction is highly exothermic, this step is done by placing a two-necked flask in a mixture of water and ice in order to reduce the reaction temperature. The synthesis equation of amino salt can be written as follows:

$$CH_3NH_2 + HBr \rightarrow CH_3NH_3Br \quad (2)$$

Then, solid $PbBr_2$ is added to the produced solution, whose reaction equation is given below:

$$CH_3NH_3Br + PbBr_2 \rightarrow CH_3NH_3PbBr_3 \quad (3)$$

It is worth noting that organic-inorganic hybrid structures are transformed into an orange powder after 24 hours at the room temperature and one week at 50 °C. All materials were used without further purification.

2.2. Design of Photodetector

In this research, photodetectors were constructed using an organic-inorganic hybrid $CH_3NH_3PbBr_3$ substance with the weight percentages of 1.2 and 1.8 percent in dimethyl sulfoxide (DMSO, ≥ 99.9 % Merck) solvent as the active region. Indium tin oxide and silver were used as anode and cathode, respectively. Indium tin oxide substrates with the thickness of one mm and dimensions of 2×2 cm^2 were purchased. These substrates were ultrasonicated with ethyl alcohol and distilled water for 10 minutes and then dried in an oven at 70 °C for 15 minutes before use. The solution was prepared from solving synthesized organic-inorganic hybrid substances with the concentrations of 1.2 and 1.8 % by weight in DMSO solvent and then layered on the indium tin oxide substrates. Next, it was placed into the oven at a temperature of 65 °C for 24 hours. Subsequently, silver was used to make the wire connections from cathode and anode and finally, characterize the current-voltage (I–V) of the built photodetector.

In order to characterize the synthesized hybrids and review the features of the crystal structure and determine their lattice parameters, X-Ray Diffraction (XRD) (Cu Kα X-ray radiation source-Ital structures model MPD 3000) with 2θ in the temperature range of 2º-50º was used. Furthermore, to evaluate the optical behavior of organic-inorganic hybrids, different approaches and equipment were used, among the most significant of which are Ultraviolet-Visible (UV-Vis) optical absorption and Diffusion Reflectance Spectroscopy (DRS) which were recorded via a Sinco S4100 spectrophotometer in the range of 200 to 800 nm at room temperature. The photovoltaic parameters were obtained through measuring the I–V curves (sharif solar PGS10) under irradiation of AM1.5. A Mercury lamp (Philips 36W) was also used as an excitation source.

3. RESULTS AND DISCUSION

Figure 2 shows the XRD pattern of the synthesized hybrid structures. The data analysis shows that the peaks observed at the angles of 14.77˚, 20.97˚, 29.95˚, 42.9˚, and 45.74˚ correspond to the Miller plates with Miller indexes of (100), (110), (200), (210), (220), and (300) related to the cubic structure of $CH_3NH_3PbBr_3$ with the lattice constant of 5.657 angstroms.

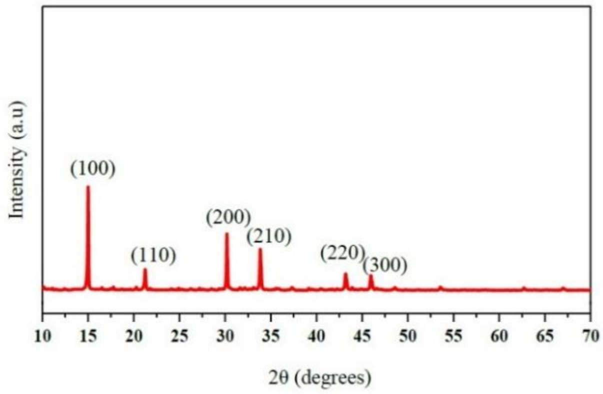

Figure 2. X-ray diffraction pattern of $CH_3NH_3PbBr_3$

Figure 3 shows the absorption spectrum of the synthesized structure. This spectrum was obtained at the room temperature. As observed, this structure is characterized by high absorption rate at the wavelength of 522 nanometers.

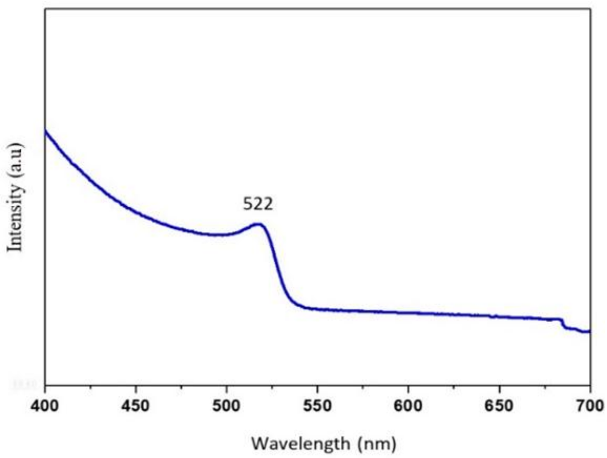

Figure 3. Uv-visible absorbtion spectra of $CH_3NH_3PbBr_3$

In order to determine the energy gap of the synthesized hybrid structure, reflection diffusion spectroscopy was employed. Diffusion reflection spectroscopy shows the transfer of electrons from the valence band to the conduction band as a result of absorbing the energy of the descended photon, thus reducing the intensity of the light in the said wavelength. Accordingly, the relative percentage of the transmitted to the reflected light decreases. Figure 4 presents the diffuse reflection spectrum of $CH_3NH_3PbBr_3$ perovskite structure according to which, at the wavelength of 580 nanometers, there is a sharp decrease in the intensity of the reflected light.

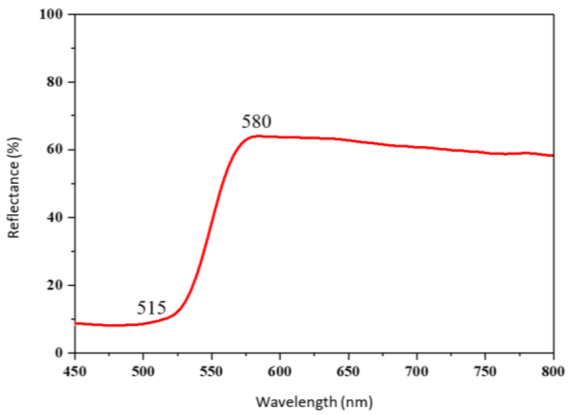

Figure 4. The diffuse reflection spectrum of $CH_3NH_3PbBr_3$ perovskite structure

Moreover, in order to determine the energy gap through the theory of Mott and Davis [16], the curve of changes $(\alpha h\nu)^2$ in the photon energy (hν) is drawn in Figure 5. By drawing a tangent line to the graph in the linear region, the energy gap for the synthesized hybrid structure is determined. As demonstrated in Figure 5, the energy gap in the $CH_3NH_3PbBr_3$ hybrid structure is 2.30 electron volts.

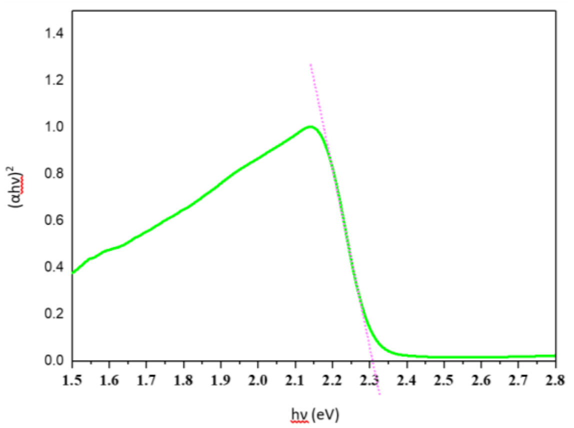

Figure 5. Curve of $(\alpha h\nu)^2$ as function of photon energy (hν) for the $CH_3NH_3PbBr_3$

Figure 6 shows the I–V diagram of the photodetector based on $CH_3NH_3PbBr_3$ organic-inorganic hybrid material made with 1.8 wt. % in dimethylsulfoxide solvent under both darkness and illumination. As observed in the diagram under illumination, the short-circuit current (I_{SC}) for this photodetector is equal to 1 μA, and the response rate of the current for this photodetector is equal to 0.027 μA/W (Equation (1)). The graph under darkness also starts from zero and increases exponentially, considering that there is no light or radiation.

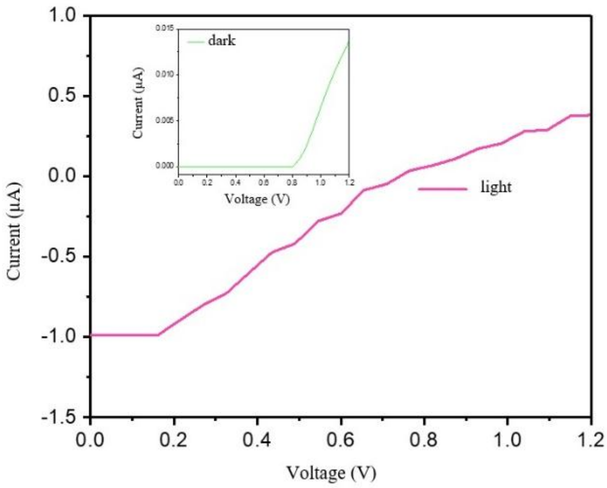

Figure 6. The current-voltage curve of photodetector based on an organic-inorganic hybrid material $CH_3NH_3PbBr_3$ with 1.8 wt. % in dimethyl sulfoxide under both darkness and light

Figure 7 depicts the I–V curve of the photodetector made based on $CH_3NH_3PbBr_3$ organic-inorganic hybrid material with 1.2 wt. % in DMSO solvent.

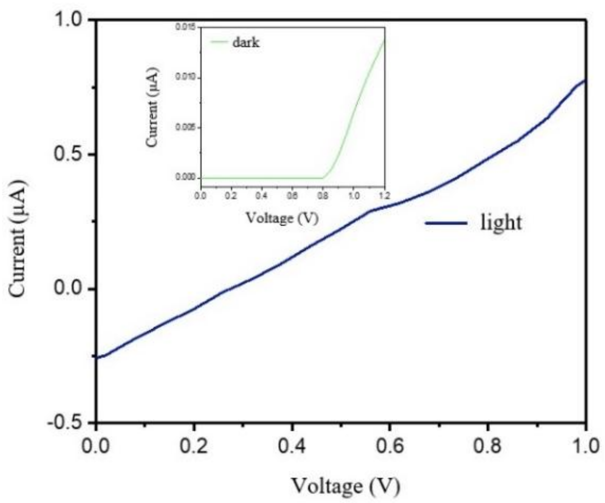

Figure 7. The current-voltage curve of photodetector based on an organic-inorganic hybrid material $CH_3NH_3PbBr_3$ with 1.2 wt. % in dimethyl sulfoxide under both darkness and light

According to the I-V curves, the I_{SC} in this detector was calculated to be 0.25 µA, and the current response for this detector was calculated to be 0.006 µA/W, which is less than 1.8 wt. %. It can be concluded that the higher the short circuit current, the greater the surface area under the I–V diagram and the higher the response rate.

4. CONCLUSION

The current study used $CH_3NH_3PbBr_3$ organic-inorganic hybrid materials to design photodetectors in small dimensions. The current response rate was calculated for the photodetector based on $CH_3NH_3PbBr_3$ hybrid material with 1.8 wt. % in DMSO solvent equal to 0.027 µA/W, which showed the highest response among other photodetectors made in this research. The results revealed that with an increase in the concentration of perovskite material, the response rate for photodetectors would increase. Application of organic-inorganic hybrids led to the development of new generation photodetectors mainly due to the optically tunable nature of these materials. As a result, an adequate band gap was obtained, hence significant efficiency in collecting the load produced by light.

ACKNOWLEDGEMENTS

The authors thank the University of Mohaghegh Ardabili for their cooperation and support.

REFERENCES

1. Huang, S. M., Huang, S. J., Yan, Y. J., Yu, S. H., Chou, M., Yang, H. W., Chang, Y. S., Chen, R. S., "Extremely high-performance visible light photodetector in the Sb_2SeTe_2 nanoflake", ***Scientific Reports***, Vol. 7, No. 1, (2017), 45413. https://doi.org/10.1038/srep45413
2. Tang, Y., Cao, X., Chi, Q., "Two-dimensional halide perovskites for emerging new-generation photodetectors", In Nayak, P. K. (ed.), ***Two-Dimensional Materials for Photodetector; InTech Open: London***, (2018), 75-101. https://doi.org/10.5772/intechopen.71032
3. Bass, M., ***Handbook of Optics: volume I - Geometrical and Physical Optics, Polarized Light, Components and Instruments***, 3rd Ed., McGraw-Hill Education, New York, (2010). https://www.accessengineeringlibrary.com/content/book/9780071498890
4. Jansen-van Vuuren, R. D., Armin, A., Pandey, A. K., Burn, P. L., Meredith, P., "Organic photodiodes: the future of full color detection and image sensing", ***Advanced Materials***, Vol. 28, No. 24, (2016), 4766-4802. https://doi.org/10.1002/adma.201505405
5. Wang, Z., Yu, C., Zhong, W. D., Chen, J., Chen, W., "Performance of a novel LED lamp arrangement to reduce SNR fluctuation for multi-user visible light communication systems", ***Optics express***, Vol. 20, No. 4, (2012), 4564-4573. https://doi.org/10.1364/OE.20.004564
6. Peng, L., Hu, L., Fang, X., "Low-dimensional nanostructure ultraviolet photodetectors", ***Advanced Materials***, Vol. 25, No. 37, (2013), 5321-5328. https://doi.org/10.1002/adma.201301802
7. Bhattacharya, P., ***Semiconductor Optoelectronic Devices***, 2nd Ed., Prentice-Hall, Inc., USA, (1997).
8. Müller, A., Konstantinidis, G., Androulidaki, M., Dinescu, A., Stefanescu, A., Cismaru, A., Neculoiu, D., Pavelescu, E., Stavrinidis, A., "Front and backside-illuminated GaN/Si based metal–semiconductor–metal ultraviolet photodetectors manufactured using micromachining and nano-lithographic technologies", ***Thin Solid Films***, Vol. 520, No. 6, (2012), 2158-2161. https://doi.org/10.1016/j.tsf.2011.09.045
9. Yoon, K. H., Ahn, J. K., Cho, J. Y., "Optical characteristics of undoped and Mn doped ZnS films", ***Journal of Materials Science***, Vol. 36, No. 6, (2001), 1373-1376. https://doi.org/10.1023/A:1017599302802
10. Zhao, Q., Sheng, T., Wang, Y., Tang, Z., Chen, Y., Cai, L., Ling, H., "M2det: A single-shot object detector based on multi-level feature pyramid network", In ***Proceedings of the AAAI Conference on Artificial Intelligence***, Vol. 33, No. 1, (2019), 9259-9266. https://ojs.aaai.org/index.php/AAAI/article/view/4962/4835
11. Feng, Q., Huang, L., Han, G., Li, F., Li, X., Fang, L., Xing, X., Zhang, J., Mu, W., Jia, Z., Guo, D., "Comparison Study of β-Ga_2O_3 Photodetectors on Bulk Substrate and Sapphire", In ***IEEE Transactions on Electron Devices***, Vol. 63, No. 9, (2016), 3578-3583. https://doi.org/10.1109/TED.2016.2592984
12. Deng, H., Yang, X., Dong, D., Li, B., Yang, D., Yuan, S., Qiao, K., Cheng, Y. B., Tang, J., Song, H., "Flexible and semitransparent organolead triiodide perovskite network photodetector arrays with high stability", ***Nano Letters***, Vol. 15, No. 12, (2015), 7963-7969. https://doi.org/10.1021/acs.nanolett.5b03061
13. Li, D., Dong, G., Li, W., Wang, L., "High performance organic-inorganic perovskite-optocoupler based on low-voltage and fast response perovskite compound photodetector", ***Scientific Reports***, Vol. 5, No. 1, (2015), 7902. https://doi.org/10.1038/srep07902
14. Ahmad, S., Hanmandlu, C., Kanaujia, P. K., Prakash, G. V., "Direct deposition strategy for highly ordered inorganic organic perovskite thin films and their optoelectronic applications", ***Optical Materials Express***, Vol. 4, No. 7, (2014), 1313-1323. https://doi.org/10.1364/OME.4.001313
15. Pradeesh, K., Baumberg, J. J., Prakash, G. V., "In situ intercalation strategies for device-quality hybrid inorganic-organic self-assembled quantum wells", ***Applied Physics Letters***, Vol. 95, No. 3, (2009), 033309. https://doi.org/10.1063/1.3186639
16. Papavassiliou, G. C., Mousdis, G. A., Raptopoulou, C. P., Terzis, A., "Preparation and Characterization of $[C_6H_5CH_2NH_3]_2PbI_4$, $[C_6H_5CH_2CH_2SC(NH_2)_2]_3PbI_5$ and $[C_{10}H_7CH_2NH_3]PbI_3$ Organic-Inorganic Hybrid Compounds", ***Zeitschrift für Naturforschung B***, Vol. 54, No. 11, (1999), 1405-1409 https://doi.org/10.1515/znb-1999-1112