Synthesis of quasi-one-dimensional nanomaterials and heterostructures based on zinc and copper oxides

S P Murzin[1,2], M V Blokhin[2]

[1]TU Wien, Karlsplatz 13, 1040 Vienna, Austria
[2]Samara University, Moskovskoe Shosse 34A, Samara, Russia, 443086

•Abstract

ZnO nanostructures are used in optical electronics and microelectronics, microsystems engineering. Characteristics of ZnO-based materials are improved by producing heterojunctions with oxides of other metals, including copper oxide. The use of quasi-one-dimensional structures provides the possibility for the total surface area of a heterojunction to be increased. Investigations aimed at the study of controlling the morphology of quasi-one-dimensional oxides are rather limited, so that the aspect considered in this regard continues to be very relevant. As a result, the search for the most efficient synthesis processes that give not only greater productivity, but also higher quality and improved material properties continues. A method for the synthesis of the ZnO/CuO heterostructure based on zinc oxide nanowires by pulse-periodic laser irradiation is described. The improvement of systems for shaping the laser beam with elements of diffractive computer optics provides an opportunity to control the processes involved in such synthesis.

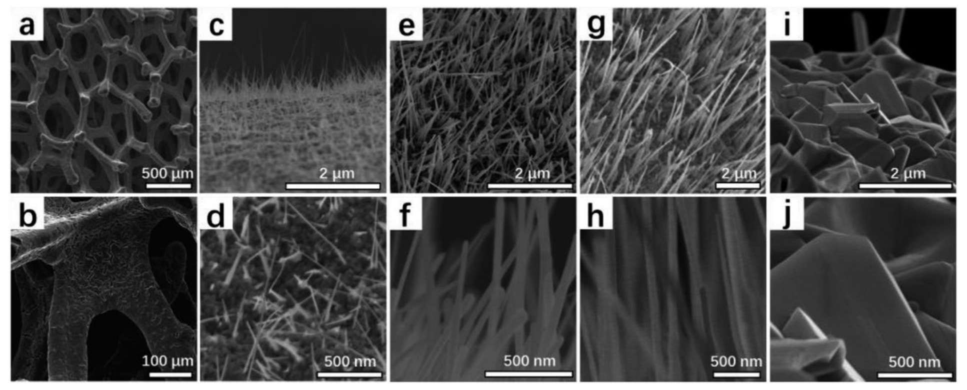

Figure 1. Scanning electron microscopy (SEM) images of CuO nanowires grown by heating a copper foam substrate (a, b) in air for 4 hours at temperatures: 400 °C (c, d); 500 °C (e, f); 600 °C (g, h), 700 °C (i, j) [1].

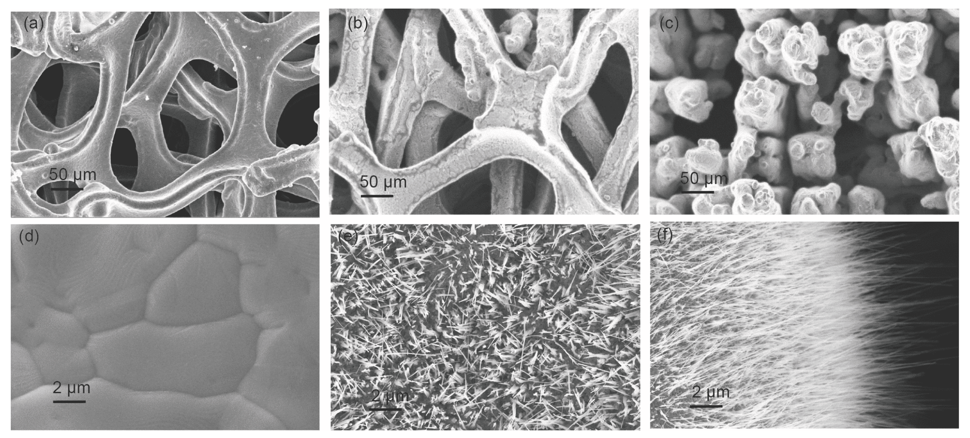

Figure 2. SEM images of CuO nanowires: the initial sample (a, d), CuO nanowires obtained by direct thermal oxidation (b, e), CuO nanowires obtained by laser nanosecond texturing and thermal oxidation (c, f) [2].

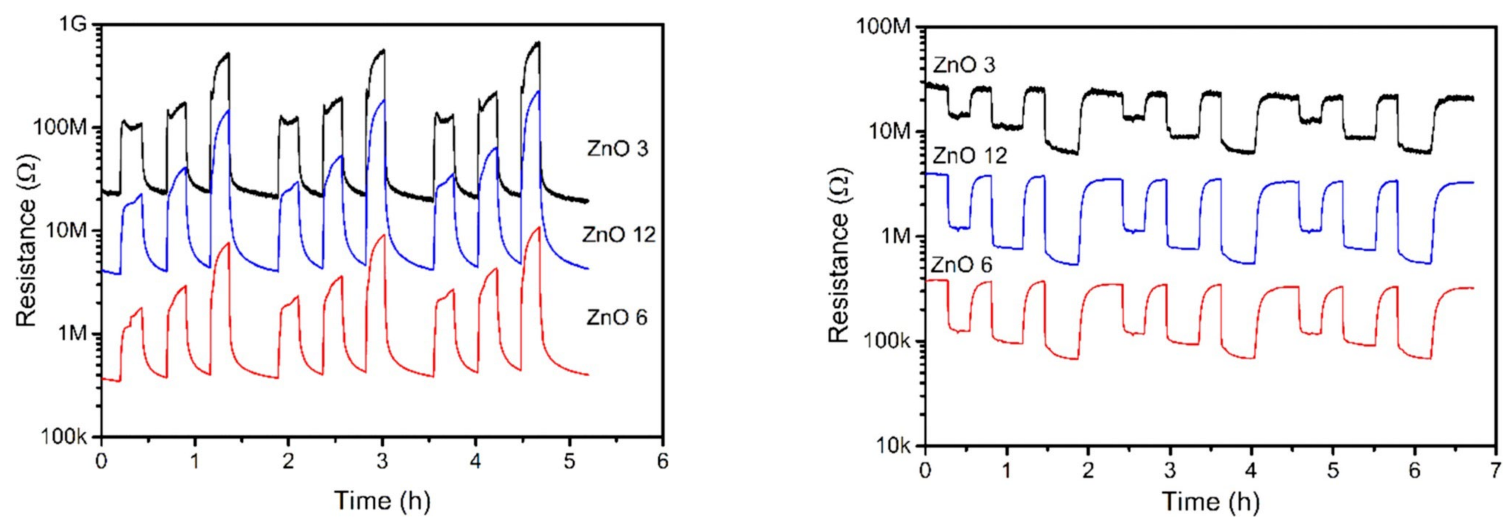

Figure 3. Resistance behaviour of the created gas sensors based on ZnO nanowires synthesized by vapor phase deposition to the cycles of triggering and recovery of increasing concentrations of nitrogen dioxide (top) and ethanol (bottom). The sensors were operated at 250°C[3].

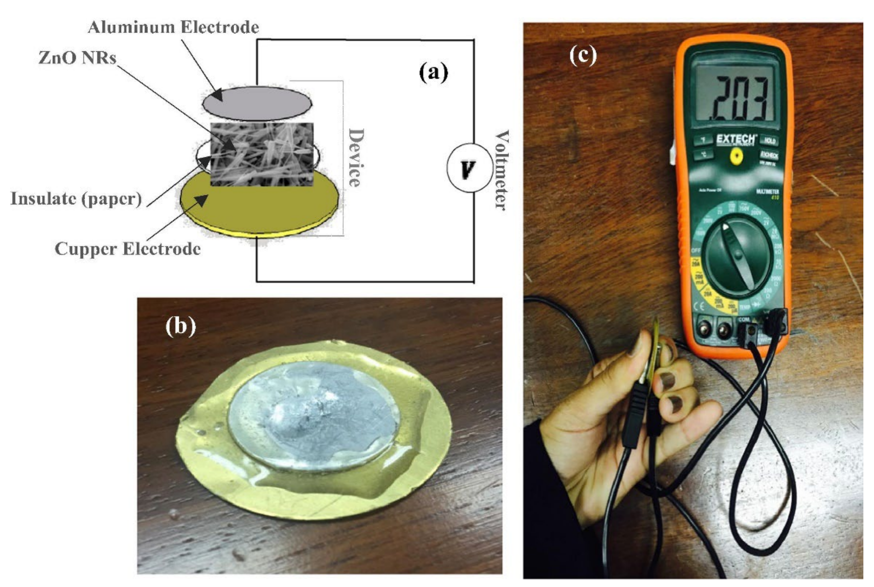

Figure 4. Piezoelectric nanogenerator based on ZnO nanorods: device setup (a); photo of the device (b) and testing the nanogenerator's operability(c) [4].

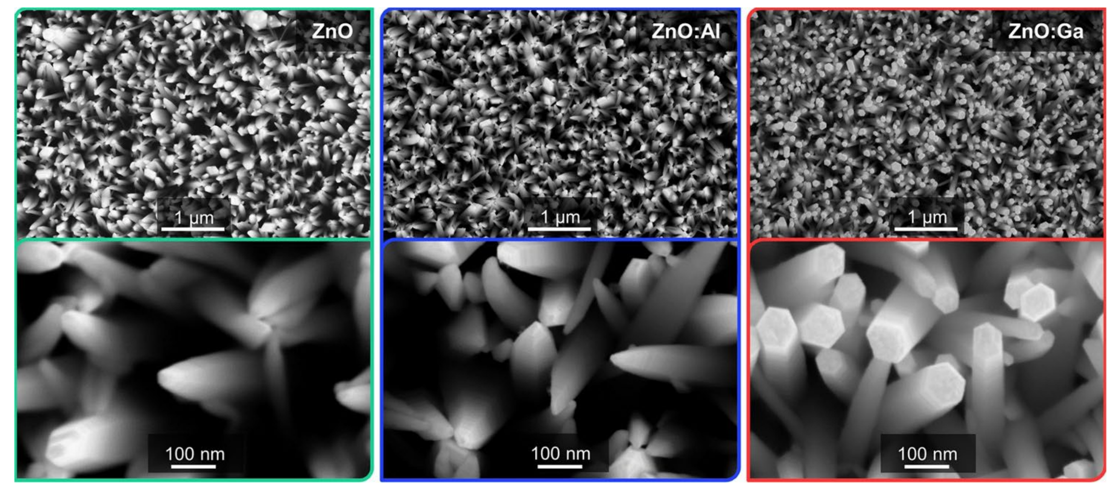

Figure 5. SEM images of synthesized unalloyed (left) as well as aluminium-doped (center) and gallium-doped (right) ZnO nanowire arrays[5].

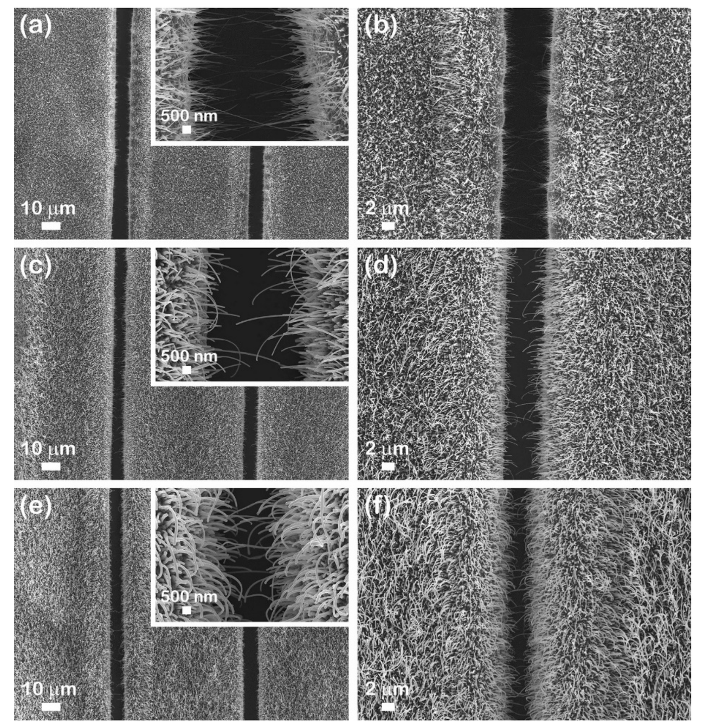

Figure 6. Field emission scanning electron microscope (FESEM) images - at different magnifications - of synthesized CuO nanowires (a,b) and arrays of CuO-ZnO core-shell nanowires produced with two different regimes: with 20-minute ZnO deposition time (c,d) and with 30-minute ZnO deposition time (e,f) [6].

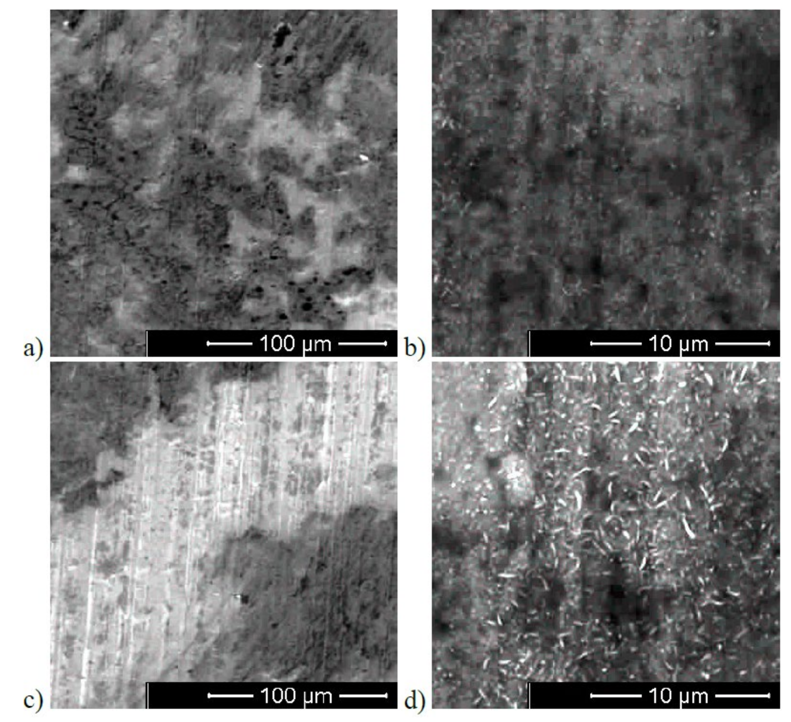

Figure 7. SEM images of ZnO nanowires and CuO nanofilms formed on a mechanical grinded Cu-Zn alloy substrate after laser selective oxidation using different treatment parameters (a), (c). Magnified images (b), (d) [7].

•Conclusion

The characteristics of ZnO-based materials are improved by obtaining heterojunctions with other metal oxides. CuO copper oxide that is a semiconductor with indirect bandgap and p-type conductivity, can be successfully applied to obtain a heterojunction with ZnO. The applied quasi-one-dimensional structures enable us to increase the total surface area of the heterojunction.

The methods for synthesis one-dimensional nanostructures are chemical vapor deposition, liquid-phase methods, and template synthesis. The use of chemical vapor deposition involves the creation of specific growing conditions. Surface-active substance molecules can selectively adsorb on the faces of nanocrystals, inhibiting their growth in these directions, which is a significant disadvantage of liquid-phase methods. The structures produced by the template method have insufficiently high crystalline perfection; in addition, there is a need for subsequent removal of the template substance. Therefore, the problem of developing reliable methods for the synthesis of such nanomaterials with predetermined properties remains relevant.

A method for the synthesis of ZnO/CuO heterostructures based on zinc oxide nanowires by pulse-periodic laser irradiation is described. Oxidation products that were formed by the laser treatment were dependent on the initial composition of the surface. A network of zinc oxide nanowires coated with copper oxide nanofilms was formed on the dezincified surface of the copper-zinc alloy during laser irradiation. A fundamentally important distinguishing feature of this direction was, in fact, the use of laser-initiated vibrations, which contributed to more intense diffusion processes compared to the simple effects of laser beam heating in the solid phase of metallic materials. The stated physical effect was achieved through the synergy of heating and vibration in the sound/infrasound frequency ranges, which led to a nonstationary stress-strain state. The improvement of the systems responsible for laser beam shaping with elements of diffractive computer optics makes it possible to effectively control of thermochemical processes of synthesis of a quasi-one-dimensional ZnO-based structure. Variants of such materials include creation of multilayer structures based on metal oxides.

•References

[1] C. Wang, F. Yang, Y. Cao, X. He, Y. Tang, and Y. Li, “Cupric oxide nanowires on three-dimensional copper foam for application in click reaction,” RSC Adv., vol. 7(16), pp. 9567–9572, 2017.

[2] H. Yan, Z. Chen, X. He, K. Zhang, S. Shen, Z. Wang, and R. Zhou, “Fabrication and photocalytic performance of CuO nanowires on copper foam based on laser texturing,” Sci. Sin.: Phys. Mech. Astron., vol. 49(1), 034209, 2019.

[3] E. Navarrete, F. Güell, P.R. Martínez-Alanis, and E. Llobet, “Chemical vapour deposited ZnO nanowires for detecting ethanol and NO2,” J. Alloys Compd., vol. 890, 161923, 2022.

[4] M.S. Al-Ruqeishi, T. Mohiuddin, B. Al-Habsi, F. Al-Ruqeishi, A. Al-Fahdi, and A. Al-Khusaibi, “Piezoelectric nanogenerator based on ZnO nanorods,” Arab. J. Chem., vol. 12(8), pp. 5173–5179, 2019.

[5] P. Gaffuri, T. Dedova, E. Appert, M. Danilson, A. Baillard, O. Chaix-Pluchery, F. Güell, I. Oja-Acik, and V. Consonni, “Enhanced photocatalytic activity of chemically deposited ZnO nanowires using doping and annealing strategies for water remediation,” Appl. Surf. Sci., vol. 582, 152323, 2022.

[6] A. Costas, C. Florica, N. Preda, C. Besleaga, A. Kuncser, I. Enculescu, “Self-connected CuO–ZnO radial core–shell heterojunction nanowire arrays grown on interdigitated electrodes for visible-light photodetectors,” Sci. Rep., vol. 12(1), 6834, 2022.

[7] S.P. Murzin, S.A.Afanasiev, and M.V. Blokhin, “Pulse-periodic laser action to create an ordered heterogeneous structure based on copper and zinc oxides,” J. Phys. Conf. Ser., vol. 1096(1), 012139, 2018.