Self-forming nanocomposite concept for ZnO-based thermoelectrics

Kiryl V. Zakharchuk[1], Marc Widenmeyer[2], Denis O. Alikin[3,4], Wenjie Xie[2], Sascha Populoh[5,6], Sergey M. Mikhalev[7], Alexander Tselev[3], Jorge R. Frade[1], Anke Weidenkaff[2,8], Andrei V. Kovalevsky[1]

1 — Department of Materials and Ceramic Engineering & CICECO, University of Aveiro
2 — Institute for Materials Science, University of Stuttgart, Germany
3 — Department of Physics & CICECO, University of Aveiro
4 — School of Natural Sciences and Mathematics, Ural Federal University, Russian Federation
5 — Empa, Materials for Energy Conversion, Switzerland
6 — ABB Switzerland Ltd., Semiconductors, Switzerland
7 — Department of Mechanical Engineering & TEMA-NRD, University of Aveiro
8 — Technische Universität Darmstadt, Germany

Thermoelectric (TE) technology allows direct production of electrical energy from waste heat and natural heat sources. Although today TEs are hardly competitive in efficiency with heat engines at the large scale, absence of moving parts, inherent simplicity and scalability of this solid-state technology enable various applications for harsh and remote environments, for solar energy conversion as well as in automotive/aerospace sectors. In these applications, requirements to thermal stability, cost and toxicity may even dominate over efficiency. Zinc oxide (ZnO) is one of TE materials already known for an extraordinary combination of useful electrical, catalytic and photochemical properties. However, coupling between electrical and thermal transport properties restricts improvement of the TE conversion efficiency in the material. The efficiency can be represented as figure-of-merit, $ZT=\sigma x \alpha^2 x \kappa^{-1}$, highlighting the great TE challenge to simultaneously increase the electrical conductivity (σ) and Seebeck coefficient (thermopower, α) while suppressing the thermal conductivity (κ). Independent tuning of the involved material properties is the only way to boost the conversion efficiency.

This work demonstrates a new nanocomposite concept for ZnO-based materials, employing intentional incorporation of the external ZrO_2 nanoparticles (Figure 1, left: bright and red) and in situ formation of a new $ZnAl_2O_4$ nanophase (Figure 1, left: dark and blue), promoted by controlled chemical interactions between the composite components. An interplay between the presence and exsolution of the nanophases and modification of the host ZnO-based matrix leads to an enhanced electrical performance, simultaneously suppressing the thermal transport due to phonon scattering at the interfaces created by the nanoparticles (Figure 1, right). Such decoupling of the electrical and thermal transport is highly promising for implementation in other TE oxide systems.

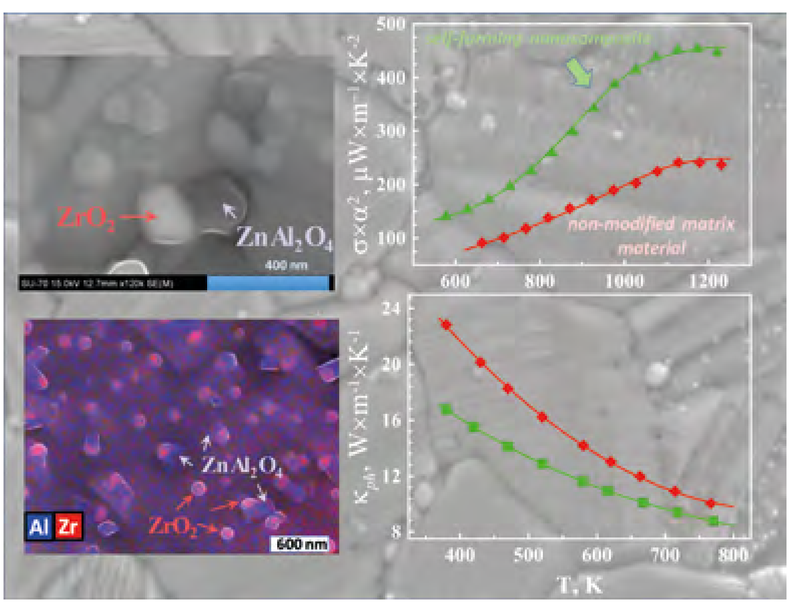

FIGURE 1
Microstructure and chemical composition (left), and electrica $\sigma x \alpha^2$ and thermal (κ) counterparts of the thermoelectric efficiency (right).