Subject:

Thermoelectric technologies for power generation, cooling and sensor applications

Leader:

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Abstract (max 150 words):

The Thermoelectric Research Laboratory (TRL) at AGH is a leading research center for thermoelectric innovation in Poland, integrating cutting-edge research with advanced technological development. The team has developed unique semiconducting materials and engineered breakthrough devices for direct heat-to-electricity conversion and thermoelectric cooling, demonstrating their applicability in real-world applications. Our solutions demonstrate a high level of technological maturity, with an estimated average Technology Readiness Level (TRL) exceeding 6+, including the assembly of a laboratory-scale production line for thermoelectric converters.

The primary goal of this project is to scale these advanced thermoelectric technologies to industrial production, driving progress in renewable energy applications. Thermoelectric solutions align closely with multiple United Nations Sustainable Development Goals (SDGs), particularly in the areas of energy efficiency, sustainability, and climate action.

For further details, please refer to the related presentation or visit the TRL AGH website: http://www.thermlab.agh.edu.pl/.

Related founding (last 5 years):

The TRL team has carried out over 20 projects related to thermoelectric technology. The most important are:

- IMPRESS-U NAWA, BNP/NSF/2023/1/00010/DEC/01, *„Decoupling Structure and Composition with Zintl Phases*, National Agency for Academic Exchange, Partners: Michigan State University, University of Lviv, (2024-2026), **~ 250 000 USD**
- OPUS-2023/51/B/ST11/00329/R, *„Diamond-like semiconductors as low-cost thermoelectric materials for direct conversion of waste heat into electricity*", National Science Centre (2024-2027) **~ 180 000 USD**
- MAITEG, WEAVE-UNISONO 2022/04/Y/ST5/00139, *„Entropy engineering and interface optimization in materials for highly effective thermoelectric energy conversion*", National Science Centre and German

Research Foundation, Partners: German Aerospace Institute (DLR) and University of Duisburg-Essen (UDE), (2024-2027), **~500 000 USD**

- PRELUDIUM-21/2022/45/N/ST5/02070 *„Relationship between structural and thermoelectric properties in Cu_6Te_3S and $Cu_{9.1}TeSb_3$ materials with close-packed tetrahedra structure*" (2023-2025), ~60 000 USD
- DIAMANT GRANT, 0025/DIA/2020/49, *„Organic Peltier Elements based on Conducting Polymers", Ministry of Science and Higher Education* (2020-2024), **~60 000 USD**
- TEAM-TECH/2016-2/14, *„New approach for the development of efficient materials for direct conversion of heat into electricity"*, Foundation for Polish Science (2018-2022), **~ 900 000 USD**
- TECHMATSTRATEG2/408569/5/NCBR/2019, *„Development of a technology for the production of a new type of thermoelectric modules for the conversion of low-parameter waste heat into electricity"*, National Centre for Research and Development (2019-2022), **~2 500 000 USD**

and other international, national and R&D projects with several industrial partners such as: **Honda LTD, Sasol Technology Ltd, EDF Poland, Synthos S.A., Collins Aerospace Poland, General Electric Aviation Poland, and Mesko S.A..** and others.

Total funding: > 6 million USD

Selected publications (last 5 years):

1. Taras Parashchuk, Bartłomiej Wiendlocha, Oleksandr Cherniushok, Kacper Pryga, Kamil Ciesielski, Eric Toberer, Krzysztof T. Wojciechowski, *Multiple defect states engineering towards high thermoelectric performance in GeTe-based materials*, Chemical Engineering Journal, 499 2024, s. 1-15.
2. Maja Sajdak, Janusz Toboła, Taras Parashchuk, Maciej Krzywiecki, Paulina Powroźnik, Krzysztof T. Wojciechowski, *Probing hydrogen content in steel using the thermoelectric effect,* Chemical Engineering Journal ; 485, 2024
3. A. Lis, K. Zazakowny, O. Cherniushok, J. Tobola, M. Gajewska, T. Parashchuk, K.T. Wojciechowski, *Nanostructured $Cu_{12+x}Sb_4S_{13}$ tetrahedrites prepared by solvothermal synthesis in 1-(2-aminoethyl)piperazine for efficient thermal energy harvesting*, J. Alloys Compd., 977, 173337 (2024) IF 6.2, DOI: 10.1016/j.jallcom.2023.173337
4. R. Knura, M. Maksymuk, T. Parashchuk, K.T. Wojciechowski, *Achieving high thermoelectric conversion efficiency in Bi_2Te_3-based stepwise legs through bandgap tuning and chemical potential engineering*, Dalton Trans., 53, 123-135 (2024). DOI: 10.1039/D3DT03061J
5. M. Maksymuk, T. Parashchuk, A. Burbelko, K.T. Wojciechowski, *Thermoelectric converter with stepwise legs for high energy conversion efficiency*, J. Chem. Eng., 472, 144899 (2023).
6. M. Maksymuk, K. Zazakowny, A. Lis, A. Kosonowski, T. Parashchuk, K.T. Wojciechowski, *Development of the anodized aluminum substrates for thermoelectric energy converters*, Ceram. Int. 49, 3, 4816-4825 (2023).
7. T. Parashchuk, R. Knura, O. Cherniushok, K.T. Wojciechowski, *Ultralow Lattice Thermal Conductivity and Improved Thermoelectric Performance in Cl-doped $Bi_2Te_{3-x}Se_x$ Alloys*, ACS Appl. Mater. Interfaces 14, 29, 33567–33579 (2022).
8. T. Parashchuk, B. Wiendlocha, O. Cherniushok, R. Knura, and K.T. Wojciechowski, *High Thermoelectric Performance of p-Type PbTe Enabled by the Synergy of Resonance Scattering and Lattice Softening*, ACS Appl. Mater. Interfaces, 13, 41, 49027–49042 (2021).
9. A. Kumar, P. Bhumla, T. Parashchuk, S. Baran, S. Bhattacharya, K.T. Wojciechowski, *Engineering electronic structure and lattice dynamics to achieve enhanced thermoelectric performance of Mn-Sb co-doped GeTe*. Chem. Mater., 33, 10, 3611–3620 (2021).
10. K.T. Wojciechowski, T. Parashchuk, B. Wiendlocha, O. Cherniushok, and Z. Dashevsky, *Highly efficient n-type PbTe developed by advanced electronic structure engineering*, J. Mater. Chem. C, 8, 13270-13285 (2020).

Related patents and patent applications (selected):

1. K. Wojciechowski, T. Parashchuk, O. Cherniushok, *Gamma-argyrodite structure material for thermoelectric conversion and the method of obtaining the same,* EP4292982A1 (2023)
2. O. Cherniushok, T. Parashchuk, K. Wojciechowski, EP24219360 (P.450136), *Cu, Te, and S-based material for thermoelectric conversion and method of preparation thereof* (2024)
3. *K. Wojciechowski, A. Kosonowski, A. Słyś, Method of obtaining Cu-Sb-S group compounds with a tetrahedral structure, patent* PL 243015 B1, (2023)
4. K. Wojciechowski, T. Parashchuk, M. Maksymuk, *Thermoelectric converter based on functionally graded materials,* EP23190983A (2023)
5. M. Musiał, K. Wojciechowski, *Cascaded thermoelectric converter, utility model* PL73351Y1 (2023),
6. K. Wojciechowski, M. Musiał, *System for generating electricity, especially from waste heat,* PL444457A1, (2023)
7. K. Wojciechowski, K. Marszalek, *A hybrid solar energy converter, EU patent* EP2827383B1 (2017)
8. K. Wojciechowski, *Method for control of energy flow in a thermal object, in particular a chemical reactor* PL243914B1 (2020),
9. K. Wojciechowski, Tadeusz Wójcik, Karol Sztekler., *Method for transformation of gas heat energy in electrostatic filter,* PL228901B1, (2017)
10. K. T. Wojciechowski, M. Sajdak *Thermoelectric indenter and measuring system for determining hydrogen content and microhardness*, EP23215081.3, (2024)
11. K. Wojciechowski, *Method for measuring properties of thermoelectric materials and the measuring probe for this method,* PL238822B1 (2021),