Redox reaction of thermally excited carriers: Semiconductor-sensitized thermal cell

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We present a novel thermal energy conversion technology named the semiconductor-sensitized thermal cell (STC), conceptually derived from the dye-sensitized solar cell (DSSC). In DSSCs, organic dye molecules absorb photons, causing electron excitation. These electrons are transferred to the electron transport layer and flow through the external circuit to the counter electrode, where they reduce electrolyte ions. The cycle completes via redox reactions involving the remaining holes in the dye. This closed-loop electron flow generates electricity under light irradiation. Inorganic alternatives such as quantum-dot-sensitized solar cells have also been explored to overcome the photodegradation of organic dyes.

Inspired by this mechanism, we hypothesized that thermal excitation of a semiconductor—in place of photoexcitation—could initiate a similar charge transfer cycle. In STCs, the semiconductor plays an analogous role to the dye, enabling thermally excited electrons to flow from the working electrode through the external circuit to the counter electrode, and back via ionic conduction in the electrolyte. This thermally driven electron cycling effectively converts low-grade heat into electricity.

Following successful theoretical validation and early experimental demonstration of STC operation [1, 2], we founded elleThermo, Ltd. to advance this technology toward practical applications. Our proof-of-concept studies have included:

- Recharging lithium-ion batteries using STC modules installed in geothermal environments in Mexican mining sites.
- Harvesting waste heat from immersion-cooled data center servers to generate electricity, contributing to energy recycling in high-performance computing infrastructure.

These results confirm the STC's potential as a flexible and scalable platform for low-temperature heat recovery in diverse environments.

References

[1] S. Matsushita, Chem. Commun., 61 (2025) 5556-5562.
[2] S. Matsushita, A. Tsuruoka, E. Kobayashi, T. Isobe, and A. Nakajima, Mater. Horiz., 4 (2017) 649–656.

Figures

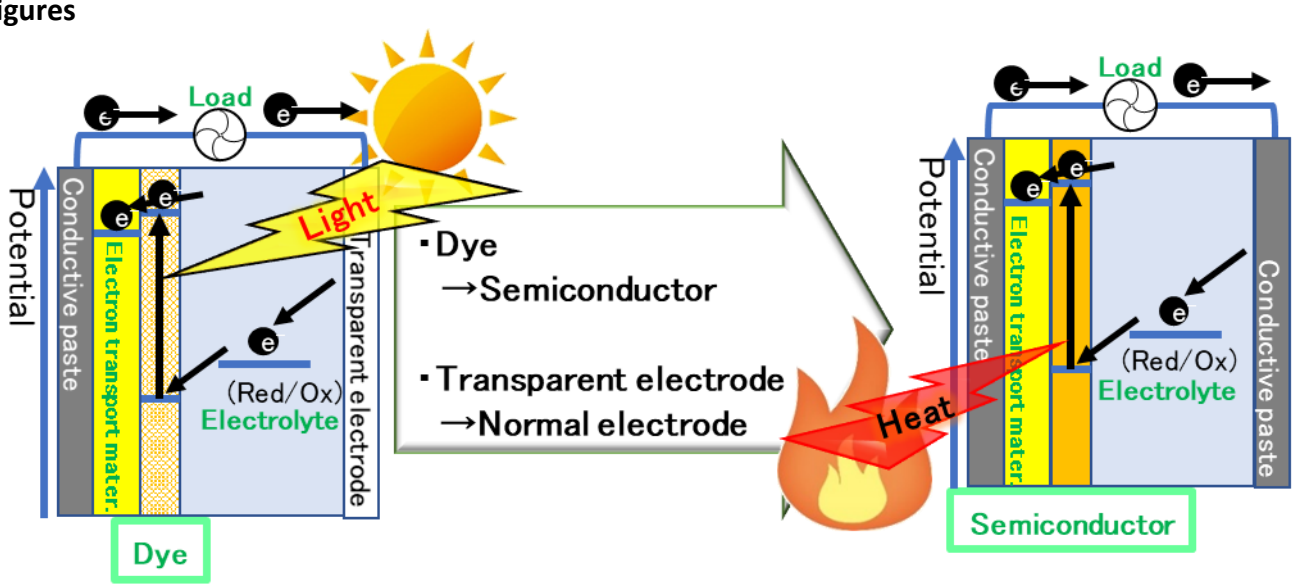

Figure 1: Schematic image of a dye-sensitized solar cell and a semiconductor-sensitized thermal cell. [1]