Just add water; boiling up high-performing thermoelectrics

Thermoelectric materials can realise direct conversion from thermal to electrical energy and offer unique opportunities to harvest useful electricity from waste heat. Tin selenide (SnSe) is one of the best thermoelectrics currently known as it combines an excellent energy conversion efficiency with relatively low toxicity. Furthermore, its component elements are Earth-abundant and inexpensive. Unfortunately, the synthesis of the material takes a large amount of time and energy involving the heating and melting of the starting materials at high temperature (800 -1223 K). So-called "bottom-up" solution synthesis can realise the synthesis of SnSe nanostructures at relatively lower temperatures. When SnSe forms nanostructures, its properties can be enhanced. However, organic surfactants are needed in the synthesis to limit the growth of the SnSe crystals and these molecules, which coat the surface of the SnSe, are commonly electrically insulating. This coating can drastically reduce the electrical conductivity and hence degrade the thermoelectric performance of the material. It is imperative to develop a fast, cheap, scalable surfactant-free solution route to high-performance SnSe before its potential in a device can be fully realised.

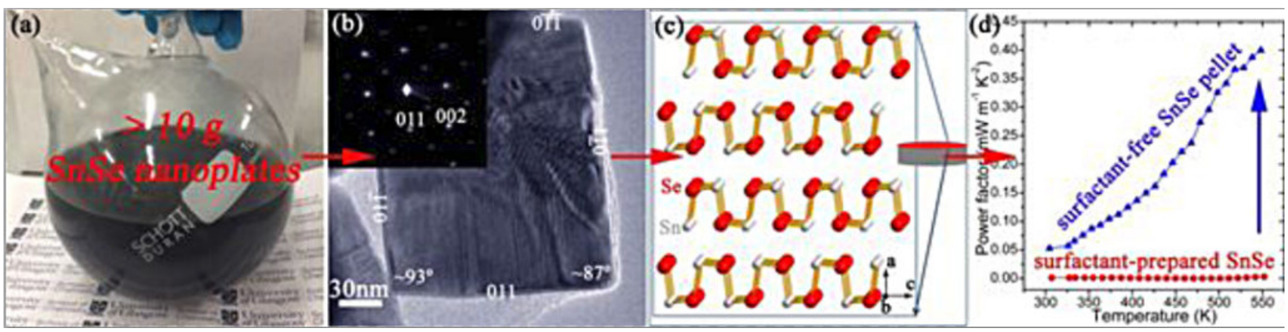

Fig. 1. (a) Nanoplate solution after a typical synthesis; (b) TEM image of a SnSe nanoplate and its corresponding selected area diffraction pattern; (c) idealised schematic of the aligned crystalline layers within fabricated nanostructured bulk pellets; (d) thermoelectric power factors of pellets made from surfactant-free vs. surfactant-coated SnSe nanostructures.

To address this, we have developed a surfactant-free aqueous solution synthesis that is straightforward and rapid. It produces nanosized plates of SnSe that can be consolidated into dense pellets with exceptional electrical performance. The two major advantages of the synthesis route are:

> *Green and sustainable*: The synthesis simply requires water as a solvent and the boiling of a solution of the NaHSe and Na_2SnO_2 starting materials for 2 h. More than 10 g of SnSe nanomaterials can be made in a batch (Fig. 1a,1b). The thin sheet-like plates grow without the need for an organic surfactant and so the particle surfaces remain conducting.

High performance materials result: When the nanoplates are hot pressed into pellets, the grains align in accordance with the anisotropy of the crystal structure (Fig. 1c). The dense compacts exhibit excellent electrical conductivity and thermoelectric power factors at *ca*. 200-250 °C and are comparable to the best-performing polycrystalline SnSe materials (Fig. 1d).

To summarise, we have developed an energy-efficient, rapid and sustainable route to SnSe nanoplates that are hot pressed into nanostructured pellets with high thermoelectric power factors. Thermoelectric devices require 2 types of semiconducting material; “p-type” and “n-type”. We have extended our approach to make not only p-type but also n-type SnSe nanostructures (the relevant results will be reported soon). Therefore, this solution method offers a single cheap processing route to large quantities of both the essential materials needed for a thermoelectric device.

*Dr **Guang Han** and Prof. **Duncan H. Gregory***
WestCHEM, School of Chemistry, University of Glasgow, United Kingdom

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