Nanotechnologies, Materials, Energy

Development of ecofriendly nanostructured materials with high thermoelectric performance

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Abstract

As one of the clean power sources, thermoelectric conversion is highly attractive. To enhance the thermoelectric performance, lowering thermal conductivity and enhancing thermoelectric power factor are both required. Unlike heavy element-based materials with inherently-high thermoelectric performance, light element-based materials, which are ecofriendly, originally exhibit low thermoelectric performance. We succeeded in simultaneous realization of low thermal conductivity and high thermoelectric power factor by using nanostructuring technique. For example, connected Si nanodot system exhibited ultralow thermal conductivities beyond amorphous limit. Using nanodots with low thermal conductivity, in the Au-SiGe system including Ge-rich nanodots, higher power factor was achieved.

Background & Results

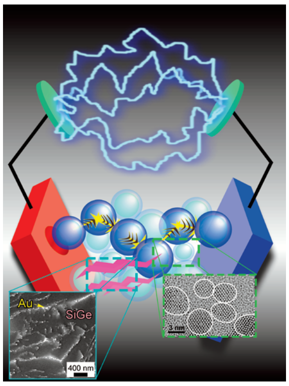
Thermoelectric conversion from wasted heat is drawing considerable attention as one of the clean power sources. For thermoelectric conversion, materials must have higher power factor and lower thermal conductivity simultaneously. Therefore, conventional thermoelectric materials are composed of heavy elements because of their inherently low thermal conductivity although they are generally toxic and expensive. On the other hand, ecofriendly light element-based materials, suitable to the social use, exhibit low thermoelectric performance in general. Using our nanostructuring technique, we have established a pronounced methodology to overcome the long-standing issue of thermoelectric conversion: simultaneous realization of low thermal conductivity and high thermoelectric power factor in ecofriendly materials. We first developed epitaxial connected Si nanodots (CSNs) with ultrasmall diameters, where nanodots worked as phonon scattering centers. The CSNs exhibited ultralow thermal conductivities beyond amorphous limit because of ultimate confinement of phonon. Recently, we expanded the nanostructure technique to development of transparent thermoelectric materials for reuse of heat on windows using nanowires.

Using this information about ultralow thermal conductivity nanostructures, we recently formed SiGe with a small amount of Au, where Ge-rich nanodots with low thermal conductivity exist around Au. Therein, due to the large contrast of thermal conductivity, large temperature difference is dominantly applied to Ge-rich nanodots (or SiGe) that has high Seebeck coefficient, not to Au with small Seebeck coefficient. Furthermore, resonant scattering occurs by Au impurity level in SiGe, which enhances Seebeck coefficient. By this strategy: thermal distribution control and resonant level scattering, we achieved twice enhancement of power factor.

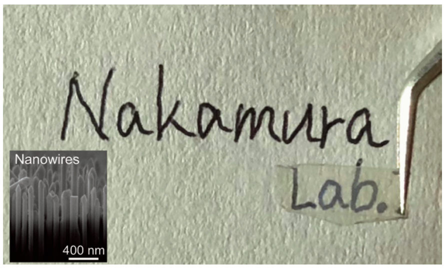
Thus, we succeeded in enhancing thermoelectric performance of light element-based materials, opening an avenue of ecofriendly thermoelectric materials suitable to social application.

Significance of the research and Future perspective

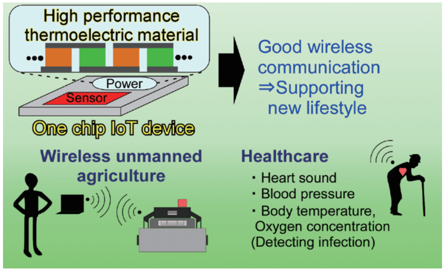
Our nanostructuring technique overcome the long-standing issue of thermoelectric conversion: simultaneous realization of low thermal conductivity and high thermoelectric power factor. This success shows us that even eco-friendly light element-based materials can have a potential as thermoelectric materials. Nowadays, the sensor network society is coming, which changes our lifestyle largely. If our nanostructured thermoelectric materials meet the requirement of social use as thermoelectric generator, they will play an important role in supplying electrical energy to the sensor.



High performance thermoelectric materials including well-controlled nanodot crystals



Transparent thermoelectric material including nanowires.



Future vision

Patent Japanese Patent Application No. 2019-220283, No. 2012-124940 PCT／JP2013／063580

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Keyword thermoelectric material, nanocrystal, ubiquitous element, crystal orientation, ecofriendly material