Nanostructures for Enhanced Solid-State Thermoelectric Power Generation

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Around 60% of total annual use energy in the U.S. (~100 quads) is rejected as heat. Therefore, recovering waste heat for power generations via an efficient means has become an imperative engineering task. In principle, solid-state thermoelectric generators (TEGs) are analog to thermal engines and particularly suitable for scavenging waste heat because they are compact, scalable, quiet, and no carbon emission. To make an impact on the energy crisis as well as environmental protection, thermoelectric (TE) materials must possess a very challenging, high figure of merit, $zT = S\sigma^2T/\kappa > 4$. This requires exceptional electrical properties (Seebeck coefficient, $S$, and electrical conductivity, $\sigma$) and thermal properties (both lattice thermal conductivity, $\kappa_l$, and electron thermal conductivity, $\kappa_e$) that do not coexist in any known bulk material system. Currently, the concepts with technical strategies widely adopted in the material research community are: the thermal conductivity reduction in nanostructures through phonon-surface scattering and size confinement effect, and the Seebeck coefficient enhancement in nanostructures through quantum confinement effect (i.e Mahan-Sofo theory).

The Wang group has developed a facile nanofabrication process based on nanosphere lithography for creating porous Si, and has demonstrated that the TE performance of porous silicon is highly enhanced by thermal conductivity reduction through phonon-surface scattering. As a part of the integrated REU program, an REU student will participate in the development of nanoporous Si/Ge alloys. Si/Ge alloy is one of the important commercialized TE materials, which is specifically used for high quality heat sources. The nanoporous structure theoretically could further enhance the TE performance in Si/Ge alloys through phonon suppression. A breakthrough of figure of merit will open the opportunity of extending the Si/Ge TEG applications for automobile power systems.

The research activities for the REU student includes Langmuir-Blodgett trough for nanosphere self-assembly, diffusion doping, photolithography, e-beam evaporation, deep reactive-ion etching, and hydrofluoric acid etching. The REU student will also use the state-of-the-art analytical instruments such as the scanning electron microscope and the semiconductor parameter analyzer. Finally, an electrical device will be fabricated for inspecting both Seebeck coefficient and electrical conductivity.

Figure hands-on research experience: fabrications of Si/Ge nanoporous ribbons.