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Quantum Materials Research for Energy Conversion Applications[1]

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The search for clean and renewable energy production methods is directly related to discovery of novel materials and composites with desired structural and electronic properties. Thermoelectric devices, which allow for direct energy conversion between heat and electricity, have a unique place in this effort since they enable solid state schemes for power generation and refrigeration/heating, involve no harmful gasses/liquids, avoid energy losses and wear/tear from mechanically moving parts, and take advantage of naturally occurring temperature gradients. These characteristics make them ideal for applications including electricity generation in extreme and remote environments. In order to efficiently convert energy using thermoelectricity, several optimized properties are required. These include a high electrical conductivity σ, a large Seebeck coefficient S, and a low thermal conductivity κ. Together, these quantities define the dimensionless thermoelectric figure of merit, $ZT = S^2\sigma T/\kappa$, where T is the absolute temperature. Larger ZT values directly correspond to more efficient thermoelectric devices and there are no known fundamental limitations on how large ZT can be. Although all electrical conductors exhibit a thermoelectric effect, their efficacy is limited by a fundamental proportionality between electrical conductivity and the electronic component of the thermal conductivity. In this talk I will report several approaches that have been undertaken in the search for new quantum materials for potential energy conversion applications. For example, a prevailing strategy to overcome the competition between electrical and thermal conductance is to produce materials with large and cage-like unit cells where phonons are strongly scattered but electrons move easily. Following this strategy, we recently investigated the heavy-fermion compounds $\mathrm{Yb}TM_2\mathrm{Zn}_{20}$ (TM = Co, Rh, Ir) and showed that they exhibit competitively high power factors in addition to large ZT values at 35 K. Our latest results indicate that compositional modifications contribute to further enhanced thermoelectric properties.

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