Materials for Sustainable Energy—Recent Development in Superconductivity and Thermoelectricity

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The discovery of the first high temperature superconductor with transition temperature above the liquid nitrogen boiling temperature was made in the Chinese New Years Eve of 1987. 25 years have passed after this groundbreaking discovery. The superconductivity research community has made great achievement in sciences and had important impact on the society in the past 25 years. Many important new phenomena associated with the so-called strongly correlated electron systems, including the cuprate superconductors, multiferroic systems, and Fe-based superconductors have become the focus of current condensed matter researches. At the first part of my talk, I shall give an overview of the development of high temperature superconductivity research. In addition to the cuprate superconductors, I shall present in details the newly discovered superconducting FeSe.

The tetragonal phase **β**-FeSe, which is a member of the newly discovered Fe-based superconductors, has provided a unique platform for the detailed investigation of the correlation between the physical properties and crystal structure due to its simplest crystal structure. This has made FeSe the most attractive system to better understand the possible origin of superconductivity in the new iron-based superconductors. We have carried out a series of properties characterizations by measuring resistivity, magnetic susceptibility, Raman, NMR and femtosecond spectroscopy on **β**-FeSe single crystals grown by flux-melt or high-pressure synthesis. Our results show clearly the presence of anomalies in all the characterized properties at the temperature where a structural distortion from tetragonal to orthorhombic (or monoclinic) appears for all superconducting samples, but not in the non-superconducting ones. This structural distortion was observed not accompanied by a magnetic ordering as commonly occurs in the parent compounds of FeAs-based superconductors. All the observations suggest that the low temperature structural distortion is essential for the occurrence of superconductivity in **β**-FeSe.

The history of thermoelectricity dates back to 1823 when Seebeck observed electric potential difference across a material with temperature gradient. The efficiency of thermoelectric materials is determined by the dimensionless figure-of-merit ZT [defined as ZT $\sigma S^2T/(k_L$ $k_E)$]. Good thermoelectric materials should possess a large Seebeck coefficient (S), high electrical conductivity (**σ**), and low thermal conductivity (L + E). Recent prediction that nanostructural engineering can greatly enhance thermoelectric efficiency has attracted great attention. Quantum confinement effect can reduce thermal conductivity (L) via suppressing phonon transport and at the same time enhance electric conductivity (**σ**), provide great potential to achieve the goal of higher figure of merit.

Meanwhile, complex bulk materials have been developed and demonstrated for enhanced Seebeck coefficient (S).

On the other hand, there are also interest in correlated semiconductors for thermoelectric applications because the strong Coulomb repulsion between “localised” dor f-electrons along with their weak hybridization with delocalized band states leads to a large (and asymmetric) electronic density of states at the band edges of the hybridization gap. This favors a large thermoelectric power factor PF = S2·**ρ –** 1 (where S is the Seebeck coefficient and **ρ** is the electrical resistivity). It has been shown that a large S combined with reasonably low **ρ** is possible at low temperatures. I shall present the preliminary results of our recent efforts to the search for high ZT material. The results suggest the formation of composite material using nanocrystalline material and bulk material maybe the key to achieve high ZT.