MAR15-2014-020260

Abstract for an Invited Paper
for the MAR15 Meeting of
the American Physical Society

Development of thermal rectifier using unusual electron thermal conductivity of icosahedral quasicrystals

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The bulk thermal rectifiers usable at high temperature were developed using the unusual increase of electron thermal conductivity of icosahedral quasicrystals (ICQ's) at high temperature. Our previously performed analyses in terms of linear response theory suggested that the unusual increase of electron thermal conductivity of ICQ was brought about by the synergy effect of quasiperiodicity and narrow pseudogap at the Fermi level. Since the linear response theory suggests that the unusual increase of electron thermal conductivity is coupled with the small magnitude of Seebeck coefficient, the composition of Al-Cu-Fe ICQ, where the thermal conductivity shows the most significant increase with increasing temperature, was determined with a great help of Seebeck coefficient measurements. Consequently obtained $Al_{61.5}Cu_{26.5}Fe_{12.0}$ ICQ, which was characterized by the small magnitude of Seebeck coefficient, possessed 9 times larger value of thermal conductivity at 1000 K than that observed at 300 K. The increasing tendency of electron thermal conductivity with increasing temperature was further enhanced by means of small amount of Re substitution for Fe. This substitution definitely reduced the lattice thermal conductivity while the electron thermal conductivity was kept unchanged. The lattice thermal conductivity was reduced by 35 % under the presence of 0.5 at.% Re, and the thermal conductivity at 1000 K consequently became about 11 times larger than that at 300 K. The thermal rectifiers were constructed using our newly developed ICQ ($Al_{61.5}Cu_{26.5}Fe_{12.0}$ or $Al_{61.0}Si_{0.5}Cu_{26.5}Fe_{11.5}Re_{0.5}$) together with one of the selected materials (Si, Al_2O_3, $CuGeTe_2$ or Ag_2Te) that possess thermal conductivity decreasing with increasing temperature. The heat current flowing in the rectifiers was confirmed to show significant direction dependence. The consequently obtained $TRR = |\boldsymbol{J}_{\mathrm{large}}| / |\boldsymbol{J}_{\mathrm{small}}|$ for the composite consisting of $Al_{61.0}Si_{0.5}Cu_{26.5}Fe_{11.5}Re_{0.5}$/ $CuGeTe_2$ reached 2.24, and that is the largest value ever reported for the bulk thermal rectifiers.