Thermal diode fabricated using bulk superconducting materials

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Abstract

Thermal management is one of the technologies crucial for creating new application and improving the performance of electronic devices.[1] Among the thermal management technologies, thermal switches, which achieve a large change in thermal conductivity (κ), and thermal diodes, which enable thermal rectification under temperature difference, are essential for active heat control. Materials and devices for thermal switches and diodes have been actively studied.[2-4] Superconductors are good candidates for magneto-thermal switching (MTS) materials because of a large change in κ through the superconducting transition, by changing temperature and/or magnetic field, while the working temperature is limited to below the transition temperature.[5] For high-purity Pb sample, 2000% of large MTS ratio (MTSR) which is an index to assess the effectiveness of MTS was observed at 3.2 K.[6] Here, we use the MTS of Pb to achieve fabrication of thermal diode.

After the theoretical design and experimental investigation of thermal diodes,[7] the thermal diodes using superconductors have been proposed in 2013.[8] However, the experimental observation of superconductor-based thermal diode effect in a bulk-size materials has not been reported so far. In the presentation, we will show that the bulk superconductor-normal conductor junction made of high-purity wires of Pb (5N purity) and Al (5N purity) exhibits clear thermal rectification. Effective thermal conductivity for the junction (κ^*) is measured under H using the thermal transport option (TTO) of Physical Property Measurement System (PPMS, Quantum Design) by the four-terminal method. The highest thermal rectification ratio (TRR), defined as TRR = κ^*_F/κ^*_R where κ^*_F and κ^*_R are κ^* measured in the forward and reverse direction, respectively, reaching 1.75 was observed at T = 5.2 K under H = 400 Oe. Furthermore, the Pb-Al diode exhibits a large difference in effective thermal conductivity ($\Delta\kappa^*$) between forward and reverse heat directions; the largest $\Delta\kappa^*$ observed in this study is 270 W m^{-1} K^{-1}. The large $\Delta\kappa^*$ would be the advantage of this material in designing practical applications highly improved owing to active thermal control. In the presentation, we will show the fabrication of jointless thermal diode as well.

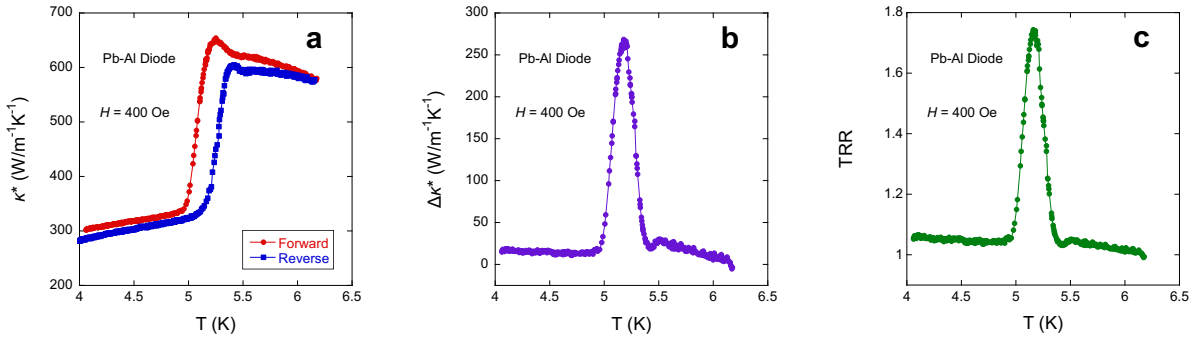

Figure 1 T dependence of a) κ^*, b) $\Delta\kappa^*$, c) TRR under magnetic field of H = 400 Oe for the Pb-Al diode

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Keywaords: thermal diode, superconductor, thermal conductivity, Pb wire, magneto-tunable