Contributions of electron and phonon transport to the thermal conductivity of GdFeCo and TbFeCo amorphous rare-earth transition metal alloys

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Electron-phonon coupling in metals

- Areal storage density of hard disk drives
- Recent advancement by Seagate Technology and their HAMR devices (red diamonds)
Outline

- Electron-phonon coupling in recording layer
- What is temperature dependence of e-p coupling factor in amorphous metals?
Amorphous GdFeCo and TbFeCo

- How does amorphous “lack of structure” affect transport?


The electron–phonon coupling constant of amorphous metals

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Thermal conductivity of RE-TMs

We show the thermal conductivity of a pure metallic glass with temperature. This is a similar trend as to what has been observed in other metallic glasses, for example, Fe alloys which increase, nearly linearly, with temperature. This same trend is observed in the mean values of both films, as plotted in Fig. 3. The electronic thermal conductivities are determined from the TDTR measurements (Fig. 3). From these measurements, we calculate the thermal conductivities of the amorphous RE-TM alloys in Fig. 2. The error bars in these data represent the uncertainties in these electrical resistivity measurements by considering the effects of contact size and placement along with the sample geometry.

The electronic thermal conductivities increase with temperature trends similar to the phononic heat capacity. This constant propagates from the relative uncertainties in the TDTR and electrical resistivity data that were previously discussed. The slight increase that is observed in the mean values is hard to conclusively discern. However, the amorphous metals with boron or phosphorous (Fe-B, Fe-P) all exhibit nearly linear trends with temperature. This linear trend in thermal conductivity is due to the uncertainty in the assumed heat capacity. We determine the Al film thickness to within 3.0 nm, via picosecond ultrasonics. Therefore, the majority of the Al transducer thickness, and the amorphous RE-TM alloy heat capacity. We estimate the relative uncertainties in the thermal conductivities of these amorphous RE-TM alloy films as a function of temperature via the Wiedemann-Franz Law. For the GdFeCo and TbFeCo films, we also plot the reported electron contributions to the thermal conductivities of the metallic glasses with non-metal impurities (Fe-B, Fe-P). The electronic thermal conductivities also show similar temperature trends in electron thermal conductivity. The electronic thermal conductivities increase with temperature trends similar to the phononic heat capacity. This constant propagates from the relative uncertainties in the TDTR and electrical resistivity data that were previously discussed. The slight increase that is observed in the mean values is hard to conclusively discern.

The phonon thermal conductivity is relatively constant over the temperature range of interest. The slight increase that is observed in the mean values is hard to conclusively discern.
Electron vs. phonon contribution

Electrical resistivity

W-F Law

To quantify this, we calculate the phonon contribution.

We plot the reported electron contributions to the thermal conductivities exhibit a nearly linear increase with temperature. We estimate the relative uncertainties shown in Figs. 3 and 4. The metallic glasses all exhibit similar temperature trends in the phononic heat capacity.
Why is thermal conductivity of a-metals dominated so much by phonons?

We can use this information!!
EP coupling in GdFeCo and TbFeCo

Re-examining Electron Fermi Relaxation in Gold Films With a Nonlinear Thermoreflectance Model

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APRIL 2011, Vol. 133 / 044505-1

Journal of Heat Transfer

We can use this method for any metal
EP coupling in GdFeCo and TbFeCo

\[ G_{\text{eff}} = \frac{\pi^2 m_e v_{s}^2 n_e}{6} (A_{ee}(T_e + T_p) + B_{ep}) \]
Challenges – can we engineer the e-p coupling factor?

- Amorphous metals have high electron-phonon coupling factors
- EP scattering is primary resistance, leading to low thermal conductivity
- Structure effects on ep scattering are not as well studied as we think

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Ultrafast and steady-state laser heating effects on electron relaxation and phonon coupling mechanisms in thin gold films

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