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Inelastic electron dephasing times in Cu_xGe_{100-x} alloys

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Abstract

We have studied the inelastic electron dephasing scattering times, τ_i, in disordered Cu_xGe_{100-x} ($35 \leqslant x \leqslant 60$) alloys between 1 and 15 K. The values of τ_i^{-1} ($\sim T^p$), and especially the exponent of temperature p, are extracted from weak localization studies. We find that the value of p continuously decreases from ~ 3 to ~ 1 as x gradually decreases from 60 to 35. Our observation is understood in terms of a crossover of the inelastic electron dephasing in impure metals from e–ph scattering to critical e–e scattering as the disorder greatly increases and the system moves significantly toward the mobility edge.

Keywords: Dephasing times; Disordered metals; Electron–electron relaxation; Electron–phonon relaxation

The temperature dependence and electron elastic mean free path l dependence of the inelastic electron dephasing scattering times τ_i are of fundamental interest in disordered metals. Information about these dependences is crucial to a profound understanding of the underlying dynamics of the inelastic electron scattering. Theoretically and experimentally, the electron–phonon scattering time, τ_{ep}, and electron–electron scattering time, τ_{ee}, in various dimensional metals have been explored for over 15 years now. However, the nature of the e–ph interaction in the presence of strong impurity scattering is still debated [1,2]. On the other hand, it is found that the dynamics of e–e interaction near the mobility edge reveals critical behavior which is distinctly different from the diffusive behavior expected for the more widely studied weak-disordered regime [3].

We have fabricated a series of three-dimensional Cu_xGe_{100-x} films with the nominal composition x ranging from 35 to 60. Appropriate amounts of Cu and Ge were first arc-melted in an Ar gas, and then thermally evaporated in vacuum to make (> 5000 Å) thick film samples. Electrical conduction being concerned, the samples show weak-disordered behavior when x is large (> 48) and they undergo a metal–insulator transition at x below about 35. In terms of the electron diffusion constant D, the value of D for our samples spans a very wide range from 0.09 to 3.2 cm^2/s as x increases from 35 to 60.

The magnetoresistances of our samples were measured between 1 and 15 K and compared with weak-localization predictions to extract the values of the responsible τ_i^{-1}. In all cases, we found that the temperature dependence and magnitude of the magnetoresistances for each sample are totally controlled by an effective electron dephasing rate

$$\tau_\phi^{-1}(T) = \tau_0^{-1} + \tau_i^{-1}(T) = \tau_0^{-1} + AT^p, \tag{1}$$

where τ_0 is a residual dephasing rate of current interest [4,5], A is a constant, and p is the exponent of temperature for the effective inelastic scattering rate. Note that we have included only one effective inelastic scattering process in Eq. (1). This should cause no ambiguity particularly at the limits of large x (where $\tau_i^{-1} \approx \tau_{ep}^{-1}$) and small x (where $\tau_i^{-1} \approx \tau_{ee}^{-1}$).

The value of p for the responsible τ_i^{-1} for each of our alloys has been determined according to Eq. (1). We find that the value of p changes systematically among samples. Fig. 1 shows the variation of the experimentally determined p with D for our alloys. For samples with large values of D, we see that $p \sim 3$. This is understood in

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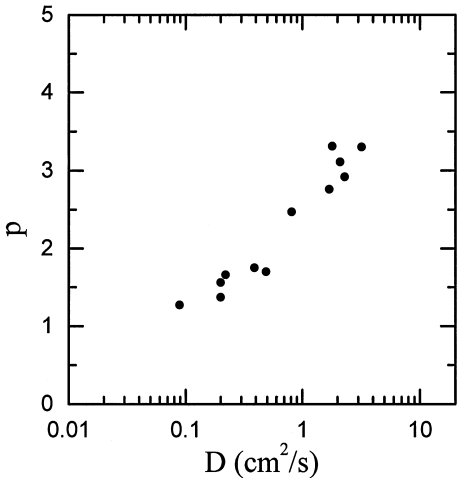

Fig. 1. p versus D for disordered Cu_xGe_{100-x} alloys.

terms of e–ph scattering in weak-disordered metals. For large D (or x), our samples consist of large parts of very weakly disordered Cu grains. Thus, the e–ph scattering in these Cu grains demonstrates a cubic temperature dependence. On the other hand, with reducing D, the relative contribution of e–ph interaction to the total τ_i^{-1} weakens. For reference, we obtain $\tau_i^{-1}(10\,\mathrm{K}) \approx 4.4 \times 10^{10}\ \mathrm{s}^{-1}$ for $x = 56$. The e–ph rate in Cu-rich alloys is expected to decrease as D (or l) decreases [1]. Finally, when D is sufficiently small so that the samples approach the Anderson transition, e–ph interaction is no longer the dominating inelastic process for electron dephasing. Instead, e–e interaction becomes significantly more important and is now greatly responsible for the measured τ_i^{-1}, causing $p \sim 1$. (More precisely, we obtain $p \sim 1.27$ for $x \approx 35$.) For reference, we obtain $\tau_i^{-1} \approx 1.6 \times 10^{11}\ \mathrm{s}^{-1}$ for $x = 40$.

In the case of three dimensions, the behavior of $\tau_i^{-1} \sim T$ has been theoretically investigated. Belitz and Wysokinski [3] have calculated the inelastic quasiparticle lifetime due to a Coulomb interaction in strongly disordered 3D metals. They found that the inelastic e–e scattering is very sensitive to the critical current dynamics in systems near the mobility edge. Particularly, they observed a linear T dependence of the inelastic scattering rate. Their predictions are in line with our results for those alloys having very low values of D.

In conclusion, we have established a crossover of the inelastic electron dephasing in impure metals from e–ph scattering to critical e–e scattering as the amounts of disorder greatly increase and the system moves significantly toward the mobility edge. The dependences of τ_{ep} on T and l (especially in the dirty-limit regime of $ql \ll 1$, where q is the wave number of the thermal phonons) are of current interest but require further theoretical clarification [1,2]. On the other hand, the underlying inelastic electron dynamics near the mobility edge is theoretically understood [3] and has been experimentally verified in several low-diffusivity metals with significantly different characteristics [6].

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