Comment on "Observation of a Linear Mean-Free-Path Dependence of the Electron-Phonon Scattering Rate in Thick AuPd Films"

Recent paper [1] has raised again a question about the electron-phonon (EP) relaxation rate in impure metals. From weak localization (WL) measurements the authors have found that the dephasing rate in AuPd disordered films follows the $T^2\ell$-law (ℓ is the electron mean free path). The main point of the paper is the first time observation of the linear ℓ-dependence, which agrees with theory [2,3] in the dirty limit. The observed temperature dependence is different from the expected T^4-law (dirty limit). The authors conclude that the current theoretical understanding of the EP interaction should be re-examine.

electron-phonon interaction
impure films
hot electrons

Theory [2,3] predicts that in the presence of strong disorder ($q\ell \ll 1$, $q = T/u_s$ is the wavevector of the thermal phonon, u_s is the sound velocity) the EP interaction should weaken, and for 3D-phonons the electron energy relaxation rate, $\tau_{e\text{-}ph}^{-1}$, is of the order of $(ql)\tau_0^{-1} \propto T^4\ell$ ($\tau_0^{-1} \propto T^3$ is the relaxation rate in a pure material). In the dirty limit $q\ell < 1$ and also in a wide intermediate region $q\ell \cong 1$ the contribution of transverse phonons to the electron relaxation dominates significantly over the contribution of longitudinal phonons. The limiting case of the theory $q\ell \ll 1$ is hard to achieve, therefore the dependence $\tau_{e\text{-}ph}^{-1} \propto T^4\ell$ has been rarely observed in experiments [4]. In the intermediate region the dependence of the relaxation rate changes from $T^4\ell$ ($q\ell \ll 1$) to $T^2\ell^{-1}$ ($q\ell \gg 1$). The temperature dependencies close to $\tau_{e\text{-}ph}^{-1} \propto T^3$ along with a weak mean free path dependence [5,6] were likely an indication of the transition region between these two limiting cases rather than of the clean limit. The latter can be observed only at very high temperatures ($q\ell >$ 20-40) where longitudinal phonons may dominate in the relaxation.

Theory [3] also predicts a T^2-contribution to the resistivity due to electron-phonon-impurity interference at $q\ell \sim 1$ [7] which has been observed in a number of recent experiments in Au, Nb,

Al, Be and NbC films [5,8]. The constant of EP interaction determined from the resistivity data agrees well with that found in the τ–measurements [5].

The electron-phonon relaxation in AuPd films has been studied using both electron heating [9] and WL technique [1]. The sample used in [9] with the diffusivity D = 7.2 cm^2/s falls in the middle of the diffusivity range used in Ref. 1. If we apply theory [3] for AuPd films it gives the result shown in Fig. 1. The experimental data of the temperature dependence $\tau_{e\text{-}ph}^{-1} = 5\times10^7 T^{3.7}\ s^{-1}$ [9] were divided by factor of ≈ 7.5 to take into account the difference between energy averaged data of Ref. 9 and a single-electron rate of Ref. 1. The data of Ref. 9 are in very good agreement with the theory. This suggests that the results of [1] should be more carefully analyzed. The electron-electron interaction should be properly taken into account when the EP relaxation rate is determined from the WL data. The effect of the phonon dimensionality cannot be a reason for such large discrepancy. Indeed, if one assumes a 2D phonon spectrum then the exponent in the temperature dependence of the relaxation rate should be by a unity smaller than that for 3D-phonons. In contrast, as seen in Fig. 1, very thick (≈ 400 nm) films of Ref. 1 demonstrate a weaker temperature dependence than a thinner (31 nm) film of Ref. 9.

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[1] Y.L. Zhong and J.J. Lin, Phys. Rev. Lett. **80**, 588 (1998).

[2] A. Schmid, Z. Phys. **259**, 421 (1973); J. Rammer and A. Schmid, Phys. Rev. B **34**, 1352 (1986).

[3] M.Yu. Reizer and A.V. Sergeev, JETP **63**, 616 (1986); Int. J. Mod. Phys. B **10**, 635 (1996).

[4] Yu.F. Komnik et al., Phys. Rev. B **50**, 15298 (1994).

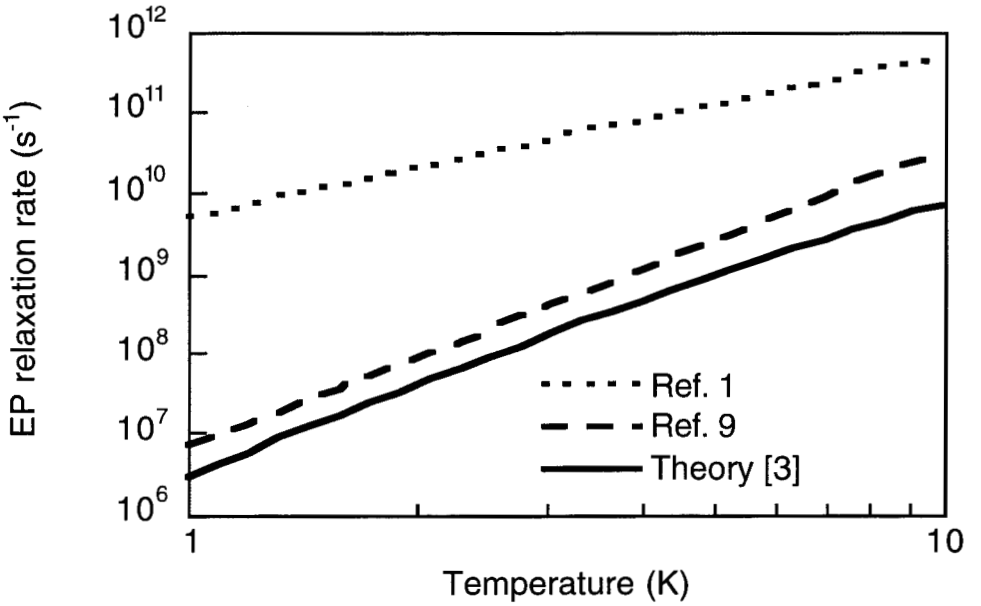
[5] K.S. Il'in et al., Phys. Rev. B **57**, 15623 (1998).

[6] P. Santhanam and D.E. Prober, Phys. Rev. B **29**, 3733 (1984); M.L. Roukes et al., Phys. Rev. Lett. **55**, 422 (1985); P.M. Echternach et al., Phys. Rev. B **46**, 10339 (1992).

[7] M.Yu. Reizer and A.V. Sergeev, JETP **65**, 1291 (1987).

[8] P.M. Echternach et al., Phys. Rev. B **47**, 13659 (1993); N.G. Ptitsina et al., JETP **80**, 960 (1995); N.G. Ptitsina et al., Phys. Rev. B **56**, 10089 (1997).

[9] R.A. Lee and M.N. Wybourne, J. Phys. F 16, L**169** (1986).



B.S. Karasik and A.V. Sergeev, PRL

Fig. 1

Figure caption

Fig.1. Comparison of data for AuPd films with the theory. The temperature range approximately corresponds to that of Ref. 9.