Metal-insulator transition in quasicrystalline AlPdRe

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Abstract

Transport properties of icosahedral AlPdRe alloys are studied. The magnetoresistance displays a metal-insulator transition, MIT, as a function of increasing resistance ratio R [$=\rho(4.2\text{ K})/\rho(295\text{ K})$]. The conductivity, σ(T), saturates at a finite value also for insulating samples at low enough temperatures. σ(0 K) for i-AlPdRe is found to decrease over 4 orders of magnitude for increasing R with a change of slope at the MIT.

Key words: icosahedral AlPdRe; metal-insulator transition ; electronic transport ;

1. Problem

Electrical transport properties of quasicrystals remain a great challenge for experimentalists and theoreticians. Icosahedral (i) AlPdRe provides a unique tool for these studies, since the resistivity, ρ, and resistance ratio R [$=\rho(4.2\text{ K})/\rho(295\text{ K})$] can be varied over wide ranges in the i-phase. It has long been suspected that i-AlPdRe should be insulating at large ρ(4.2 K) [1,2], but this assertion has not been possible to prove unambigously from the low temperature conductivity σ(T). Widely different analyses of σ(T) in terms of variable range hopping theories, VRH, illustrate the problems, with e.g. results for the characteristic hopping temperature from 1 mK to 1600 K [3,4]. These difficulties may be associated with the tendency for σ(T) to saturate at a constant value at low enough temperatures, which is not compatible with VRH.

In the present note we illustrate that the magnetoresistance gives direct indication of a metal insulator transition (MIT) in i-AlPdRe. Estimates of σ(0 K) are discussed. It is shown that there is a change of slope of σ(0 K, R) at the MIT with a continued exponential decrease of σ(0 K) on the insultaing side.

2. Magnetoresistance

The magnetoresistance MR is a powerful tool to study transport properties, since the experimentalist has available the vast (B, T) plane for analyses. Hence, detailed quantitative tests of different theories can be made with satisfactory numerical stability.

Signatures of the relation $\Delta\rho(\text{B})/\rho(0)$ *vs* B can reveal important information already prior to detailed analyses. The change of the MR across the metal insulator transition is one example, Fig. 1. At R=11, ρ(4.2 K) of i-AlPdRe is 29 mΩcm, and quantum corrections to transport properties of weakly disordered metals at low T are prominent. At small magnetic fields all such contributions to $\Delta\rho(\text{B})/\rho(0)$ increase as $\sim\text{B}^2$ in alloys with not too weak spin-orbit interaction, while at larger B, one observes instead $\Delta\rho(\text{B})/\rho(0) \sim\text{B}^{1/2}$ [5]. At R=160, i-AlPdRe is well into the insulating region. The MR then follows Efros-Shklovskii variable range hopping, with successive regions of $\Delta\rho(\text{B})/\rho(0)$ varying as $\sim$ -B, $\sim +\text{B}^2$, and $\sim\text{B}^{2/3}$, for increasing B [6].

Fig. 1 thus indicates that an MIT occurs for intermediate R-values. In fact, detailed analyses of the MR from the metallic and insulating sides, and of the metallic σ(T) at T >400 mK, all indicate that an MIT occurs in the region R $\sim$20-30 [7–9].

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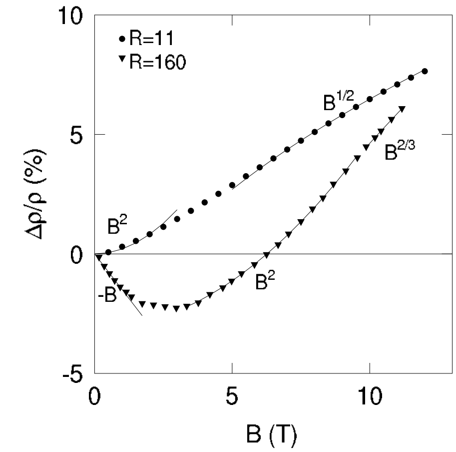

Fig. 1. MR at 4.2 K for two i-AlPdRe samples on each side of the MIT (R=11 metallic, R=160 insulating). Signatures of metallic and insulating (Efros-Shklovskii) MR are indicated by characteristic exponents and corresponding field dependent curve segments on different parts of the data.

3. Finite zero temperature conductivity

Although σ(T) at low temperatures would normally be the most immediate source of information on an MIT, this is not the case for i-AlPdRe, where the existence of a finite σ(0 K) much complicates analyses. A non-zero $\sigma(0)$ appears to be a general property for i-AlPdRe. However, in high-R sample one must go to ultralow temperatures, < 20 mK, to observe it [10].

In Fig. 2 the estimated $\sigma(0)$ is shown *vs* R for a range of i-AlPdRe samples. Circles are data obtained from measurements taken to below 15 mK [10]. For up-triangles ρ(T) was found to saturate at a constant value below about 100 mK [11]. For lower R samples higher temperatures were used; 1.5 K for down-triangles [7], and 4.2 K for a single grain sample (filled square) [12]. In these cases the small values of ρ and dρ/dT make the differences in extrapolation procedures insignificant.

σ(0, R) in Fig. 2 decreases monotonously with R over 4 orders of magnitude for a wide range of different samples. This result indicates that a finite $\sigma(0)$ is an intrinsic icosahedral property also in the insulating state. For small R, in the metallic state, σ(0, R) drops precipitously with increasing R, while there is a change of slope in a region of R-values which coincides with the estimated MIT from magnetoresistance [8]. At larger R-values, in the insulating state, σ(0, R) decreases exponentially with R of the form σ(0, R) $\sim$exp[-R/R_o], where empirically R_o is of order 100.

The reason for this behavior is not known.The results suggest that quantum tunneling occurs at low temperatures between residual critical states leading to a temperature independent contribution to $\sigma(0)$. The result in Fig. 2 would then imply that such remaining critical states vanish exponentially with increasing R.

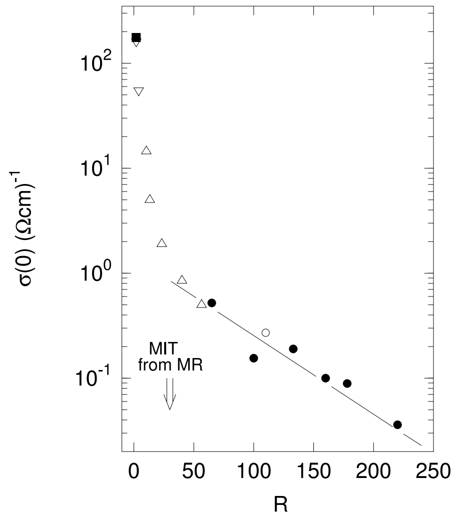

Fig. 2. Estimated σ(0 K) for i-AlPdRe samples. Open symbols; polygrained melt spun samples, filled circles; polygrained ingots, filled square; single grain sample [12]. σ(0 K, R) changes slope where an MIT is indicated at R≈30 from MR [8]. The straight line is an empirical fit to data in the insulating region.

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