The Coulomb Anomaly in Strongly Disordered Films
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Electron tunneling measurements of the Coulomb anomaly in the density of states in strongly disordered quench condensed granular films are presented. The strength of this anomaly grows with increasing sheet resistance, $R_N$, at low $R_N$ but saturates at high $R_N$. We suggest that the granular morphology of these films is responsible for the saturation.

1. INTRODUCTION

Increases in the static disorder in metal films degrades the screening capabilities of the conduction $e^-$, increases spatial correlations among them and thus, increases the effective $e^- - e^-$ interactions. This leads to a decrease of the density of states about $E_F$. [1 - 3] In two dimensional weakly disordered systems, this decrease is given by [4]:

$$\frac{\delta N(E)}{N_0} = A_{\mu} \ln(\frac{l}{\xi}) \ln(\frac{|E - E_F|}{\hbar \tau_{el}})$$

(1)

where $A_{\mu}$ depends on the strength and form of the effective $e^- - e^-$ interactions, $l$ is the mean free path, $\xi$ is the localization length and $\tau_{el}^{-1}$ is the rate of elastic collisions. This density of states anomaly appears as an anomaly in the conductance as a function of voltage, $G_j(V)$ of tunnel junctions with a disordered film as one of the electrodes. Here, we present preliminary studies of this anomaly in films that range from the weakly disordered limit, where this theory applies, to the strongly disordered limit, where it does not. We find that film morphology plays an important role in determining the strength of this anomaly and thus, the strength of the $e^- - e^-$ interactions in strongly disordered films.

2. SAMPLES

The disordered films were deposited onto cooled substrates ($\sim 8K$) on which an oxidized Al strip had been previously deposited. The disordered film and Al strip served as the tunnel junction electrodes. Four terminal measurements of $G_j(V)$ were performed at 8K in situ. In fact the normal state conductance $G_j(V)$ does not depend on temperature for $eV > kT$. We have measured $G_j(V)$ of granular Pb and Sn films with $R_N$ ranging from 10Ω ($k_F l \geq 1$) up to 70kΩ ($k_F l \sim .04$).

$G_j(V)$ can be written

$$G_j(V) = \int_{-\infty}^{\infty} N_{Al} N_{Film} \frac{\partial f(E + eV)}{\partial(eV)} P(E) dF$$

where $E$ is the energy relative to $E_F$, $f$ is the Fermi distribution, $V$ is the voltage across junction, $N_{Al}$ is the density of states for the Al strip and $N_{Film}$ is the density of states for the investigated film. $P(E)$ is the tunneling probability. We normalized all curves by the lowest $R_N$ film for each experimental run to eliminate the effects of $N_{Al}$ and $P(E)$, so the normalized junction conductance, $G_N$, reveals corrections to $N_{Film}$ due to disorder effects.

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3. RESULTS

In Fig. 1 we show $G_N(V)$ vs. $\ln(V)$ for a series of granular Sn films. The dotted lines are data and the solid lines show linear regions. These regions shrink and their slopes grow with increasing $R_N$. The functional form of $G_N(V)$ at high voltages is unclear.

We plot the slope vs. $R_N$ for Pb and Sn films in Fig. 2. At low $R_N$ these slopes grow, but at high $R_N$ they saturate. The sheet resistance at which they saturate, $R_N^*$, and the saturation value are both higher in Sn than in Pb. This saturation value appears to scale with the inverse of the film thickness.

According to Eq.(1) the slope of this $\ln(V)$ dependence corresponds to the strength of the $e^- - e^-$ interactions and $R_N$ represents the degree of the disorder. Disorder enhances the effective $e^- - e^-$ interactions, so the slopes should grow with increasing $R_N$. We believe that this observed saturation results from a morphology change ("granular" to "uniform") that occurs near $R_N^*$. Above $R_N^*$, films are made of isolated grains and the transport properties are dominated by intergrain tunneling processes. Below $R_N^*$, the grains start to couple together and the film becomes more uniform. For the granular morphology the effective $e^- - e^-$ interactions are dominated by grain charging effects. These depend only on the intergrain capacitances which are independent of $R_N$. For the uniform morphology, where the theory applies, the effective interactions depend on $R_N$.

4. SUMMARY

We have measured the density of states of granular Pb and Sn films with $R_N$ up to 70k$\Omega$. The strength of the coulomb anomaly saturates at high $R_N$. We attribute this effect to the granular morphology of the films.

REFERENCES

Work supported by this grant has resulted in five manuscripts. These manuscripts describe in detail the technical progress made. They are:


