Chapter 5

Conclusions

Due to the facts that the tunneling geometry allows one to obtain more information than the bulk sample does and the localized moments of $S = 1/2$ case is never studied in planar tunnel junctions, we studied Kondo effect through the Al/AlO_x/Sc tunnel junctions.

The Al and Sc films are deposited through thermal evaporation in sequence and the AlO_x insulating layers was grew on the surface of the Al films by glow discharge in a dilute O_2 atmosphere after the Al films deposition. The differential conductance dI/dV of these junctions were measured at low temperatures using a ^{3}He fridge equipped with a 4 T superconducting magnet. A ”send I measure V” and a ”send V measure I” circuit combined with lock-in techniques were devised to measure the dI/dV spectra. The quality of the AlO_x insulating barrier was examined through measuring the superconducting gap of the Al films for $T < T_c$, and the results demonstrated the leakage through the barrier could be neglected and the conduction mechanism through these junctions is dominated by electron tunneling. The height and thickness of the AlO_x insulating layer in these Al/AlO_x/Sc junctions can be determined by fitting the dI/dV spectra in Al/AlO_x/Al junctions, whose barrier were grew with the same parameters as used to grow in the former, in terms of the BDR model. The fitting results showed reasonable values of the height and thickness.

After proving the good quality of the barrier, we turn to the dI/dV spectra in these Al/AlO$_x$/Sc tunnel junctions. Although the dI/dV contained the contributions of the normal tunneling, of the $s-d$ exchange interaction, and of the DOS effect in the two metal leads, the last contribution was showed to be insignificant and could be neglected and the first contribution could be subtracted according to the BDR model. After the subtracting, the remainder conductance was found to contain an asymmetric term in it, and hence could be divided into an even term $G_{even,data}(V,T)$ and an odd term $G_{odd,data}(V,T)$.

$G_{even,data}(V,T)$ had a peak around zero-bias for $T \lesssim 32$ K, the lower the temperature, the higher the peak and the narrower the peak width. The zero-bias conductance $G_{even,data}(0,T)$ had a "$a-b\log T$" relation, namely the weak coupling regime, for 14 K $\lesssim T \lesssim$ 32 K, and crossed over to a "$c-dT^2$" relation, namely strong coupling regime, for $T \lesssim 3.6$ K. In the weak coupling regime, both $G_{even,data}(V,T)$ spectra at several temperatures (32 K, 24 K, and 16 K) and $G_{even,data}(0,T)$ could be described by Appelbaum's perturbation theory, while outside the weak coupling regime, the perturbation calculation failed to describe the experimental data. In the strong coupling regime, we fitted the $G_{even,data}(V,T)$ spectrum at 2.5 K in terms of Appelbaum's self-consistent theory which was used to calculate in the strong coupling regime, and found a good agreement between the experimental data and the theoretical calculation, and the Kondo temperature $T_K^{Appelbaum}$ could be extracted to ≈ 34.8 K from the fitting. On the other hand, we also fitted the $G_{even,data}(0,T)$

data in several samples in terms of the numerical renormalization group (NRG) calculation for the whole temperature regime (from weak to strong coupling regime), and the T_K^{NRG} could be determined from the fitting. In the sample "20061002", the fitted $T_K^{NRG} \approx 38$ K, and was quite consistent with the value of $T_K^{Appelbaum}$ (≈ 34.8 K). We attributed the existence of the $G_{odd,data}(V,T)$ to the effect of the interference between the $s-d$ exchange interaction enhanced tunneling and the impurity assisted tunneling, and tried to fit it by Appelbaum's corresponding calculation. We found the theory could describe the $G_{odd,data}(V,T)$ qualitatively, rather than quantitatively.

We also studied the effect of applying a magnetic field. For the sample "20061002" at 2.5 K, under the magnetic field 4 T, the zero-bias conductance decreased $\approx 3.4\%$ but no Zeeman splitting was observed. The absentation of the Zeeman splitting was due to the high T_K in this sample. A critical field $H_c \approx 14$ T, which was calculated using $T_K^{NRG} \approx 38$ K, was predicted to see the Zeeman splitting.