Two-impurity Kondo Effect in Al/AlO_x/Y Tunnel Junctions

Yu-Ren Lai[a], Da-Wei Wang[a], and Juhn-Jong Lin[a,b]

[a]Institute of Physics , National Chiao Tung University, Hsinchu 30010, Taiwan
[b]Department of Electrophysics, National Chiao Tung University, Hsinchu 30010, Taiwan

We have fabricated a series of Al/AlO_x/Y tunnel junctions and measured the differential conductance $G(V,T)$ at liquid-helium temperatures. We found that the zero-bias conductance $G(0,T)$ increases with reducing T below ~40 K, i.e., $G(0,T)$ obeys a $-\ln T$ law at a higher T regime (~10-25 K) and crosses over to a $-\sqrt{T}$ law at an intermediate T regime (~5-20 K). The unique $-\sqrt{T}$ feature is suggestive of a novel Kondo effect. In particular, in this intermediate T regime, we observed that the finite-bias $G(V,T)$ curves at different T's collapse closely and can be expressed by $[G(0,T){-}G(V,T)]/\sqrt{T}{=}f(\sqrt{eV/k_BT})$, where f is a universal scaling function characteristic of the two-impurity Kondo effect.
Furthermore, we have varied the junction area and the barrier thickness in different samples by adjusting the fabrication conditions. As a result, while the $G(V,T)$ behavior is essentially similar for all junctions at not too low T, we found two kinds of distinct T dependences of $G(0,T)$ at $T{<}4$ K. In the first kind, $G(0,T)$ saturates as $T{\to}0$ K, while in the second kind, $G(0,T)$ passes over a maximum and then decreases with reducing T. We explain that the first group of samples possesses a Kondo-screened ground state, while the second group possesses a singlet ground state owing to strong antiferromagnetic interimpurity coupling. The two-impurity Kondo effect arises from a minute number of spin-$\frac{1}{2}$ yttrium impurities which diffused into the insulating barrier during the junction fabrication process.