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NEGATIVE DIFFERENTIAL CONDUCTANCE IN MoRe-Si(W)-MoRe JUNCTIONS

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We have observed a strong resonant peak in the current-voltage characteristics of a nanoelectronics device formed by two MoRe-alloy superconducting electrodes with an amorphous tens-nm-thick silicon interlayer doped by oxygen and tungsten nanometer-sized inclusions. The peak and resulting negative differential conductance persist up to the superconductor-to-normal transition temperature. A model for the carrier tunneling based on a resonant two-level state approach provides a good fit to the measured device characteristics.

Introduction

In this work, we have developed a new type of a negative conductance device with a strong resonant peak in the current-voltage (I - V) characteristics and the resulting negative differential conductance persisting up to the critical temperature T_c of superconducting electrodes. Moreover, we propose a theoretical description of this effect, based on the assumption about two-level entities localized in the potential barrier that determine the magnitude of the current flowing through the appropriate transport channel. Accordingly to our assumption, such structures have a very small resistance in the ground electronic state whereas in the excited state their resistance is already considerable. We present the theory of the phenomenon that is based on the idea of a resonance tunneling effect through a semiconducting barrier with impurity centers embedded in it [1] and the model of the asymmetric two-level system [2].

Experimental

We have studied a three-layered structure with 100-nm thick $\text{Mo}_{0.55}\text{Re}_{0.45}$ films as metallic electrodes. The electrodes were in the superconducting (S) state with the superconducting-to-normal transition temperature T_c about 7 K. They have been deposited onto Al_2O_3 substrates at ambient temperatures using a DC magnetron sputtering technique in a vacuum chamber filled with argon at the pressure of 1 Pa. To create the nanostructured Si(W) interlayer, we have applied a target which consisted of a pure Si wafer and a number of tungsten 0.3 mm diameter wires. The tungsten concentration n_w in the target has been varied between 0 and 10 at.%. For a fixed n_w value the thickness of the Si(W) barrier $d_{\text{Si(W)}}$ was changed from 15 to 30 nm. The sizes of the MoRe-doped Si-MoRe junctions varied from 50 x 50 to 100 x 100 μm^2 . More details concerning samples can be found in [3].

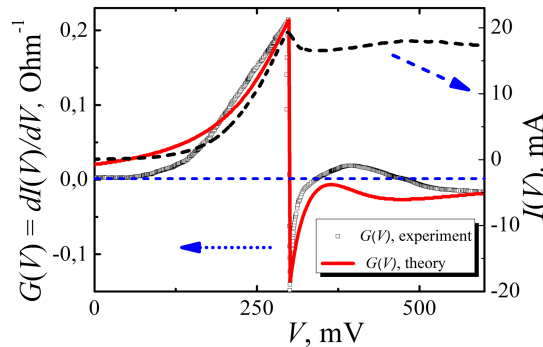


Fig. 1. Representative current-vs-voltage I - V characteristic of a three-layered MoRe-Si(W)-MoRe sample, $d_{\text{Si(W)}} = 30$ nm and $n_w \approx 4$ at. %, measured at $T = 4.2$ K (the dashed curve). Experimental and calculated conductance-vs-voltage $G(V)$ curves are shown by dotted and solid lines.

Theory

We can suppose that in our strongly disordered samples the number of the ‘open’ trajectories varies with the energy E and is peaked at $E = E_{\text{res}}$. In the vicinity of the resonance energy E_{res} the elastic-transmission probability $D(E)$ is assumed to follow the Breit-Wigner approximate formula for the resonance propagator [3]. Following the assumptions formulated above, the transmission probability amplitude for a single transport channel can be written as $t(E) = \Gamma / (E - E_{\text{res}} - i\Gamma)$ where the decay rate $\Gamma \sim 1/\tau$ with τ , the particle lifetime. As a result, the transmission probability for an electron to be transmitted through the resonance level can be approximated as $D(E) = |t(E)|^2 = \Gamma^2 / [(E - E_{\text{res}})^2 + \Gamma^2]$ and hence the differential conductance.

$$G_0(V) = \frac{e^2}{h} \frac{\Delta V^2}{(V - V_{\text{res}})^2 + \Delta V^2} \quad (1)$$

We believe that in the ground state the differential conductance $G(V) \approx G_0(V)$, and in the excited state $G(V) \approx G_1 = \text{const}$, i.e., the total current through the transport channel equals to $I(V) = I_0(V)n_0(V) + I_1(V)n_1(V)$, where $n_0(V)$ and $n_1(V)$ are corresponding occupation numbers, $n_0(V) + n_1(V) = 1$, $n_0(V) = 1$ for $eV < V_{\text{th}}$, $I_1(V) = V/R_1$. The principle of detailed balance, which consists in the equality of the forward and reverse transitions between the discrete states of the system, makes it possible to determine the occupation numbers $n_{0(1)}(V)$. For $N > 1$ equivalent excited states, the voltage dependence of $n_1(V)$ has the form

$$n_1(V) = \frac{N(e|V| - V_{\text{th}})}{N(e|V| - V_{\text{th}}) + (e|V| + 3V_{\text{th}})} \quad [2] \text{ for } |V| > V_{\text{th}} \text{ and equals to zero for } |V| < V_{\text{th}}.$$

Thus, we obtain that

$$G(V) = G_0(V) + (G_1 - G_0(V))n_1(V) + (G_1V - I_0(V))\frac{dn_1(V)}{dV} \quad (2)$$

Using equations (1) and (2), we can calculate the dependence of the differential conductance of the heterostructure under discussion on the voltage V for five values of the parameters V_{res} , V_{th} , ΔV , G_1 , and N .

To make direct comparison with the experimental data, we proposed a model, according to which quantum-percolation trajectories arise in such an interlayer between two electrodes with the probability of an electron transmission depending on the applied voltage bias. If the current along the trajectories is small, then the two-level states located on the electronic path remain in the ground state. For a sufficiently high current density, such a center can transfer to an excited degenerate state, radically changing the conductance of the resonant transport channel. The theoretical model for the carrier tunneling through a set of W nanograins provides a good fit to the measured device characteristics.

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References

- [1] I.M. Lifshitz, V.Y. Kirpichenkov, “Tunnel transparency of disordered systems,” *Sov. Phys. JETP*, vol. 50, pp. 499-511, September 1979
- [2] A. Halbritter, P. Makk, Sz. Csonka, G. Mihály, “Huge negative differential conductance in Au-H₂ molecular nanojunctions,” *Phys. Rev. B*, vol. 77, ID 075402, February 2008
- [3] V. Shaternik, A. Shapovalov, M. Belogolovskii, O. Suvorov, S. Doring, S. Schmidt, and P. Seidel, “Transition from Coulomb blockade to resonant transmission regime in superconducting tunnel junctions with W-doped Si barriers,” *Mater. Res. Express*, vol. 1, pp. 026001-026005, June 2014