Proximity induced superconductivity in DNAs

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In this report we reconcile previous findings [1-3] by showing that conduction over distances greater than hundreds of nanometers can occur if the DNA molecules are attached to a disconnected array of nanoparticles (typically 10 to 20 nm apart) that locally dopes the molecules, enhancing conduction. In addition in our case the nanoparticles are superconducting, which induces superconducting correlations in DNA at low temperatures.

In the following we present low temperature transport measurements of DNA molecules deposited through slits decorated with gallium nanoparticles (Fig.1). The samples investigated have resistances ranging from 5 to 20 kOhm at room temperature, with roughly 10 to 30 connected molecules, as deduced from the density of molecules on the substrate far from the slit. The samples were electronically and mechanically connected by gold plated spring contacts on the gold pads on the Pt/C film, and mounted in a dilution refrigerator operating down to 50 mK. The resistance was measured via lines with room temperature low pass filters. Measurements were performed in a current biased configuration using an ac current source of 1 nA operating at 27 Hz and a Lock-in detector with a low noise voltage pre-amplifier. Whereas the resistance was nearly independent of temperature between room temperature and 4 K, it dropped as T decreased, with a broad transition to a value of the order of 4 kOhm (which corresponds to the resistance of the normal Pt/C electrodes in series with the DNA molecules), see Fig. 1. This transition to partial proximity-induced superconductivity is shifted to lower temperatures in a magnetic field. It is the broadest for the most resistive sample, and exhibits the smallest magnetic field dependence.

Another superconducting-like feature is the non linear IV curves at low temperature, see Fig. 2: The dc current-dependent differential resistance is lowest at small dc current and increases with increasing dc current. The increase is non monotonous, presenting several peaks up to a current of the order of 1 μA, a sort of critical current, above which the resistance is constant and independent of dc current. The many peaks in the differential resistance curves are typical of non homogeneous superconductivity. For instance the differential resistance jumps seen in narrow superconducting wires (diameter smaller than coherence length) are associated with the weak spots of the wire. Since neither the Pt/C electrodes nor the DNA molecules are superconducting (as shown in previous experiments), these results suggest that the gallium nanoparticles, which are superconducting, induce superconductivity through the DNA molecules. The superconducting transition temperature of pure gallium is Tc=1 K but it is reasonable to expect that the gallium nanoparticles, because of their small size and their probable large carbon content, have a higher Tc [4]. It is interesting to note that the low intrinsic carrier density in the DNA molecules may prevent the inverse proximity effect, i.e. the destruction of the superconductivity of the gallium nanoparticles. Those same nanoparticles could not induce any proximity effect in metallic wires because of the high density of carriers in metals. This possibility of inducing long range superconductivity with superconducting nanoparticles was investigated recently in the context of graphene [5]. In the present case, it is also possible that the gallium nanoparticles could contribute to carrier doping of the DNA molecules in the normal state. These results invite to a systematic investigation of the possible carrier doping of DNA by metallic nanoparticles.

References

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Figures

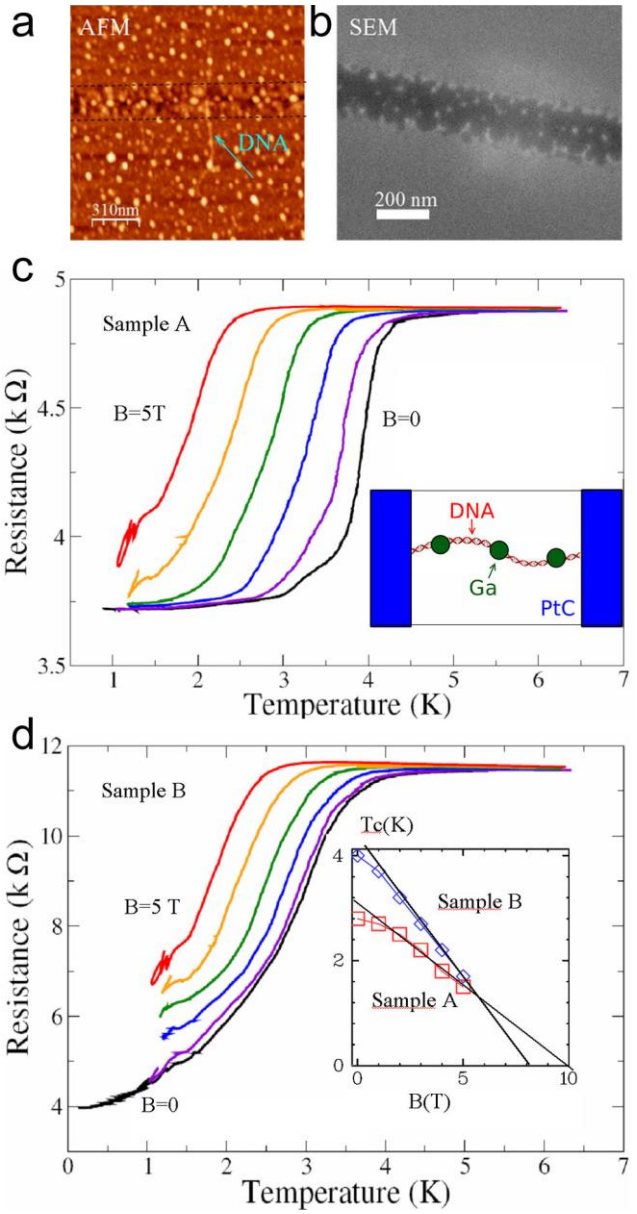

Fig.1. a) Atomic force microscopy image of one of the sample where low temperature transport was investigated, taken using an ultra sharp AFM tip and showing the presence of a DNA molecule across the slit. The slit is nearly invisible due to the scanning direction chosen to be parallel to the slit in order to optimize the DNA visualization.

b) Electron microscopy image of the same sample. Gallium nanoparticles are clearly visible in the etched slit region.

c),d) Low temperature dependence at several magnetic fields (going from 0 to 5T) of the resistance for 2 different samples where Ga nanoparticles are present inside the slit as described in the inset of the top panel. Inset of d): magnetic field dependence of the critical temperature Tc(H) deduced from the inflexion points of the R(T) curves.

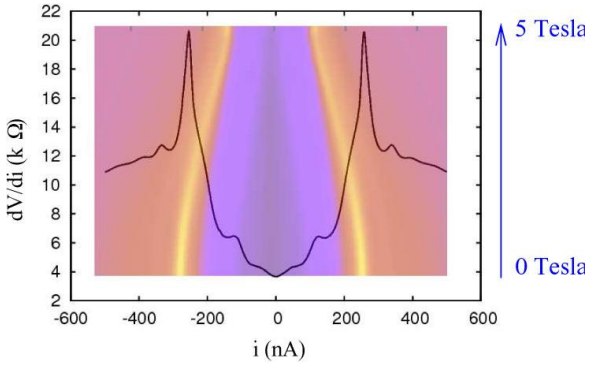

Fig.2. The black curve represents the differential resistance dV/di as a function of DC current through the 10 kOhm sample at 100 mK. The color inset in the background shows the evolution of the differential resistance encoded as a color scale with yellow/violet representing maximal/minimal differential resistance. The x axis represents the DC-current as in the main figure, and the y axis indicates the magnetic field ranging from 0 to 5 Tesla.