DNA: AN ELECTRICAL CONDUCTOR ?

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Let us make clear right in the beginning that DNA is supposed to be insulator, because a large HOMO-LUMO gap several eV in size is predicted by bandstructure calculations and also observed in optical experiments. After all, macroscopic assemblies -- such as films and ropes -- appear transparent to our eyes. However, conducting polymers are in their pure form also insulators and only become conducting if doped sufficiently. Since DNA is a quite complicated molecule, which -- for example -- is charged in aqueous solution, may have enzymes adsorbed on it, can change its conformation, is flexible etc., a sufficient density of dopping induced states is conceivable rendering DNA a conductor. The appropriate question is rather: *are there conditions such that DNA conducts electrical charge over large distances?*

The question of conduction in DNA -- or more precisely of charge transfer-- became a hot topic after the report of J.K. Barton's group (Caltech) [1] in which a surprisingly long-distance charge transfer was optically measured in DNA intercalated with luminescing donors and electron acceptor sites. This finding was quite distinct to charge transfer studied in proteins, where the hopping distance of charge is restricted to atomic distances (1 Angstrom). After seven years of research, we do not have a profound understanding of what really causes the large distance transfer. A very elegant chemical approach complementary to the optical probing has been implemented by B. Giese's (Univ. Basel) and M.-E. Michel-Beyerely's group (TU Munich) [2]. They can distinguish between hole and electron transport. Hole transport is mediated by guanines (G) which have the lowest oxidation potential and dependes on the base-pair sequence in between the G's. Hopping distances via "superexchange" of up to 300 Angstroms are inferred from the experiments. In contrast, hopping of electrons is expected to be independent of the base-pair sequence.

More recently, researcher started to measure electrical transport through DNA directly by attaching contacts to single (or a few) DNA molecules. It is not too surprising that the results are highly controversial too! The story starts with the work of Yoshio Okahata and coworkers who found a moderate electrical conductivity of approx. 20 kΩcm in aligned DNA films [3]. Thereafter, Uri Sivan an coworkers streched single λ-DNA over electric Au pads and report conduction only if the DNA strands were metalized [4]. In quite a different approach we have found a considerable (linear-response) electrical conductance through ≈ 1μm-long ropes of λ-DNA suspended over open holes in a carbon TEM support (room tempearture and in vacuum) [5]. Typical resistances are ≈ 1 MΩ, leading to a resistivity of order mΩcm. These experiments were performed in a dedicated low-energy transmission electron microscope allowing to image DNA unstained while simultaneously measuring or manipulating DNA with a movable manipulation tip, see figure 1.

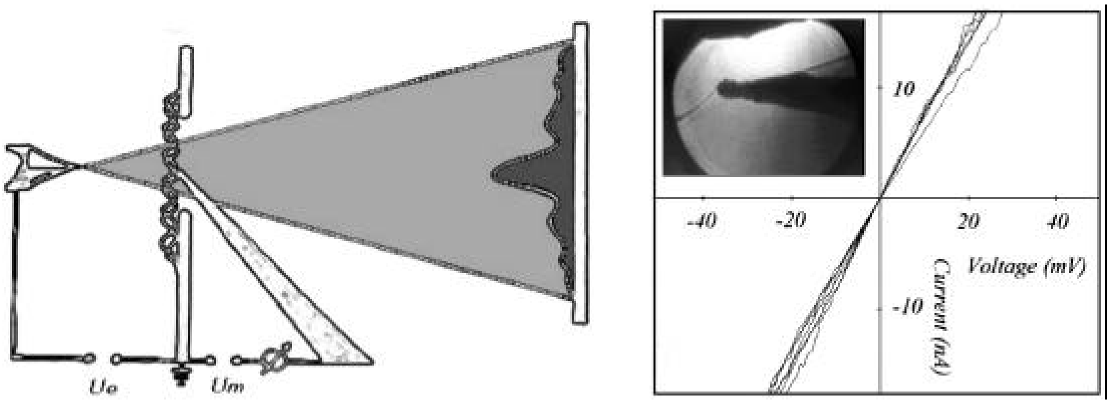

Fig. 1. Left: principle of the LEEPS microscope in which a low-energy electron beam is generated by field emission from an atomically sharp tip. Right: I-V characteristic measured at room temperature and in vacuum on a single rope of λ-DNA.

Thereafter, the group of Cees Dekker measured short poly-GC oligomers trapped in between two close Pt electrodes [6]. They find a gap of order 1-4 eV above which a considerable electrical current could be passed through the molecules (R of order 10 MΩ to 1 GΩ). Microwave measurements on macroscopic DNA assemblies yielded $\rho \approx 10\ \Omega$cm [7], while an AFM measurement (conducting tip) claims no conduction whatsoever [8], in contrast to the work of L. Cai et al. [9]. The most surprising results come from the group of H. Bouchiat. These researcher have found astonishingly small resistance values and even signatures for proximity-induced superconductivity [10].

During the recent year we have assembled DNA molecules over lithographically fabricated Au and Ti electrode fingers using "moelular combing" to strech DNA, see figure 2. These devices with contact separations in micrometer range do not show any measureable electrical conductance. In contrast, macroscopic DNA fibres show conductivity values in agreement with the finding of Okahata et al. [1].

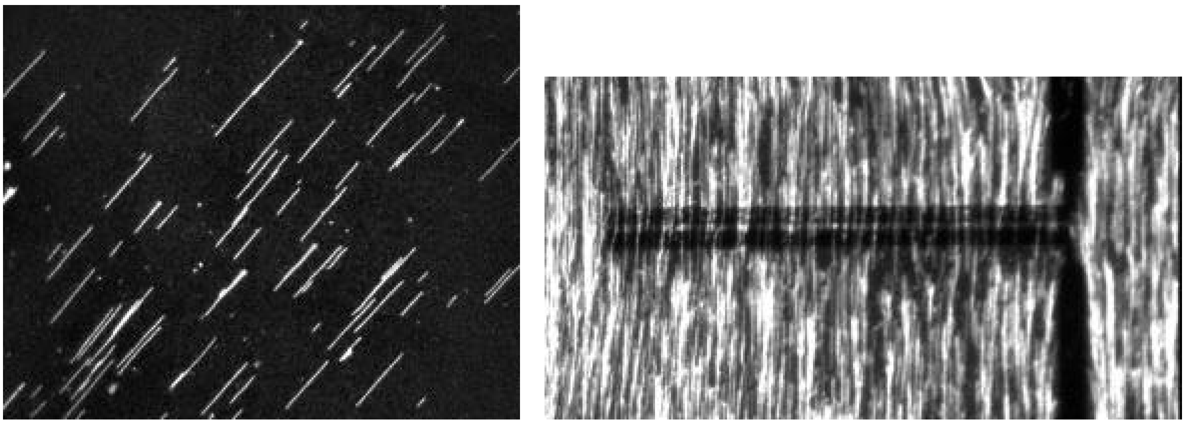

Fig. 2. Optical microscopy images (using fluorescent stained DNA) of streched λ-DNA on oxidized Si substrates. Left: homogeneous substrate; right: substrate with electrode structure. The DNA has a length of 16 µm, but gets elongated to approx. 20 µm while streched.

To summarize: there is a large range of conductivities found in direct electrical measurements on DNA. Values from zero conductance up to proximity-induced superconductivity have been reported. To unravel the underlying mechanism and controlling the important parameters is a tremendeous challengw we are faced by mother Nature.

This work has been supported by the Swiss NFS and EU-IST under the 5th framework program. We gratefully acknowledge help by Martin Heggner and Christine Brack.

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