13 Physics of Biological Systems

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13.1 Overview

Our overall motivation in studying the physics of biological systems can roughly be illustrated as follows:

- Biological systems are objects of condensed matter physics that exhibit unique properties. In comparison to inorganic materials, biological objects can exercise a number of dedicated functions. Both, their shapes and the associated functions, are governed by the same class of interactions that are known for a long time from gas-, liquid- or solid-state physics. However, what makes them unique despite all the similarities to classical physics objects, is their complexity. It manifests itself for example in the lack of symmetry if compared to crystals. On the other hand, the variety of shape and structural transitions within those systems are not just governed by random dynamics alone like in a fluid. Coming to grips with those fragile systems that react very sensitive to changes in their environment and that are capable of carrying out all sorts of surprising actions is a real challenge for physical sciences.

- In realizing the complexity of biological molecules, it might be a sensitive approach to start out by isolating individual systems. Our technique of low energy electron holography appears well suited to "look" at just a single species and we plan to push the resolution of this tool to arrive at detailed structural and electronic information on individual molecules.

- Our discovery that DNA molecules are electrical conductors, have led us to look at this molecule in an idealized way by treating it as a simple physical object and by disregarding its biological function completely. The only aspect that matters for this purpose is the fact that the DNA is long and thin. Furthermore, the chemistry of the DNA is well understood and the molecule is almost defect free in comparison to man-made structures on the nanometer-scale. To this end the DNA is a quantum wire and we plan to use this property to develop molecular electronic devices.

13.2 Interfacing bio-molecules to silicon structures

Recent experiments on DNA conductivity were done with molecules that had been deposited over an array of holes in a thin film. We thus had to rely on statistics to find a desirable configuration of molecules stretched over a certain hole. In order to fabricate devices, this seems an unsuitable approach and we thus have to develop ways to place the molecules at pre-defined sites on a silicon structure. There are several strategies to achieve this goal. One can use molecular recognition on a patterned device structure to have the molecules find their places in the liquid phase automatically. It is also feasible to use mechanical manipulation on a nanometer-scale to place them at the desired positions.

Another possibility is that, due to the electric charge of the DNA, it should be possible to use local electric fields on a device structure to stretch and trap the molecules and to thus bridge a specific site on a chip. Figure 13.1 illustrates how the arrangement of small areas on a chip with adjustable field strength can be achieved. We start out with a structure that has been fabricated for us by Clondiag Chip technologies in Jena using optical lithography. Next, the fine structuring is done in our laboratory. To create two free standing wires over

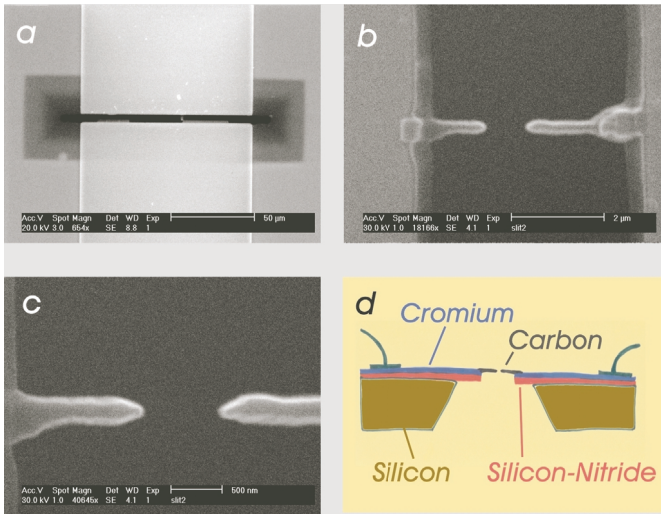

Figure 13.1:
a) Overall view of a silicon nitride membrane with an almost 5 micron wide and about 100 micron long slit and metal contacts at both sides.
b) On this structure we fabricated free standing wires facing each other to create a local electric field. Note that all the higher magnification images are rotated by 90 degrees compared to the SEM image in (a).
c) A closer look at this structure shows a gap width of about 700nm. The radius of curvature at the end of the wires is about 50nm.
d) Schematic side view of the overall structure.

a slit to which we can apply an electric potential to create a local electric field, we employ a 30 keV focused electron beam. The beam decomposes hydrocarbons along a line defined by the slow scanned electron beam. These preliminary studies, carried out in February 2001, seem encouraging since it was already possible to create gap sizes down to 30nm (not shown in the figure). This method thus holds promise for studying even smaller synthetic DNA molecules that can be synthesized to match the gap exactly. Studies to cover the carbon wires with gold and efforts to increase the writing speed to be able to routinely fabricate more complex structures, like multi-terminal devices, are currently in progress.

13.3 Mechanical manipulation of DNA molecules in the liquid phase

We are about to use (diploma thesis of C. Escher, who started in February 2001) optical techniques and local electric fields in a liquid to attach DNA molecules between two glass

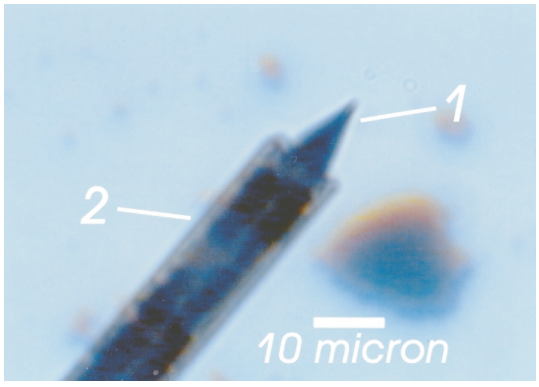

Figure 13.2: *Gold tip (1) encapsulated into a glass capillary (2).*

pipettes with a conducting gold wire inside. Electric fields of the order of 20 V/cm are applied in electrophoresis to move DNA molecules in solution. We plan to localize electric fields of this order to gap-structures which match the length of the chosen DNA molecules of several micrometer length. In order to be able to distinguish electronic current through the molecules from ionic current in the buffer solution it is necessary to minimize the exposed area of the

gold electrodes. In a first and preliminary experiment it has been possible to draw a glass capillary with a fine gold wire inside to a shape as shown in Fig. 13.2.

The purpose of this type of experiments is to be able to localize a molecule between the two electrodes in order to later mechanically move it to a desired place on a silicon structure. Furthermore it should be possible to explore the mechanism of conductivity in DNA by stretching the molecules or by changing the temperature of the surrounding liquid, just to name two of the various parameters that might effect conductivity. Eventually, we hope to achieve a fairly detailed insight into the conduction mechanism that should help us to relate to current theoretical models, like the polaron assisted hoping mechanism.

13.4 Structural biology of single proteins.

in collaboration with: Andreas Plückthun (Biochemistry Department, University of Zurich)

This effort is part of a National Center of Competence Research project on Nano-Science, headed by Hans-Joachim Güntherodt at the University of Basel. The goal is to obtain information on protein structures. In collaboration with Andreas Plckthun and his group in the biochemistry department, we are about to develop methods to prepare single proteins in such a way as to make them accessible to our LEEPS (Low Energy Electron Point Source) Microscope. We hope to be able to obtain high resolution electron holograms to derive structural information on an individual protein. A high resolution detector and new hologram reconstruction software will be available soon.

13.5 Field-ion microscopy and field-emission studies of single C60 clusters in tungsten tips.

This effort is closely related to the goal of obtaining ultimate resolution in holography with low energy electrons for structural analysis of bio-molecules. By using field ion microscopy techniques, we can characterize and shape a metal tip on the atomic scale. We have designed a dedicated field ion microscope, that is expected to be operational in summer 2001, to deposit single C60 clusters onto a metal tip that has prior been characterized on an atomic scale. The electronic structure of the C60 clusters and their bucky ball shape leads us to believe that such a structure will emit electrons with increased temporal and spatial coherence and in a larger angular regime. The theoretical 3-dimensional resolution in holography, not considering experimental aspects, is half the deBroglie wave length of the electrons. This would correspond, for the electrons we employ, to a theoretical limit of sub-atomic resolution. With this effort we hope to eventually make a significant step in resolution towards the theoretical limit, from the present 1 nm, which is not limited by the coherence of the source but by external disturbances.

Another aspect of this effort relates to surface science studies on C60 clusters carried out in the group of Jürg Osterwalder. We might be able to obtain complementary information by studying just a single adsorption event of an individual C60 cluster.