Current-Voltage Characterization on Au-DNA-Au Junctions under the Influence of Magnetic Field

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Abstract. We utilized Deoxyribonucleic acid (DNA) strands immobilized between a metal gap and its behavior was investigated. The DNA strands were initially prepared using the PCR method while gaps of 10.00 µm lengths were created on gold layer deposited onto silicon substrate. Once immobilized, current-voltage characterization was carried out on the Au-DNA-Au structure fabricated under the presence and absence of magnetic field. Experimental results clearly highlight the behavior of the DNA strands similar to semiconductor materials. An exponential decrease observed in the current in presence of external magnetic field suggests possible future application as a magnetic sensor.

Introduction

The study of the electronic behavior of organic compounds has led to important research on characterization of the electronic properties of biological materials. Since deoxyribonucleic acid (DNA) is arguably the most significant molecule in nature, it has been studied extensively as an important material for molecular electronic applications [1]. Charge transport mechanism in DNA is being investigated in view of its biological implications in damage and repair, protein bonding, and envisioned integration in future bioelectronics or DNA-based chips. The electron transport phenomena of DNA changes with the base sequence, counter ion type (buffer type) and relative humidity (measurement environment, i.e. whether in the atmosphere or in a vacuum). It also depends on the sample shape and measurement method. In particular, when fixed electrodes on an insulating substrate are used, the gap length between the electrodes is a critical factor [2]. The first direct electrical transport measurement on a single, 16-µm-long λ-DNA, was published in 1998 by Braun et al. Later on, in 1999 Fink et al. [3] reported ohmic behavior in λ-DNA molecules with a resistance in the MΩ range.

Further experiment published in 2000 by Porath et al. [4] measured the electrical transport through 10.4 nm long (30 base-pairs) homogeneous poly(dG)-poly(dC) molecules that were electrostatically trapped [5,6] between two Pt electrodes. In a parallel work, Kasumov et al. [7] reported ohmic behavior of the resistance of λ-DNA molecules deposited on a mica surface and stretched between rheniumcarbon electrodes. In another attempt to resolve the puzzle surrounding DNA conduction properties, de Pablo et al. [8] applied a different technique to measure single λ-DNA molecules on the surface in ambient conditions, the results of which could be found in his paper [9].

The present work investigates the characteristic current (I)-voltage (V) of DNA strands immobilized between two metal (Au) gaps when a magnetic field was applied perpendicular to the direction of DNA arrangement. The results generally highlight high sensitivity to surrounding magnetic field suggesting possible application as a magnetic sensor.
Methods and materials

DNA molecules from Boesenbergia rotunda belonging to ginger family were extracted in Institute of Biological Science (ISB), University of Malaya. Sequence analysis indicated that the orders of base pairs are as follows; A (22%), T (20%), G (35%), C (23%). Substrate used for etching was a p-type Si wafer (orientation <100>) of diameter (150.0 ± 0.1) mm, thickness (675 ± 25) µm and a resistivity of 1 to 10 Ω-cm bought from MEMC Electronic Materials. Al wire used in thermal evaporation meanwhile was bought from Kurt J. Lesker Company and had a diameter of 1 mm and 99.999% purity. High purity chemicals (NH₃, H₂O₂, HF, HCl and acetone) were supplied by Sigma Aldrich and used directly without further purification. Deionized water was obtained using a Barnstead Company (Nanopure) water system available in-house. 150 nm thick Al films were fabricated on the p-type silicon surface prior to deposition of DNA strands.

Results and discussion

![Diagram](image_url)

Fig. 1 Two electrodes L and R (L = left, R = right) with an insulator gap in the gold-DNA-gold structure in presence of external magnetic field. I-V behaviour for DNA strands inserted within the gap was obtained after applying magnetic field in the direction shown in the diagram.

When an external magnetic field in the direction shown in Fig. 1 is applied, the energy levels increased allowing some of them to pass above the Fermi energy. Therefore, the band gap and density of states changes as well as the spins could be polarized in the electrode. In high magnetic field, the scattering amplitude for similar and dissimilar spins will differ. In the presence of some low magnetic fields, the band gap does not change efficiently. Also, the charge of material in a magnetic field will be subjected to a Lorentz force. A circular motion will be created with trajectory of electron that is perpendicular to the field. Radius of charge motion has a relationship with energy levels state in material and magnetic field. Electrons in partially filled bands and ions could be affected by external magnetic field. Fig. 1 illustrates the setup for measuring the gold-DNA-gold in the presence of a horizontal magnetic field. The sample was placed in a dry gas box under the magnetic field while connected to an electrometer analyzer.
As depicted in Fig. 2, the I-V curve characteristic for gold-DNA-gold structure shows rectifying behaviour that under forward bias, current increases exponentially with low threshold voltage. DNA strands, in this structure, act as a semiconductor equivalent to a back-to-back diode. The potential barrier in this case is calculated using the Landau equation at room temperature and equates 0.60 eV approximately. Using work function for gold and electron affinity for DNA and potential barrier in metal-semiconductor structure, potential barrier meanwhile is calculated at 0.52 eV.

The DNA buffer has free ions of Na$^+$ and Mg$^+$ that affect pi orbital electronss and ionize the medium. Thus it plays a significant role in charge transport phenomena. With increase of magnitude of magnetic field, the arrival time for carrier from the left to the right electrode will decrease and the current transfer rate will decrease. Current was therefore observed to drop with increase in exerted magnetic field as shown in Fig. 3 for each constant voltage of 0.2, 0.4, 0.6, 0.8 and 1.0 V. This figure made clear that with external magnetic field, the resistance was also increased. Therefore, the magnetic sensitivity of gold-DNA-gold structure as illustrated by the graphs promotes DNA based devices as suitable candidate for magnetic field detectors/sensors.
Conclusions

This work presents experimental study of gold-DNA-gold structure in the presence and absence of external magnetic fields with strengths less than 250 mT. This made clear that an externally imposed magnetic field would boost resistance of the MDM structure below than 250 mT and for higher magnetic field we can see an increase in potential barrier in MDM junction. The magnetic sensitivity indicates the promise of using MDM structures as potential magnetic sensors.

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References


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