ESNSTM – publishable summary

The Objective of the ESNSTM project is to combine the outstanding atomic resolution which is available by the scanning tunneling microscope, with the remarkable chemical analysis ability of magnetic resonance techniques. The ESNSTM technique is detecting the Larmor frequency of a single spin through peaks in the power spectrum of the tunneling current. The road to develop ESNSTM into a mature technique is dependent of the success to fulfill the following objectives: 1) From the instrumental point of view, the main drawback of the technique is the small S/N ratio. Several solutions are being developed to improve the SNR. 2) Different solutions to reduce the huge mismatch between the STM tunneling junction and the detector and to minimize the leakage through parasitic capacitances are being tested. Implementing different detection schemes specially designed for this project is an important part. 3) All the experiments so far, were done at room temperature. Due to the reduction of Johnson noise, the improved stability and the smaller relaxation rates at liquid helium temperatures, the development of LT ESNSTM has a high priority in this project. 4) In addition, currently, the signal is detected in frequency domain. Detection in time domain is expected to improve the SNR.

Another objective is to demonstrate ESNSTM capabilities as a single spin technique. A successful measurement of single spin g and hyperfine tensors, of single spin relaxation times, of their variation on the single atom level compared with the macroscopic level are expected to open many possibility in chemical analysis on the single scale. Unique experiments are possible in this technique such as measuring the dependence of the local spectra on stresses and electric fields applied by the tip. Additional experiments to be performed in the direction of reinforcing the technique beyond this point are planned: To measure the hyperfine coupling between an atom on the tip and a nucleus on the surface. To use double resonance for measuring the single atom nuclear Zeeman frequency, and to develop techniques for single spin manipulation.

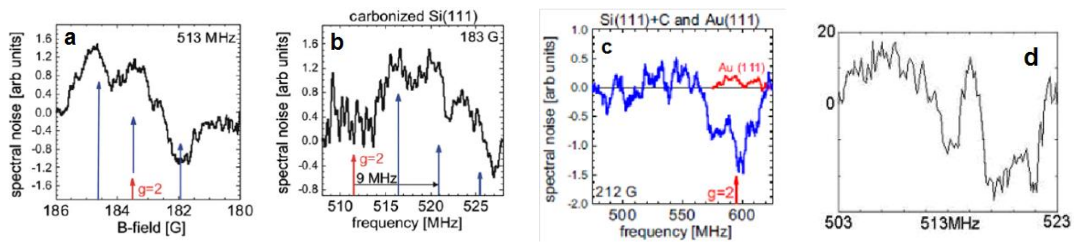

Fig. 1 Hyperfine spectra from defects in carbonized Si(111):An average of different positions as a function of field (a) and frequency – with a fixed field (b) broad sweep includes a 60MHz wide peak of presumably dangling bond overlapped with a narrow triplet from subsurface SiC vacancy shown in (a) and (b) and a spectrum over a single position, presumably identifying a neighboring ^{28}Si atom (d).

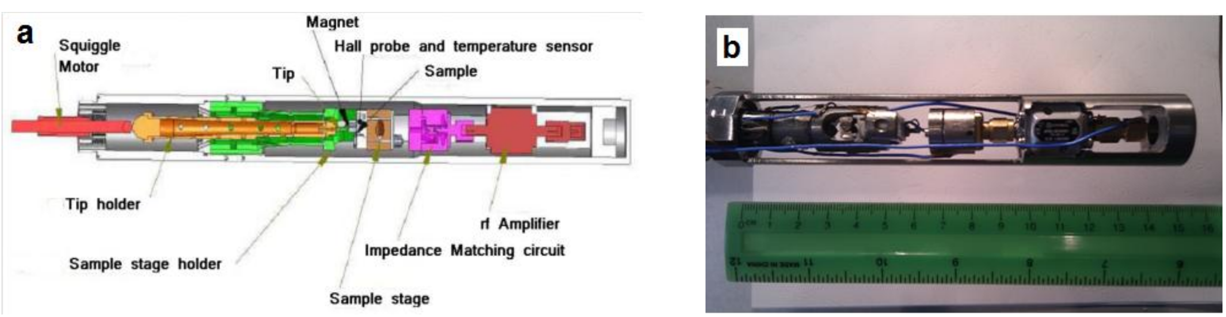

Fig. 2 A scheme of the HV LT STM head (left) and a photograph (right)

While the ability to observe chemical contrast on the atomic scale, was demonstrated before the project was started [1], it was shown that the technique is able to reliably observe a hyperfine spectrum of defect in SiC surface [2] (Fig. 1). The line-shape with peaks and dip that appears in the spectrum demonstrates a process that induces a different orientation in the spin of the tunneling electron that is not parallel to the magnetic field. Tunneling of such polarized electrons into a single impurity gives peaks or dips at the Larmor frequency. Similarity with the macroscopic spectrum was demonstrated by accumulating spectra from different positions on the surface. Different ways to improve the sensitivity, for example to use active matching circuits and to work with a single frequency using field sweep were demonstrated.

Several low temperature (LT) ESNSTM machines were successfully constructed (SC) and operated or are in construction (C) within the development of the project. One of them is a HV machine (SC) in BGU which will be mainly dedicated to working on drop casted molecules and defected graphene (Fig . 2). Others are UHV-LT machines (C) (Fig. 3), one with a bath cryostat in BGU and the other with a flow cryostat (APE and INSTM). These LT microscopes will be dedicated to the study of molecules and atoms that can be sublimed at UHV and to UHV clean surfaces. Several matching circuits (Fig. 4) with LT rf components were implemented on these microscopes

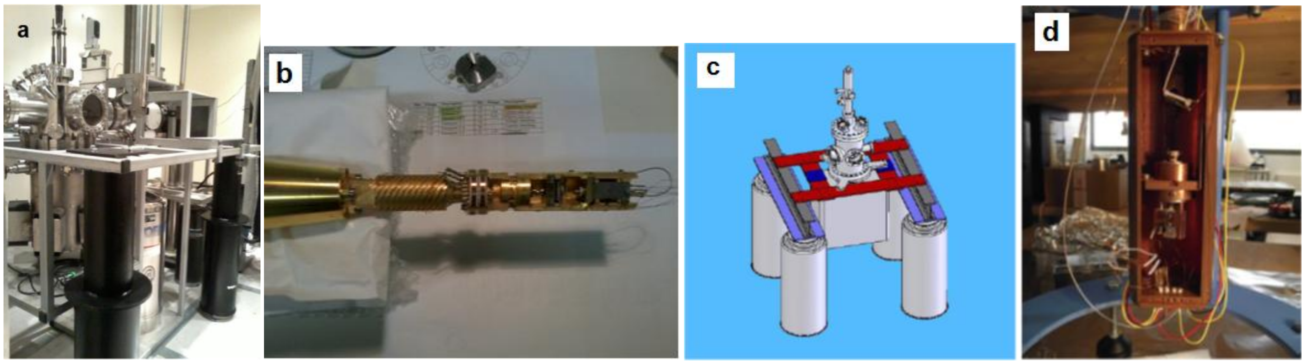

Fig. 3 LT UHV ESNSTM based on a bath cryostat (a),(b) and on a flow cryostat (c),(d).

The preparation of different surfaces on which paramagnetic full organic or metallo-organic molecules or molecular magnets are adsorbed enable achieving a better control on the spin system, where the distances between the paramagnetic atoms, and their electronic structure is more well defined – compared to randomly deposited or prepared atoms and defects. Molecules that will be firstly tested with ESNSTM are phthalocyanine molecules (Cu and Y) that can be sublimed and their ESR spectrum is well defined. These molecules are easy to be imaged with an STM. Macroscopic ESR Studies were performed on surfaces on which such molecules were deposited for the purpose of comparison with future ESNSTM experiment. Systems that were already prepared or are under preparation and characterization are pyrene derivatives of the nitronyl nitroxide radical deposited on rutile TiO_2(110) single crystals and on Au(111), Si(111), SiO_2 and Al_2O_3 [3-6].

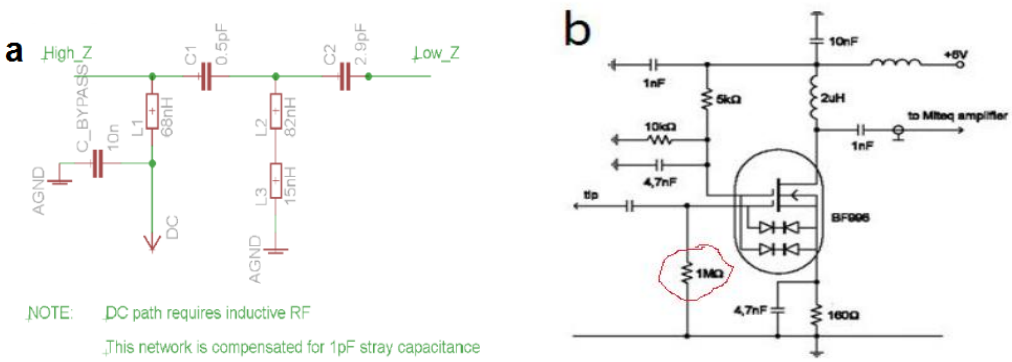

Fig. 3 Passive (a) and active (b) matching circuit used in ESNSTM experiments.

An effort to build new detection systems is being implemented. It is possible to use the fact that the tunneling current is, according to the proposed mechanism, spin polarized. Using a SQUID detector, a larger signal can be induced by the magnetic moments of the electrons from the tunneling junctions. This may overcome the impedance matching problem. In addition, since it is a superconducting device, there is not heat dissipation, which is a big advantage in a LT microscope. Other new detection systems were developed [7]. A significant improvement in sensitivity can be gained when a single digital reference can be used to drive all the facilities in the detection system. A signal with an intensity of -165 dBm can be detected which is an improvement compared with existing detecting systems. Other solutions based on virtual ground, on increasing the detector impedance (for reducing the mismatch) and reducing the detector impedance, to minimize losses to the parasitic capacitance are implemented.

A successful development of the technique into the level of a mature technique can be of a significant scientific and technological impact. This impact can be broad and relevant to many different fields. In surface science it can provide a detailed and atomically resolved chemical analysis. In the direction of spin physics, it can be used to study fundamental questions like single atom relaxation or single atom spin – spin coupling for neighboring atoms etc. It can be used to study fundamental phenomena in condensed matter physics such as the decay of the magnetic moment in the Kondo effect, and the dynamics of the Cu spins in cuprates in high T_c superconductivity. It might be even used, for a new imaging technique for example in biological samples, measuring the distance dependent hyperfine coupling between a paramagnetic atom on the tip and the hydrogen nuclei on the sample (for example on protein molecules) and to use it as a feedback parameter.

During the first two years of the project, the appointees involved in ESN-STM have started an effective integration, as illustrated by transfers of materials and collaborations, bilateral meetings, research secondments (a total of 20.5 m/M out of 84). Despite some initial difficulties in the training received by the appointees, they benefited by common activities between different types of partners (Academic and SME). Despite the delays in the performance of secondments the progress achieved in all Work Packages is in line with the initial plan and was supported also by internal resources.

References:

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Project webpage: http://in.bgu.ac.il/en/Labs/esn-stm/Pages/default.aspx