Fabricating Nanoscale Tunnel Junction for IETS Measurements

Y. Hamidi Zadeh, Z. A. K. Durrani
Optical and Semiconductor Device Group, Department of Electrical & Electronic Engineering, Imperial College London, South Kensington, London SW7 2AZ
y.hamidi-zadeh10@imperial.ac.uk

Inelastic electron tunnelling spectroscopy (IETS)[1,2,3,4] provides a means to characterise the phonon spectrum of a molecule by measuring the phonon-assisted tunnelling current through a potential barrier impregnated with target molecules. Traditionally, this technique has used metal-insulator-metal (MIM) junctions and the molecules of interest are adsorbed on to the insulator during junction fabrication. At low applied voltage V, tunnelling through the barrier is elastic. However, inelastic tunnelling caused by electron interaction with vibrational states in the adsorbed molecules creates additional conduction channels, with a change in energy $\hbar\omega$. These lead to peaks in the d^2I/dV^2 vs. V characteristics for each additional channel, giving a spectrum of the molecular vibrational modes (Figure 1). As energy separations in the vibrational spectrum are relatively small compared to the electronic spectrum, the full vibrational spectrum is measured only at <30 K. However, it may be possible to measure part of the spectrum even at room temperature, raising the possibility of a molecular detector.

We are investigating nanoscale tunnel junctions for IETS measurements of well-characterised molecules such as CH_3COOH, from 300K to 20K. The nanoscale tunnel junction consists of a Si nanowire (NW) / SiO_2 / Al NW structure (Figure 2). The Si NW is fabricated in silicon-on-insulator (SOI) material using electron beam lithography. The devices use Si NW widths down to ~ 50nm. The NW is then thermally oxidised at 1000ºC to create a SiO_2 layer ~ 10nm thick. An Al NW ~ 120nm in width is defined such that it crosses the Si NW, forming a nanoscale Si / SiO_2 / Al tunnel junction ~ 50 × 120nm in area. The reduction in device dimension to the nanoscale increases the sensitivity of the device to molecules adsorbed on the tunnel junction. Furthermore, the use of SOI material can allow modulation of the tunnel junction using the back gate formed by the SOI substrate. The back gate voltage can then control the Fermi energy and electron concentration in the NW, and hence the IETS characteristics.

Figure 4(a) illustrates the I-V characteristics of the tunnel junction before and after immerse in acetic acid. The tunnel junction resistance increases after being immersed in acetic acid. Figure 4(b) displays the dI/dV characteristic of the device. Finally, Fig 4(c) shows the d^2I/dV^2 characteristics of the device. Peaks can be observed at ~ -0.35V and -0.65V, which correspond to the first and second excitation modes of a C-H bond.[1]

---

[1] R. C. Jaklevic and J. Lambe, Phys. Rev. Lett. **17**, 1139 (1966).

[2] R. G. Keil, T. P. Graham, and K. P. Roenker, Applied Spectroscopy, **30**, 1 (1976).

[3] K. W. Hipps and U. Mazur, J. Phys. Chem. **97**, 7803 (1993).

[4] U. Mazur, X. D. Wang, and K. W. Hipps, Anal. Chem. **64**, 1845 (1992).

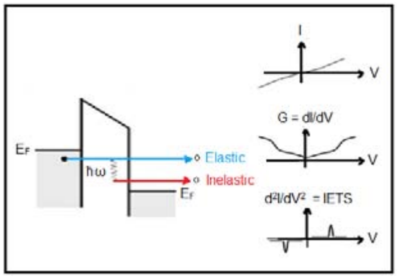

Figure 1. Inelastic tunneling and IETS signals

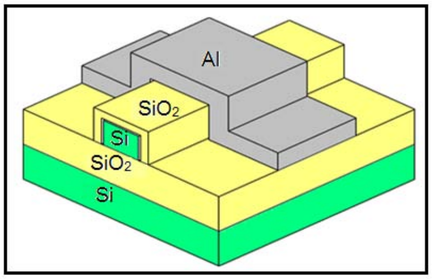

Figure 2. Schematic diagram of a crossed nanowire tunnel junction

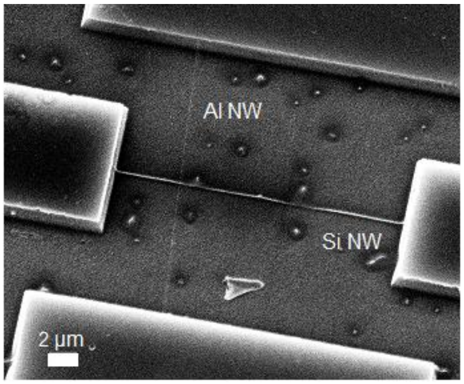

Figure 3. Magnified SEM Image of Si NW/SiO_2/Al NW tunnel junction

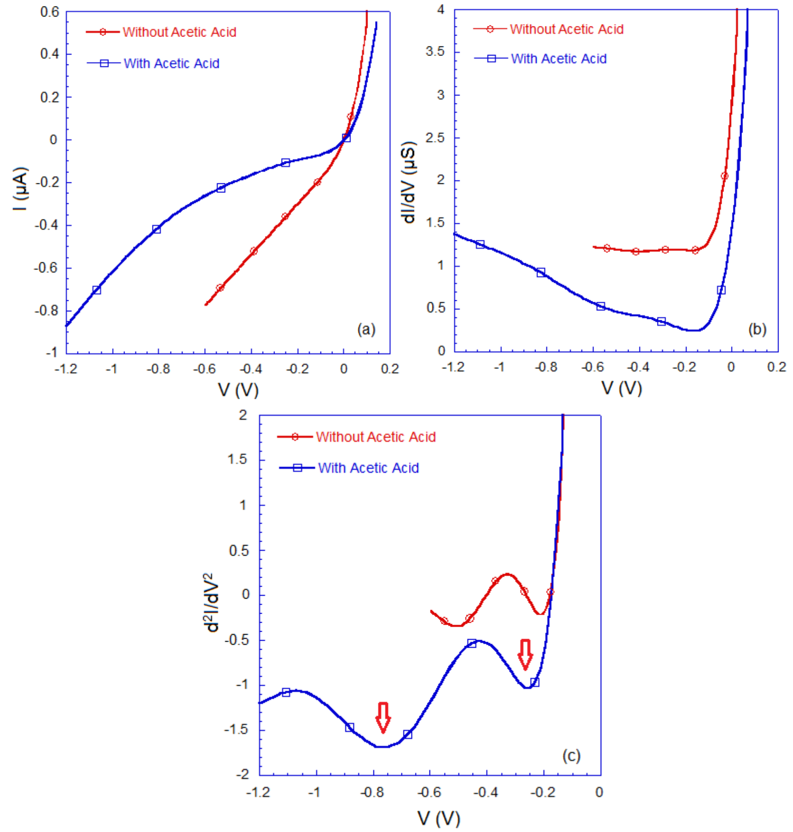

Figure 4. IET spectrum of Acetic Acid on Si NW/SiO_2/Al NW tunnel junction at 300K