Project No: 236885
Project Acronym: FUNSENS
Project Full Name: Functionalised Carbon Nanotube Electrochemical Sensors

1. FINAL PUBLISHABLE SUMMARY REPORT

This section normally should not exceed 2 pages.

This is a comprehensive summary overview of results, conclusions and the socio-economic impacts of the project. The publishable report shall be formatted to be printed as a stand alone paper document. This report should address a wide audience, including the general public.

Please ensure that it:

- Is of suitable quality to enable direct publication by the REA or the Commission.
- Is comprehensive, and describes the work carried out to achieve the project's objectives; the main results, conclusions and their potential impact and use and any socio-economic impact of the project. Please mention any target groups such as policy makers or civil society for whom the research could be relevant.
- Includes where appropriate, diagrams or photographs and the project logo, illustrating and promoting the work of the project.
- Provides the address of the project Website (if applicable) as well as relevant contact details.

Carbon based electrodes will most certainly play an important role in future technological devices. Carbon nanotubes (CNTs) have shown already their suitability for these purposes, but it is the recent discovery of graphene with its outstanding properties that is boosting this field of research within the scientific community. The main aim of the project is the development of carbon based electrodes, specifically carbon nanotubes and graphene, (evaluating simultaneously different methods of synthesis, arrangement, configuration and functionalization) for applications in the sensing arena..

For analytical applications, and especially in the case of CNTs, the optimal device will not rely uniquely on their intrinsic electrical properties (semiconductor and metallic behaviour). The different configurations or arrangement in which CNTs can be obtained-synthesized are important in order to enhance their overall performance. Much effort have been invested in the first period of this project to the design of different carbon nanotube configurations, e.g. network of SWNT, parallel array of SWNT, vertical aligned forest SWNT and single SWNT devices fabrication. Indeed, networks of nanotubes grown on insulating substrates are suitable for the detection of catecholamine neurotransmitter serotonin, as demonstrated in this project, improving by three orders of magnitude the limit of the detection of the standard glassy carbon electrode and also by one order of magnitude a boron doped diamond which had been previously considered to be the best carbon electrode for this type of target analyte. (*published*)

However, in order to design an optimal electroanalytical sensor, it is necessary to fully understand how electron transfer proceeds on these sp2 carbon allotropes, a topic of extended debate within the scientific community. In that sense, our work with vertical aligned nanotube forests is an example of how a fundamental study brings us towards an optimal sensor design. Our results show that the electrochemical activity of pristine CNT closed ends is both high and equivalent to that of the CNT side walls. Crucially showing it is thus unnecessary to open the nanotubes to achieve a significant electrochemical activity. This fact is of major importance if future analytical devices employing this type of CNT of configuration are to be studied. (*submitted Angew Chemie*)

Ideally fundamental studies to understand the electron transfer on sp2 carbon allotropes need to be carried out at the single nanotube scale. For these studies we are in a privileged and unique situation, thanks to the unique to Warwick and recently developed (in the group) electrochemical scanning technique, Scanning Electrochemical Cell Microscopy, SECCM, which is able to perform electrochemical studies at the micro-nanoscale. This has been the aim of the second period of research, employing this technique to study different arrangements of SWNT, e.g., network of nanotubes and single nanotube. The outstanding results obtained so far are definitive to unravel the long debate of whether electron transfer at CNTs is at defects or at the sidewalls of the nanotubes (*in preparation*). Simultaneously, a finite element model simulation of the technique has been developed, in order to provide quantitative information on the electrochemical activity of the SWNT. (*submitted*)

We are in the graphene era, and the use of this new form of carbon as electrode is being extensively evaluated. The electrical, optical, thermal and mechanical properties of graphene have been reported extensively, but there is still a lack of an accurate study of the electrochemical behaviour of this new material. Therefore, in parallel to the SWNT studies, efforts on obtaining graphene for the first time in our lab in both synthetic form (CVD growth at atmospheric and low pressure) and natural form (by mechanical exfoliation) have been invested successfully. This one atom thick sp2 carbon layer have been obtained as single layer and multilayer form and studied in depth by means of SECCM and other complementary techniques such as AFM, FE-SEM, microRAMAN, etc. In order to elucidate how the underlying substrate affects the ET properties of graphene, experiments on suspended graphene is currently underway. The unprecedented results obtained, show how the electron transfer kinetics are affected by the presence of single or multilayer graphene, but also by the underlying substrate, both for synthetic graphene and exfoliated. This will be a point of reference for future work on the electrochemistry of graphene and its future (many) technological applications. (*in preparation*)

In parallel, it is noteworthy to mention several related projects carried out during this project, including the functionalization of single nanotube devices as proof-of-concept new forms of gas sensors, and the fabrication of patterned graphene nanoribbons on semiconductor substrates. Besides their high chances to be successful projects and publications, these are also starting points for new future funding applications.

All these studies have focused on the electrochemistry at the nanoscale of both carbon nanotubes and graphene, which will consolidate the world recognised reputation of the Electrochemical and Interfaces Group at Warwick and become a reference in this field of research, increasing the number of collaborations and funding from public and private corporations.