Nanotechnology and Integrated BioEngineering Centre (NIBEC)

www.nibec.ulster.ac.uk

UNIVERSITY OF ULSTER

Introduction

NIBEC - the Nanotechnology and Integrated BioEngineering Centre (formerly the Northern Ireland Bioengineering centre and NRI) is a world class research complex at the University of Ulster's Jordanstown campus.

NIBEC represents a consolidation of eight advanced functional materials research groups, dealing with thin film material types used in electronics, photonics, nanotechnology, sensors, MEMS, optical, environmental, magnetic and bio-material devices. The key scientific **thrusts** that unite the groups are currently represented by following headings:

- Medical Sensor Fabrication and Characterisation
- Tissue Engineering and Regenerative Medicine
- Nanomaterials growth and Patterning
- Photocatalysis Materials

The purpose-built facilities house some of the most sophisticated nano fabrication, manipulation and characterisation equipment in the world.

The focus of NIBEC will be to develop a thin-film material characterisation and fabrication engineering facility, capable of vertical dimension scaling down to the sub-nanometre level, and lateral scaling for large area and three-dimensional coverage. Interdisciplinary research is evolving powerful new concepts and capabilities such as atomic-scale manipulation, self-assembly, and biological structure/function relations together with increasingly powerful computational tools that are rapidly converging from disparate research fields to enable a viable molecular nanotechnology. This in turn allows generic science to develop a wide range of device applications related to both the bioengineering and ICT sectors.

Research: Carbon and Nano Devices Group

The group's general interests include applications in flat panel displays, thin-film coatings, electronic materials and optical sensors. Industrial contracts include research on the subject of amorphous carbon (DLC) coated medical guidewires, and another on patented plasma based co-axial DLC coatings of very long wire and 3D products.

Currently they are working closely with Seagate Technology on the scientific development of nanofilm (10nm) hard-wear DLC coatings for the magnetic head/disc interface, which has led to studies of nano-mechanical properties of ultra-thin-film DLC, using PECVD and IBD coatings on various substrates and a study of the growth mechanisms associated with carbon based ultra thin-films. Film properties such as nanotribological properties corrosion resistance, surface energy, Raman characterisation as well as stress/strain/wear and coefficient of friction are being studied.

Other interests include plasma diagnostics and technological plasma processing surface plasma resonance sensing; electro-optical testing of wide band gap materials such as DLC, II-VI phosphors and metal oxides. The group have also developed a laser ablation transfer technique to fabricate nanostructures of metal and oxides, for micro-electronic and opto-electronic applications and she also has experience in ellipsometry techniques recently receiving a Royal Society award to carry out this work.

Significant industrial partners include: Cheeseborough Ponds, Courtaulds, Sendx (USA), 3M (USA), TFX (NI), AVX-Kyocera (NI) and Meridian (NI).

Group Projects: Diamond Like Carbon and Carbon Nanotubes

Ultra–thin DLC coatings can contribute to improve wear resistance, decrease stiction, lower the friction coefficient and improve corrosion protection for numerous applications. Much emphasis is currently placed on the attainment of low stress ultra-thin films exhibiting good adhesion to device-based substrates without lowering the wear resistance and corrosion resistance of such films. Approaches such as deposition of DLC films on silicon pre-coated substrates, doping the DLC with different elements, development of PECVD and FCVA DLC deposition are all been investigated at UU for medical, data storage, MEMS, electrical and packaging applications.

Filtered vacuum cathodic arc (FVCA) offers scope for improved deposition capability and flexibility. High-density plasmas with up to 96% ionisation fractions are available and this has delivered tetragonal a-C layers with up to 85% sp3 fraction, i.e. highly diamond-like. The substrate is remote, with separate bias (pulsed or continuous) to provide selectable ion energies.

Dopant incorporation can be via target, background gas or dedicated ion or neutral beam. The research programme can be divided into two components: plasma measurements/optimisation and layer characterisation/ optimisation.

It will concentrate on assessing nanocrystalline ta-C for applications related to its extreme high hardness (>80Gpa), low surface energy (110o), high density and superior electro/optical properties. Applications are already been found in; data recording, packaging/bottling photonics and general passivation. Nanocrystallite copper is being investigated on various substrate types and electrical and film integrity properties with studies against grain size film properties and the fundamental plasma parameters of a FCVA system. Using selected molecular sources in the make-up gas, the plasma contents show the presence of cluster fragments, the relative abundances of which can be systematically varied via the control of the operational parameters.

The resultant film characteristics change accordingly. This seminal work will be extended to a wider range of molecular cluster-forming precursors than has so far been used, including selected organometallics as routes into semiconductive and photoactive thin films and related layer structures. Substrate types will typically be silicon, ceramic and polymer. Work has also commenced on routes to the fabrication of nanotube devices for biomedical applications. Studies are looking at the AC impedance characteristics with the view to nanotube-based biosensors. CVD and Arc based deposition is allowing device structures to be grown and this is currently being investigated as a possible nanoelectrode layer within sensors.

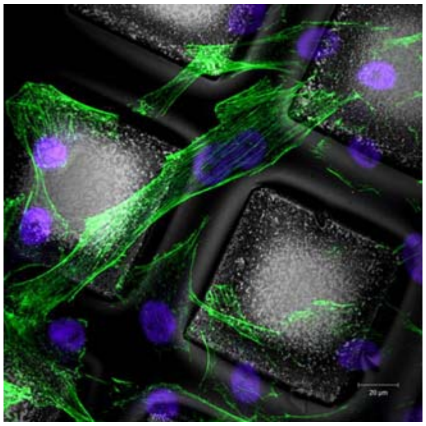
Research: Bioceramics and Tissue Engineering Group

The development of new and improved biomaterials, i.e. those materials which, in use, are required to be in contact with biological systems, is critical for the provision of the next generation of medical devices and therapies. Such devices specifically encourage and enhance the restoration and repair of body tissue function *in vivo*. To this end, the group at UU seek to develop and exploit advances in area of micro- and nano-technology that can directly provide surface engineered systems for important applications in regenerative medicine and tissue engineering

The concept of tissue engineering (and regenerative medicine), whereby specific cell types (including stem cells) are harvested, expanded in culture and subsequently transplanted into a human host as a means of replacing damaged or diseased tissues or organs offers tremendous potential for improved healthcare and direct benefit to patients. To date, most research effort has been directed towards understanding and controlling the basic science required for obtaining successful cellular processes that accurately reflect the correct combination of growth factors and other biomolecules and accounts for creation of the essential dynamic factors via an appropriate (bioreactor) environment. Our ability then to accurately manipulate chemical, physical and structural features of surfaces, and thereby devices, at the sub-micron to nano-scale level provides the potential for new and exciting medical technologies.

Extensive R&D effort is being directed at the following key areas: deposition of high performance bioactive coatings for the enhancement tissue/implant interactions; modification of biopolymer surfaces by atmospheric plasma processes; the role of nano-scale properties in the delivery of targeted cell/protein surface interactions on surfaces and within 3-D scaffolds; nanocomposite systems for medical and dental applications; investigation of the role of nanoclays in the development of high performance glass-ionomer dental cements. An important strength of the group is availability of extensive expertise in the use of state-of-the-art surface analysis techniques (XPS, AES, SIMS, SEM/EDX, XRD, FTIR, AFM, Optical and Stylus Profiling, etc.) to advanced biomaterials research. In addition, determination of the biofunctionality of such materials is facilitated by dedicated in-house cell and tissue culture facilities. The group carries out much of its work in collaboration with colleagues in the appropriate clinical sectors.

Group Projects: Biosurfaces



Physical coating technologies using sputter deposition and surface modification processing via methods such as dielectric barrier discharge offer an extensive range of options for the engineering of the surface features of biomaterials surfaces. The ability to manipulate the properties of an active film or to changes modified surface region offer the possibility of targeted and controlled bio-response.

With controlled pit/pore density, size, shape, depth, distribution and chemical activity, nanosurfaces can be considered for bio-active cell culture matrices. Such surfaces can also be used for nanosensor and micro-electrode (below diffusion layer thickness) applications. In addition to cell culture, surfaces can be filled with virtually any liquid phase material. Nanometer scale structure-forming systems in biology are inherently self-organising, and exhibit highly selective molecular recognition properties. Hence, exploration of the biomolecular mechanisms involved in control of the size, distribution, and assembly of interesting and functionally applicable inorganic nanostructures offers direct applications in tissue engineering, sensors and coatings.

Our R&D work in plasma-based thin film deposition and surface modification of biomaterials allows a better understanding of the basic science and routes to applied devices. Several aspects of these studies are being carried out in collaboration with our international partners

Research: Photocatalysis Research Group (PCRG)

This group has established internationally recognised research programmes on the structure, characterisation, application and degradation of semiconductor and biosensor materials and the use of nano-scale photocatalytic TiO_2 in environmental and industrial pollution control context. The photocatalysis research group works on the development of semiconductor materials, which will convert light energy into electrochemical energy for the oxidation (or reduction) of chemicals such as environmental pollutants. Examples include the mineralisation of oestrogens or the conversion of carbon dioxide into fuels. Methods used to immobilise the catalysts include electrophoresis, CVD, and plasma methods. The group also develops sensors and biosensors for detecting environmental pollutants. The photocatalysis research group is currently working on two European funded projects.

Group Projects: Photocatalysis

Developments over the last three decades have led to an exponential growth in research concerning semiconductor photocatalysis and the related applications. The photocatalysis research group aims to expand research activities in the areas of photoelectrochemistry and photocatalytic energy conversion, and photocatalysis for environmental applications. Nanometer-scale control of the surface structure of the semiconductor electrode is critical to the photoelectrode behaviour. Recently the group has shown that by preparing nano-crystalline microporous TiO_2 electrodes, the quantum efficiency for photo generated electrons was increased from less than 5% up to 40% under UV irradiation. The use of advanced methods of thin film deposition techniques supported by advanced surface characterisation and analytical techniques are essential for the group to remain at the for-front of this highly competitive field. Particle size, crystal phase, dopant density, stoichiometry, etc. all have an effect on the photocatalytic and photo electrochemical properties of the semiconductor material.

The group aims to develop multi-layered semiconductor electrodes for the photo-splitting of water to give O2 and H2 under solar illumination. It has recently been reported that an efficiency of 12% has been achieved for water electrolysis under solar illumination using a GaInP2(Pt)/GaAs photoelectrochemical cell. The group aims to develop solar powered n-p photoelectrochemical cells for the photolysis of water, reduction of CO_2 to fuels, and for selective oxidative/ reductive processes for the chemical industry. This will require surface doping of the semiconductor with nano-structured metal clusters to catalyse the desired electron transfer processes. The group aims to maintain its for-front position in the advanced oxidative treatment of water using photoelectrochemical cells.

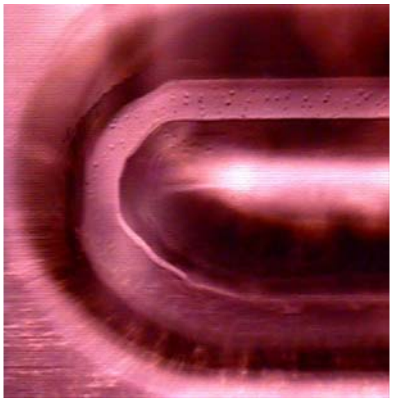
The main direction is in the development of photo-anode materials with nano-structure, high photocatalytic activity, and high surface area, which can be deposited on large areas of supporting substrates for use in water treatment processes. Currently photocatalytic reactors for water treatment give quantum yields in the region of 1% under UV illumination. Using a photoelectrochemical cell quantum yields can be increased dramatically. Other areas of interest include the deposition of optically transparent photocatalytic TiO_2 thin films that act as self-cleaning surfaces under solar or internal lighting conditions. These films may be deposited on tiles, mirrors, or car windscreens. In addition to the self-cleaning properties, TiO_2 thin films have also been reported to display super-hydrophilic properties with contact angles for water approaching zero

Research: Electrodes/Sensors Group

This group has extensive experience and expertise in the design, fabrication and characterisation of a wide range of sensors and related devices (biosensing, electrophysiological monitoring, pacing, defibrillation, iontophoresis). The group has major strengths in the areas of ac impedance/dielectric spectroscopy, cyclic voltammetry and potentiometry and in their use in the characterisation of materials, interfaces and devices. Work is carried out on modelling of the linear and non-linear electrical properties of electrode-electrolyte interfaces (platinum, iridium, Ag/AgCl, biological tissues, surface coatings, corrosion resistance) and materials (biological tissues, membranes, surface coatings). The group has also developed a wide range of expertise linked into point-of-care monitoring; wireless integrated sensors and vital signs monitoring.

Group Projects: Electro-chemical Characterisation and coatings

Impedance and dielectric measurements can be and have been used to study and characterise the electrical properties of materials and their interfaces. Such data can in turn be used to furnish information on the homogeneity, thickness and integrity of layers, the roughness and quality of interfaces and on reactions, such as corrosion, taking place at interfaces. At UU suitable measurement cells have been designed and constructed and the AC impedance system adapted and used successfully to study the integrity and surface topography of deposited coating layers. Until recently, techniques for direct measurement of corrosion have been crude.



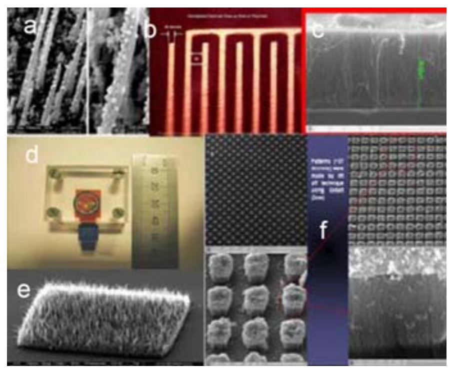
Electrical Impedance Spectroscopy (EIS) is now the accepted technique for both determining corrosion rates and identifying corrosion reaction mechanisms due to its ability to detect interfacial relaxations covering a wide range of relaxation times and thus distinguish the different corrosion processes taking place, unlike DC techniques which only provide an overall corrosion rate.

These advances are due to the development of suitable FRA instruments, theoretical models and appropriate software, all of which are available at UU. Such 'global' mathematical/equivalent circuit models of interface processes tend to be based on assumptions of the properties of local reactions, the distribution of these properties over the interface and of the effects of surface topography. Film integrity at the early stages of growth can be correlated with process parameters thus enabling their accurate modelling and the identification of optimum nano-scale film growth conditions.

This research has lead to the patenting of five products in this area (including a world-wide best selling ECG electrode), and to the commercialisation of an extensive range of products (including patient monitoring harnesses) and to the solving of costly manufacturing problems experienced by several leading companies e.g. Laboratoires Fournier; Elan Corporation, SenDx.

Group Projects: Sensors

UU has extensive experience and expertise in the design, fabrication and characterisation of a wide range of Point of Care sensors and related devices. As demands on human implantable diagnostic devices increase, then the need for micro-electrode implant devices and research in biomaterials becomes of great importance. Thin-film micro-fabrication can offer a wide range of special advantages to the device design. Choice of materials such as biocompatible silicon and stable polymers can perform as substrates for the noble metal conductors, namely platinum, gold, iridium, titanium and in some cases silver. At UU special attention has been devoted to the study of flexible electrode/substrate systems suitable for both 20mA stimulation/sensing of nerve bundles as well as in vivo biosensing.



Requirements for such a thin-film sensing device include high substrate/metal adhesion, long-life durability, mechanical stability, the ability to be patterned and also exhibit full biocompatibility. It is therefore our future objectives to research suitable thin-film coatings and processes with relevant characterisation techniques that will permit the development of long life in vivo sensor devices. This involves understanding the bio-response of the body to various forms of thin-film and plasma surface modification processes. Also the thin-film sensing materials of interest such as platinum, gold, iridium/oxide, titanium, and various polymers require characterisation. Cell and platelet growth studies will be correlated with surface science studies in order to develop optimal plasma modification- or deposition-based processes. Other sensing technology expertise includes micro pressure sensors, ion selective arrays, bio-chips, Raman sensing sensor telemetry and sensor packaging. This work has lead to three UU spin out companies.

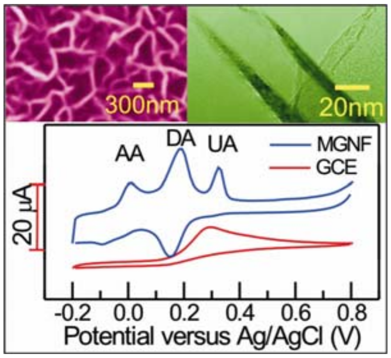
Research: Plasma and Nanofabrication Group

Plasma processing is central and generic to our research on functional materials and using this as our model, we can map out a route to controlled ultra-thin deposition and conditioning. Plasmas represent a complex and non-linear system where detailed understanding of the relationship between input, the equipment design and operational parameters, and output, the film properties, is often weak, forcing development to proceed with a significant empirical input over a wide parameter space. Improved plasma designs and access to the internal plasma variables, from species generation, transport mechanisms and reaction with the substrate/growing film are therefore required.

The material characteristics of the films, such as structure and composition, have then to be correlated with their ultimate functional properties. This entails development and use of nanoscale microscopical techniques appropriate to films at the dimensions envisaged. Also, the importance of interfaces, surfaces and the initial growth layers is paramount and hence characterisation of the growing film cannot be avoided. By linking the initial process input parameters to the ultimate functional properties via measurement and characterisation at all stages, we will obtain a scientific understanding of ultra thin film growth processes which will lead to enhanced control and reproducibility, greater flexibility in equipment and process design and therefore the ability to accurately tailor the functional properties of films to their applications, across the thickness and lateral dimension range.

Research: Carbon Based Nanomaterials

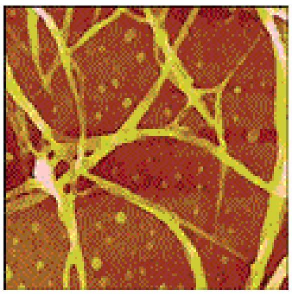
The research activities are directed towards the design, synthesis and characterization of carbon based nanomaterials such as carbon nanotubes, nanotips, graphene sheets and diamond nanowires. Because the surface to volume ratio is very high in these nanomaterials, their surface properties and interfacial transport have significant implications in various technologically important areas such as nano-electronics, sensing, biomedical, energy storage and conversion devices. The research is aimed at understanding and controlling the surface and interfaces and their effect on the electronic transport, bonding and reactivity. In particular the interactions between biological molecules and nanostructured electrodes are probed in light of developing protocols that will provide a foundation for future biosensing devices.



Research: Nanolayers Characterisation

The preparation of nanomaterials and the manufacture of nanoscale devices rely on a feedback between preparation and characterisation and indeed the same techniques can sometimes be used for both purposes. Therefore, nanoscale characterisation is not established but constantly evolving. The group’s activity focuses mainly on using nanomechanical probes to evaluate ultra-thin carbon films, although other techniques and materials are also examined. In the main, there are four interrelated areas of activity;

- The nano-mechanical characterisation of ultra-thin carbon layers, searching for the intrinsic film’s properties using a combination of techniques.
- The nano-viscomechanical analysis of energy dissipation in carbon films and proteins.
- The comparative nanometrology of ultra-thin steps.
- The preparation of hard carbon nanostructures and nanotemplates using ion beams, e beams and probe microscopy.



Ongoing Projects

As well as being of direct and immediate benefit to companies in Northern Ireland and the border counties, the establishment of the Nanotechnology and Integrated BioEngineering Centre will consolidate and improve the overall infrastructure for nanotechnology and advanced functional materials.

This is to be done by harnessing and co-ordinating the input from personnel and attendant facilities within the University of Ulster (UU) across the relevant areas of Engineering, Biomedical Sciences and Informatics. Hence, these resources are an important platform for the attraction of future inward investors with high technology operations to the most needy areas of Northern Ireland and the surrounding catchment.

NIBEC draws directly on the success of the Northern Ireland Centre for Advanced Materials (NICAM) and the proposed areas of work fall within several internationally recognised research strengths in nanotechnology at UU, including its application to:

- Sensors
- Surface Science and associated characterisation techniques
- Lithography and surface patterning
- Ferroelectrics and other advanced ceramics
- Mixed oxide systems, including photocatalytic formulations
- Diamond-like carbons, their nitrogen-, boron- and silicon-containing analogues
- Carbon Nanotubes
- Calcium phosphates and related bioactive biomaterials for tissue engineering
- Self-assembled and other highly ordered monolayer/multilayer systems
- Plasma-based film deposition and other surface modification methods
- Modelling of surface growth processes on a nanometric scale
- Photonic based materials

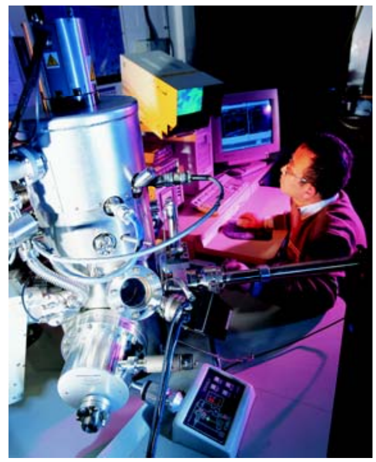
Expertise: Fabrication Tools and characterisation

- Inductively Coupled Plasma RF Etch system for deep trenching as used in the patterning of micromachined devices
- Filtered Cathodic Vacuum Arc: High Dense Plasma Technique for producing nanostructured copper interconnects, high refractive index materials and ultra hard nanostructured films with sub-nano thickness capabilities
- Nanotribology; Nanoindentaion and nanofriction studies of surface modifications with plasma based processing

- Dense Plasmas: Filtered Cathodic Vacuum Arc and Pulsed rf ICP reactive ion etching and deposition (providing control of nano-cluster size distribution e.g.: on-going work on CxNy:H)
- Electrochemical analysis: bio-cellular based system; of nanometer a-C:H and ta-C

Expertise: Devices

- Microcard: Micromachined Implantable Si needle with microsensors for na, K, Ca, ph, temperature and impedance monitoring
- Photonics: GaN deposition, high refractive index based materials; device and characterisation studies; Also photovoltic nanostructures
- Nano-sensors. Bio-chip based devices using micro-spectrophotometers/micro-electrode; self assembled bio-selective fluids; and surface modification techniques
- Atom beam doping of carbon materials and a study of nanostructural/electrical effects
- Surface studies using nano-probe techniques such as AFM/STM applied to medical coatings/bio-surface interfaces and hard disc systems;



- Nanoscale Photocatalytic materials: Waste water treatment and sensors
- Pulsed-laser deposition (PLD) of nanocomposite carbon/magnetic matrices

Expertise: Bulk Materials/Films with Nanofeatures

- Diamond Like Carbon/amorphous Carbon/nanotubes: Nanostructured 1nm ultra thin films for tribology; high refractive index photonics; field emission; insulating/dielectric and biocompatible applications. And nanotubes as a biosensor
- LB and Sol Gel deposition on nanostructured wave-guides for SPR sensor applications
- Nanocomposites medical coatings
- In-situ studies of thin-film growth mechanisms during various deposition techniques; ellipsometry and the relationship with the hardness of carbides; Studies of the evolution of the surface topography and composition during etching
- TM oxynitrides; and carbides studies

Expertise: Molecular Nanotechnology

- Tissue Engineering; Bioactive materials e.g.: RF sputtered Hydroxyapatite Biocomposite Mixtures
- Biosurfaces: protein/lipid attachment mechanisms and the prevention at a molecular level with functionalised coatings
- Biosensors: Immobilisation of bioselective fluids on atomically controlled thin film structures
- AFM probe analysis of inter-atomic forces between bio-fluids and surfaces

Facilities

- Nanotechnology Fabrication Laboratory (including Nanotube facility)
- Nanotechnology Characterisation Lab
- Surface Energy Suite: DCM and Projection Angle
- Surface Science Suite: XPS, SIMS, Auger, AFM and SEM
- Plasma Modification Suite
- Plasma Diagnostics Monitoring Suite
- Metrology: Nanoindentor, Interferometer, Stylus Stress Tester
- Clean-room with microfabrication facilities
- Micro Plastics Fabrication
- Photonics Lab
- Microsensors Lab
- Photocatalysis Lab
- Cell Biology/Tissue Culture Lab
- Confocal Micro-Raman Spectroscopy
- Focused Ion Beam and Ion Milling.
- Scanning Electron Microscope (SEM)
- Atomic Force Microscope (AFM)
- X-ray Photoelectron Spectroscopy (XPS)
- Secondary Ion Mass Spectroscopy (SIMS)
- X-ray Diffraction (XRD)
- Contact Profiler (CP)
- Optical profiler (OP)
- Raman spectroscopy
- FTIR (Fourier Transform Infrared) Spectroscopy
- RF and DC Magnetron Sputter System
- Filtered Cathodic Vacuum Arc (FCVA)
- RF–PECVD
- Thermal CVD
- Microwave-PECVD

Technology Transfer

We will grow our ability to undertake technology transfer especially in the areas of medical and electronic devices thus supporting the Universities exploitation strategy through UUTECH; in house incubators; and the Northern Ireland Science Park. Our ten years experience has lead to twenty filed patents and new spin out companies established recently include Heartscape Inc, (www.meridianmeds.com/home.html) HeartSine Ltd (www.heartsine.com), and Sensor Technology and Devices Ltd (www.stnd.com)

Nanotec Northern Ireland

Nanotec Northern Ireland is a formal collaborative programme between the University of Ulster and Queens University Belfast. It is a Centre of Excellence for the design, fabrication, characterisation and commercial exploitation of nanotechnology, devices and systems, and builds on the already close ties that exist between researchers at both universities. (www.nanotecni.co.uk)

MATCH

The MATCH (Multidisciplinary Assessment of Technology Centre for Healthcare) project, worth £6.3m, is a university/industry partnership initiative funded by the EPSRC/DTI, with significant contributions from Invest Northern Ireland and the National Patient Safety Agency, in tandem with equal research funding from industry.

The project, which links the University of Ulster with Brunel, Nottingham, Birmingham and King's College, London, was launched by science minister Lord Sainsbury at the House of Commons.

In Northern Ireland, the project is driven by a world-class research team based at the University of Ulster's Bioengineering Centre (NIBEC) at Jordanstown. (www.match.ac.uk)

CACR

The University of Ulster (UU) and the Royal Victoria Hospital in Northern Ireland, have jointly created the Centre for Advanced Cardiovascular Research (CACR), an establishment which will research on cardiovascular disease. The main goal of the CACR is to advance the basic research and development of devices and clinical techniques for safe and effective solutions in cardiovascular treatments.

The main ongoing projects are:

- Electrocardiographic Mapping Systems and Methods
- Ventricular and Atrial Defibrillation Techniques
- Atrial Fibrillation Characterisation and Predictive Modelling
- Cardiac Nano-sensors for Blood Enzyme
- Cardiac Informatics and Connected Health
- Heart Waveforms Fitness Check for the Young
- Cardiac Risk Factors in Diabetic Patients
- Haemodynamics Modelling and Monitoring Devices
- Pulse Waveform Characterisation for Non-invasive Cardiovascular Assessment

(www.cacr.ulster.ac.uk)

Connected Health

The European Community is calling for a new healthcare delivery model based on preventative and person centred health systems where quality care is provided outside of traditional medical settings.

NIBEC, in conjunction with the Computer Science Research Institute (CSRI) and the Biomedical Diagnostics Institute DCU are currently undertaking research and development to expedite the diagnosis of adverse healthcare symptoms using minimally invasive point of care (POC) diagnostics. POC diagnostics offer the advantage of convenient and immediate testing of the patient and reduced waiting times for test results. This work will help bring the current health care system one step closer to the realisation of patient self-management and hence fully embrace the shift from 'reactive' to 'preventative' healthcare delivery. (www.compeng.ulster.ac.uk/conhealth)

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