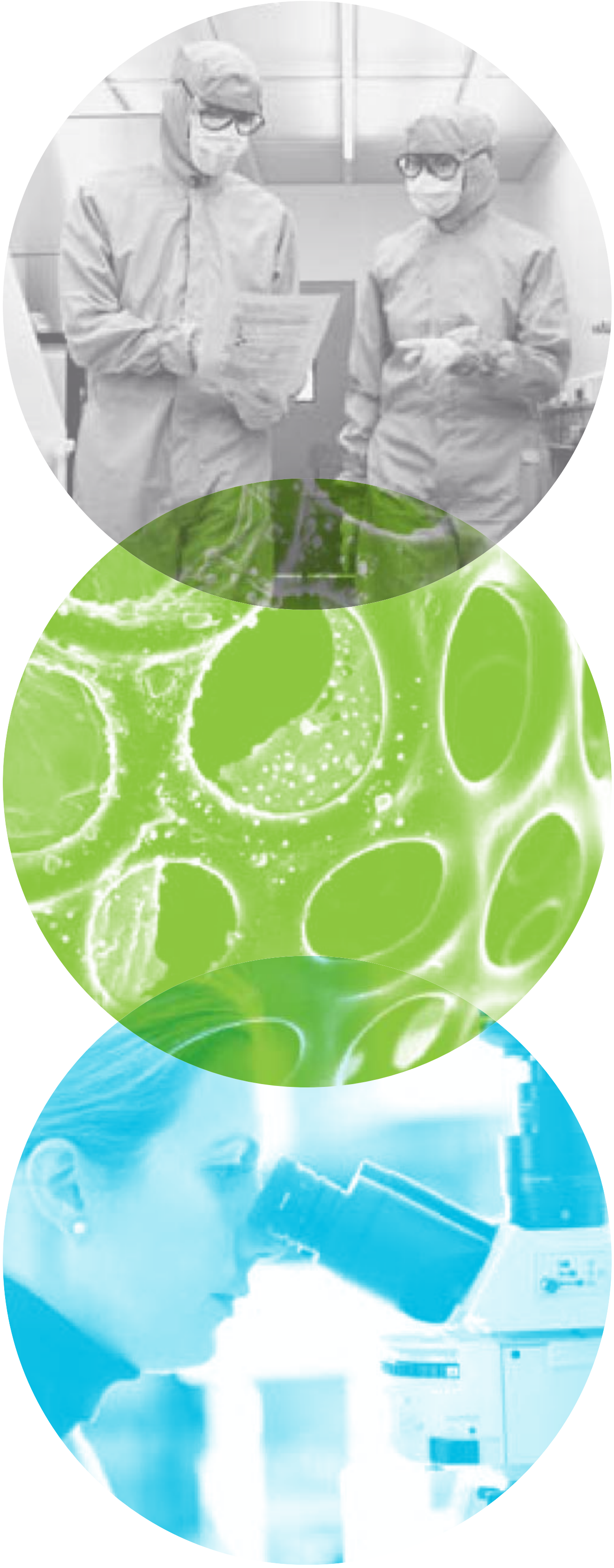
CRANN



CRANN REPORT

2009—2010

Fondúireacht Eolaíochta Éireann
Science Foundation Ireland

TCD

CONTENTS

The **CRANN** institute brings together a critical mass of exceptional researchers based across a diversity of Schools and Departments within **Trinity College Dublin** and **University College Cork**—delivering world leading research and direct value to industry.

INTRODUCTION FROM THE MANAGEMENT TEAM

Since our last public report in 2008 CRANN, funded through Science Foundation Ireland, has continued to establish itself as a national and international force in nanoscience and nanotechnology research and collaborative industry engagement. CRANN is the flagship research institute within Trinity College Dublin and in partnership with its collaborating Principal Investigators (PIs) in University College Cork, now has over 250 researchers within the Institute and its partner Schools. This community is made up of researchers from over forty countries and exemplifies CRANN's ambition to attract the best global researchers to Ireland, to carry out world leading research, which can directly benefit the local economy and increase the competitiveness of companies based in Ireland.

The success of the last two years has validated our operational model, which couples world leading research with effective and flexible industry engagement. On the research side, CRANN has published over 270 papers since mid-2008. The quality of these publications has been independently validated by a Thomson-Reuters report in late 2010 which placed Ireland 8th globally for materials science research based on citations per publication for the decade 2000—2010. CRANN researchers were responsible for > 70% of the outputs leading to this national ranking. Similarly Ireland has been ranked 6th globally for our research in nanoscience. It is now evident that CRANN is one of the key drivers of Ireland's growing international research reputation.

Further evidence of our growing international reputation is the evolution of our engagement in the European Framework funding programmes and other international funding schemes over the last two years. CRANN is presently leading two large collaborative programmes and is participating in another 11. In total we are actively collaborating with over 60 universities and 40 companies through European Framework programmes. Furthermore, CRANN PI Prof. Jonathan Coleman obtained a prestigious European Research Council award in 2010. In the period since our last report, CRANN PIs have obtained €8.7M in non-exchequer funding from competitive research programmes. CRANN has now emerged as a leading nanoscience research centre on the international stage.

CRANN's industry engagement has grown significantly over the last two years. We continued our engagements with major ICT companies such as Intel and Hewlett-Packard but we have grown considerably the scale of other enterprise activities. This is particularly evident in the medical devices sector where CRANN is currently engaged with both large multinational companies such as Johnson & Johnson, Boston Scientific and Millipore but also with smaller indigenous companies like Creganna, Proxy Biomedical and Aerogen. In total, we are now involved in collaborative support or contract research with 74 companies, contributing greatly to ensuring Ireland is a competitive location to attract foreign direct investment linked to research.

These engagements range from the embedding of industry researchers-in-residence within CRANN, to the development of significant collaborative research programmes, to utilising CRANN's unique capital infrastructure for material characterisation and failure analysis. This style of engagement provides measureable value to companies in the short term but also creates an engine for innovation allowing our partner companies to continually improve their products and processes.

Since 2008 CRANN researchers have made 37 invention disclosures, 21 patent applications across international territories with four patents granted, and have had two licenses negotiated. Two companies, Glantreo and Miravex, have been spun out by CRANN PIs; both demonstrating significant potential. Glantreo recently signed a $10 million deal to supply silica-based materials to a US company specialising in chromatography and chemical separations. Miravex was awarded the first Eircom University Challenge Award at the Irish Technology Leadership Forum (ITLF). CRANN is now demonstrating how university research can lead to the generation of intellectual property that has impact in the real economy, resulting in job creation, company formation and technology exports.

We have also taken a leadership role in developing a coordinated approach to nanotechnology in Ireland across academia and industry. CRANN is the lead for the INSPIRE consortium which brings together all the leading third level institutions with nanoscience research on an all island basis.

The success of the last two years has validated the operational model for **CRANN** which couples world leading research with effective and flexible industry engagement. **CRANN has published over 270 papers since 2009** and now partners with 74 companies.

CRANN also co-hosts, with the Tyndall National Institute, the Competence Centre for Applied Nanotechnology (CCAN), an industry-driven consortium which is harnessing the research and infrastructure excellence at CRANN to enable industrial research and development. Furthermore, CRANN is one of the founders of NanoNet Ireland, a group of the key stakeholders in developing nanoscience and nanotechnology across Government, academia and industry in Ireland. Its goal is to encourage and facilitate all organisations and partners involved in nanoscience so as to achieve growth in nanotechnology-related markets.

CRANN continues to develop its infrastructure capabilities and in 2010 opened the CRANN Advanced Microscopy Laboratory (AML). The AML is a national asset which houses some of the world's most powerful microscopes, allowing materials to be viewed at the atomic scale. The AML plays a significant role in driving new research directions for CRANN PIs, it allows Ireland to compete globally to win new research funding and foreign direct investment that previously would have been beyond our capability and provides direct value to indigenous companies.

The communication of nanoscience continues to be a focus of CRANN. The Science Gallery, pioneered by CRANN, has been a great success with over 500,000 visitors in its first two years. In addition we co-founded Nanoweek, with the goal of raising both stakeholder and public awareness of nanotechnology and its societal and economic impacts. CRANN also continues to work with all levels of the educational system, for example by developing innovative new outreach tools for secondary schools and supporting the launch of a third level graduate degree in nanoscience at TCD, N-PCAM.

The many successes of the last two years have been achieved against a backdrop of a challenging economic environment.

We believe that CRANN has helped in this period to cast a spotlight on what the future holds for Ireland if there is continuous investment in research resulting in the establishment of a "smart economy". Ireland can compete and deliver world leading research, through the creation of new indigenous technology companies, winning increased FDI from leading international companies and the growing emergence of Ireland as an international technology innovator with a reputation for excellence in research and advanced manufacturing.

The CRANN management team would like to acknowledge the support from key national funding agencies Science Foundation Ireland, Enterprise Ireland and the Higher Education Authority. The support of Trinity College and in particular the Schools of Physics and Chemistry has enabled the success of CRANN. Finally we'd like to acknowledge CRANN PIs and their research teams, the staff at CRANN, our industry partners and the continuous support of both the Institute and Scientific Advisory Boards. All have played a considerable role in enabling the significant successes achieved.

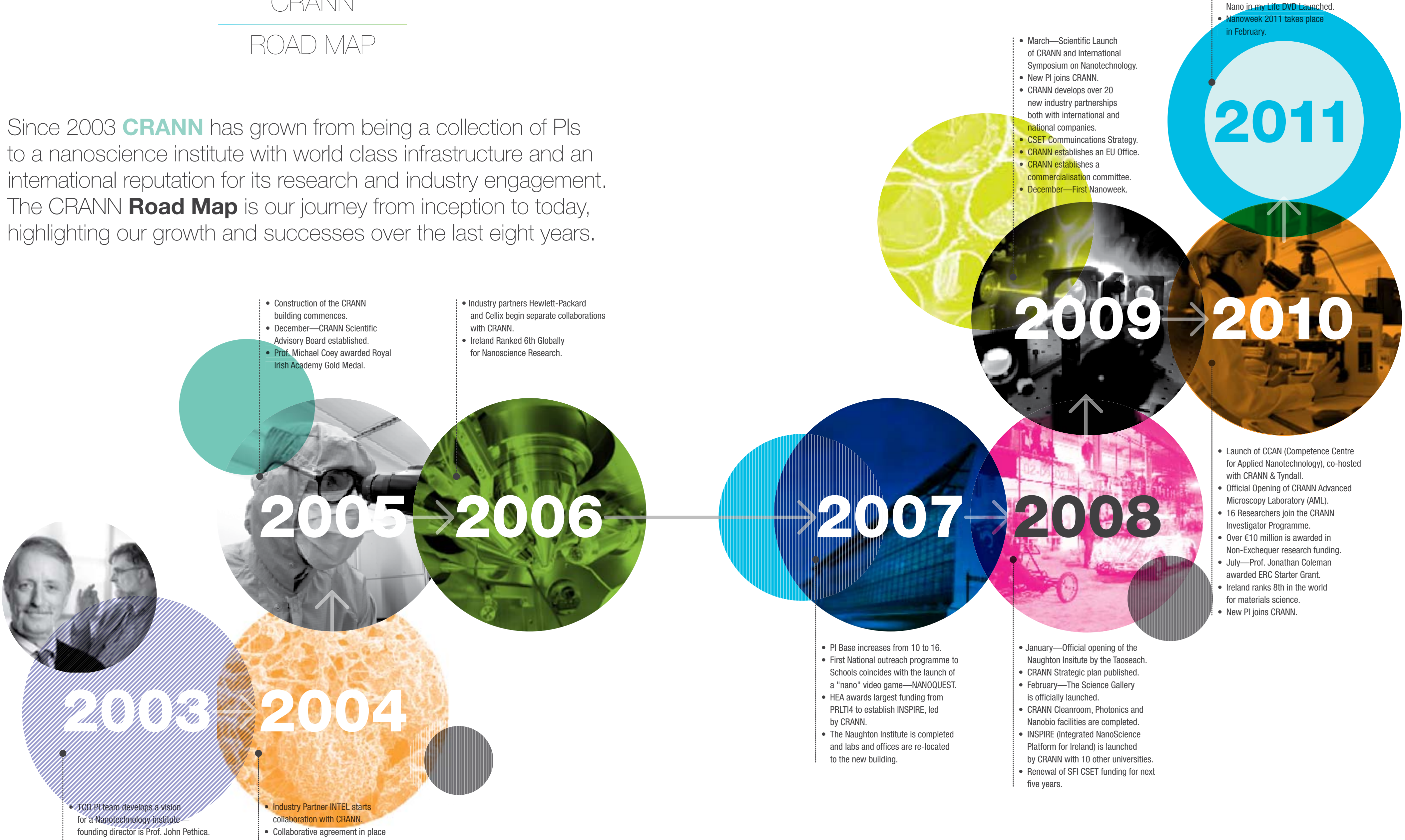
Sean Dorgan
Chair of CRANN

Dr. Diarmuid O'Brien
Executive Director CRANN

Prof. John Boland
Director CRANN

CRANN ROAD MAP

Since 2003 **CRANN** has grown from being a collection of PIs to a nanoscience institute with world class infrastructure and an international reputation for its research and industry engagement. The CRANN **Road Map** is our journey from inception to today, highlighting our growth and successes over the last eight years.



2003

- TCD PI team develops a vision for a Nanotechnology institute—founding director is Prof. John Pethica.
- CRANN CSET is funded by Science Foundation Ireland.
- Dr. Martin Naughton provides philanthropic donation to CRANN.

2004

- Industry Partner INTEL starts collaboration with CRANN.
- Collaborative agreement in place with UCD and UCC.

2005

- Construction of the CRANN building commences.
- December—CRANN Scientific Advisory Board established.
- Prof. Michael Coey awarded Royal Irish Academy Gold Medal.

2006

- Industry partners Hewlett-Packard and Cellix begin separate collaborations with CRANN.
- Ireland Ranked 6th Globally for Nanoscience Research.

2007

- PI Base increases from 10 to 16.
- First National outreach programme to Schools coincides with the launch of a "nano" video game—NANOQUEST.
- HEA awards largest funding from PRLTI4 to establish INSPIRE, led by CRANN.
- The Naughton Institute is completed and labs and offices are re-located to the new building.

2008

- January—Official opening of the Naughton Insitute by the Taoseach.
- CRANN Strategic plan published.
- February—The Science Gallery is officially launched.
- CRANN Cleanroom, Photonics and Nanobio facilities are completed.
- INSPIRE (Integrated NanoScience Platform for Ireland) is launched by CRANN with 10 other universities.
- Renewal of SFI CSET funding for next five years.

2009

- March—Scientific Launch of CRANN and International Symposium on Nanotechnology.
- New PI joins CRANN.
- CRANN develops over 20 new industry partnerships both with international and national companies.
- CSET Commuincations Strategy.
- CRANN establishes an EU Office.
- CRANN establishes a commercialisation committee.
- December—First Nanoweek.

2010

- Launch of CCAN (Competence Centre for Applied Nanotechnology), co-hosted with CRANN & Tyndall.
- Official Opening of CRANN Advanced Microscopy Laboratory (AML).
- 16 Researchers join the CRANN Investigator Programme.
- Over €10 million is awarded in Non-Exchequer research funding.
- July—Prof. Jonathan Coleman awarded ERC Starter Grant.
- Ireland ranks 8th in the world for materials science.
- New PI joins CRANN.

2011

- National Schools Program—Nano in my Life DVD Launched.
- Nanoweek 2011 takes place in February.

HIGHLIGHTS

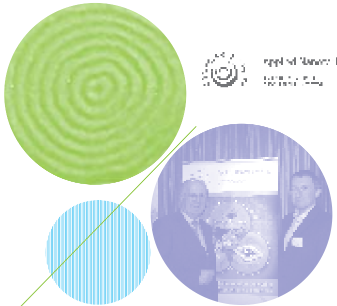
NATIONAL LEADERSHIP

INSPIRE

The INSPIRE Consortium (Integrated Nanoscience Platform for IREland) was launched on the 30th of October, 2008 in the Science Gallery. INSPIRE is a consortium of all Irish third level institutions with international leading research capability in nanoscience and nanotechnology. INSPIRE was funded to the level of €31.6M by the Higher Education Authority (HEA) via PRTLI4. This was the largest funding allocation to a national consortium.

AML Launch

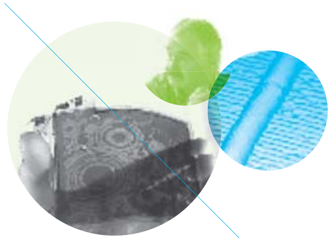
CRANN's Advanced Microscopy Laboratory was officially opened on the 27th April, 2010 by the Minister for Labour Affairs, and Public Service Transformation, Mr. Dara Calleary, TD. Over 60 people attended the opening with representatives from academia and over 40 different companies and agencies. A series of case studies highlighting industrial collaborations with CRANN took place in the morning followed in the afternoon by the official opening and tours of the AML, which were facilitated by CRANN's technical specialists.



CCAN

The Competence Centre in Applied Nanotechnology is an industry-led, collaborative, applied research centre enabling its member companies and research providers to work together to develop nanotechnology-enabled products and solutions for the ICT and biomedical industries. Launched in December 2009, it is co-hosted by CRANN and Tyndall National Institute at University College Cork. With a growing membership, the founding industry members were Aerogen, Analog Devices, Audit Diagnostics, Creganna-Tactx, Intel, Medtronic, Proxy Biomedical and Seagate.

OUTREACH



Solid Films & Surfaces

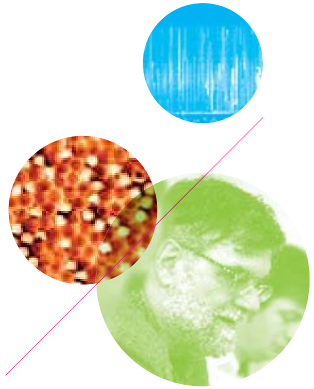
The 14th International Conference on Solid Films & Surfaces was hosted by CRANN PI, Prof. John Boland in June/July of 2008. The conference brought together 350 researchers and world experts on thin films and surfaces, with its emphasis on the electronic, photonic and spintronic applications of these materials.

Nanoweek

The first Nanoweek took place in December 2009; showcasing the relevance and importance of nanotechnology research in Ireland. Various events were organised from INSPIRE's National Scientific Meeting, to lectures and workshops for the public, schools and industry.

Scientific Launch & International Symposium

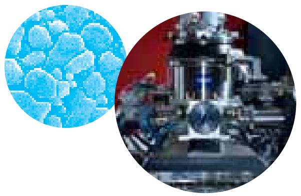
In March 2009 CRANN had its Scientific Launch which included an International Symposium on Nanotechnology. World experts from the UK, US, the Netherlands, Denmark and Germany shared their stories on the development and growth of their centres and the opportunities and challenges facing nanotechnology today. The overarching theme from all speakers was the importance of continued investment into nanotechnology and what it can achieve.



Einstein Professorship

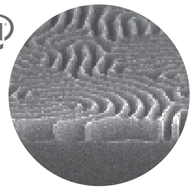
In January 2010, CRANN Principal Investigator and Lecturer in TCD's School of Physics, Prof. Michael Coey, was awarded the Einstein Professorship by the Chinese Academy of Sciences. Professorships are awarded to scientists who are actively working at the frontiers of science and technology and for conducting lecture-tours in China.

INDUSTRY



Industry

CRANN has significantly grown its industry partnerships in the last two years, and has developed formal engagements with 74 companies. In addition to Industry partnerships CRANN is working with 55 International Universities on European projects.



Intel

CRANN is working with Intel on the development of new technologies which enable scalable patterning of silicon wafers at sub 10 nm length scales. Intel has licensed these technologies and they are being evaluated for incorporation into future semiconductor manufacturing processes.

Aerogen

CRANN, through CCAN, is working alongside Aerogen to develop novel nano-particle drug technologies which will enable drug delivery via high quality aerosol.

IP/Research Awards

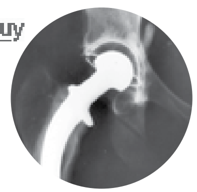
CRANN presented 17 Innovation Awards this year for the "filing" of invention disclosure forms for newly created intellectual property by our researchers. CRANN also awarded seven Research Awards in recognition of researchers publishing internationally peer reviewed papers of the highest quality.

Hewlett-Packard

CRANN is working with Hewlett-Packard to develop a transparent, flexible and highly conductive electrode for display applications. CRANN is also partnering with HP in researching new materials for sensing applications.

Western Digital

CRANN is working with Western Digital to investigate new technologies for heat assisted magnetic recording, which uses near field optical phenomena to enable increased density magnetic recording.



DePuy

CRANN is collaborating with DePuy, through an Enterprise Ireland funded Innovation Partnership award, in the development of new processes for optimising and innovating the coatings for medical implants e.g. hips.

RESEARCH & FUNDING

Global Rankings

Ireland was ranked 8th in the world for its quality of research in materials science, according to data from the Essential Science Indicators database of Thomson Reuters, covering the period from January 2000 to April 2010. Out of Ireland's top 20 research papers, 14 of these were from researchers in Trinity College Dublin. Ireland's top five papers and eight of the top ten were from researchers in CRANN.

European Research Council Starter Grant

In May 2009, Prof. Jonathan Coleman was awarded the prestigious European Research Council Starter Grant. The Starting Grants are given to only 300 top scientists across Europe, representing less than 10% of those who apply. The awards recognise scientists who are working on research with major potential. The award recognises the work Prof. Coleman is doing with graphene and his novel method of being able to split graphite down into individual layers which then could be used to make stronger and lighter materials.

Prof. Yuri Volkov

In 2010, Prof. Yuri Volkov, CRANN PI and Associate Professor in the Institute of Molecular Medicine in TCD, was awarded scientific leadership and coordination of a major European research project whose goal is to create advanced medical diagnostic devices leading to the early and rapid diagnosis of cancer. The project was awarded €12m through a European competitive process.

LAMAND

CRANN Principal Investigator, Prof. Michael Morris, UCC, was awarded European funding in 2010 (€3.5m) to coordinate LAMAND, a project involving three companies and six research partners across seven European countries. The project focuses on the development of new "smart" materials which will allow unprecedented control over the feature size of next generation electronics.

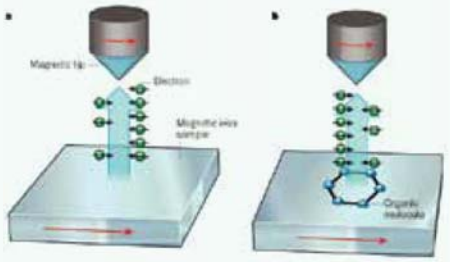
RESEARCH HIGHLIGHTS

Overview:

In 2009—2010, CRANN published 270 publications in over 85 journals. The articles below illustrate key research results in the area of computation, biology and nanoelectronics.

Sanvito, S.
Surface Science, "*Seeing the spin through*",
Nature 2010, 467 (7316), 664—665.

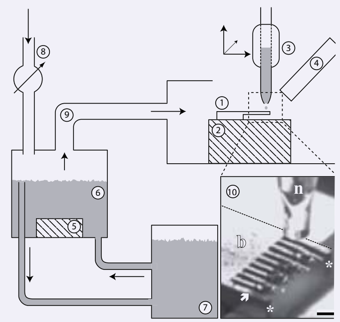
Nature is one of the highest cited scientific journals and has a large readership. In his publication, Prof. Sanvito outlines the latest development is the use of non-magnetic organic molecules as a potential transport mechanism for electronic spin. These advancements may result in commercially available memory and logic devices using cheap plastic materials.



Above Image. Studying spin transport with SP-STM. In this technique, an atomically sharp magnetic tip is scanned across a magnetic sample, and electrons tunnel through the vacuum between the sample and the tip with a preferential spin orientation.

Braun, T.; Ghatkesar, M. K.; Backmann, N.; Grange, W.; Boulanger, P.; Letellier, L.; Lang, H. P.; Bietsch, A.; Gerber, C.; Hegner, M.
"Quantitative time-resolved measurement of membrane protein-ligand interactions using microcantilever array sensors",
Nature Nanotechnology 2009, 4 (3), 179—185.

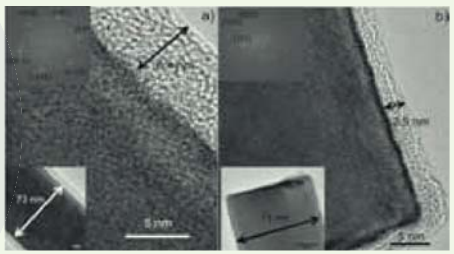
Membrane proteins are central to many biological processes and are of fundamental importance in medical research. Measuring and characterising these interactions is scientifically challenging. This research on arrays of resonating microcantilevers measures key interactions under physiological conditions. This demonstrates the potential of resonating microcantilevers for the specific, label-free and time-resolved detection of membrane protein-ligand interactions in a micro-array format.



Above Image. Diagram of the Ink Jet Spotter—a device which dispenses small quantities of liquid onto the cantilevers.

Andzane, J.; Petkov, N.; Livshits, A. I.; Boland, J. J.; Holmes, J. D.; Erts, D.
"Two-Terminal Nanoelectromechanical Devices Based on Germanium Nanowires",
Nano Letters 2009, 9 (5), 1824—1829.

A two-terminal bistable device has been demonstrated with Ge nanowires using an in situ TEM-STM measurement technique. The function of the device is based on delicately balancing electrostatic, elastic, and adhesion forces between the nanowires and the contacts, which can be controlled by the applied voltage. This provides potential application of these 1D nanostructures in high-voltage devices.



Above Image. HRTEM images of two different Ge nanowires both grown along the [110] direction with similar diameters but having a different surface oxide thickness.

CRANN
BY NUMBERS

CRANN SELECTED KEY PUBLICATION JOURNALS REVIEW 2004—2010

CRANN has published 270 papers in the last two years.

Physical Review B	70
Journal of Magnetism and Magnetic Materials	58
Journal of Applied Physics	47
Applied Physics Letters	39
Journal of Physical Chemistry C	29
Journal of Materials Chemistry	24
Nanotechnology	21
Nano Letters	16
Chemistry of Materials	15
Carbon	13
IEEE Physical Review Letters	12
Photonics Technology Letters	12
Surface Science	12
Advanced Materials	12
Nature Materials	11
Journal of Physics—Condensed Matter	11
Journal of the American Chemical Society	11
Review of Scientific Instruments	10
Small	9
Chemical Physical Letters	7
Advanced Functional Materials	7
Journal of Physical Chemistry B	6
Applied Surface Science	5
Nature Nanotechnology	5
Nature	5
Science	1

PUBLICATIONS & CITATIONS

740 publications with an overall average Impact 13.29

PUBLICATIONS

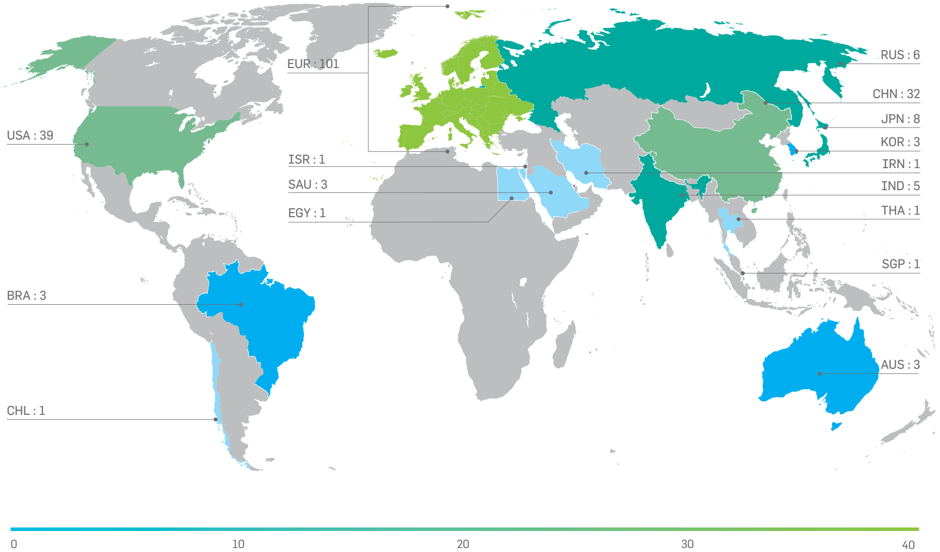
2004	61
2005	90
2006	88
2007	104
2008	122
2009	121
2010	150

CITATIONS

2004	20
2005	271
2006	275
2007	1093
2008	1820
2009	2477
2010	3347

DISTRIBUTION OF CO-AUTHORS BY COUNTRY

CRANN is collaborating and published research with 157 Universities around the world.



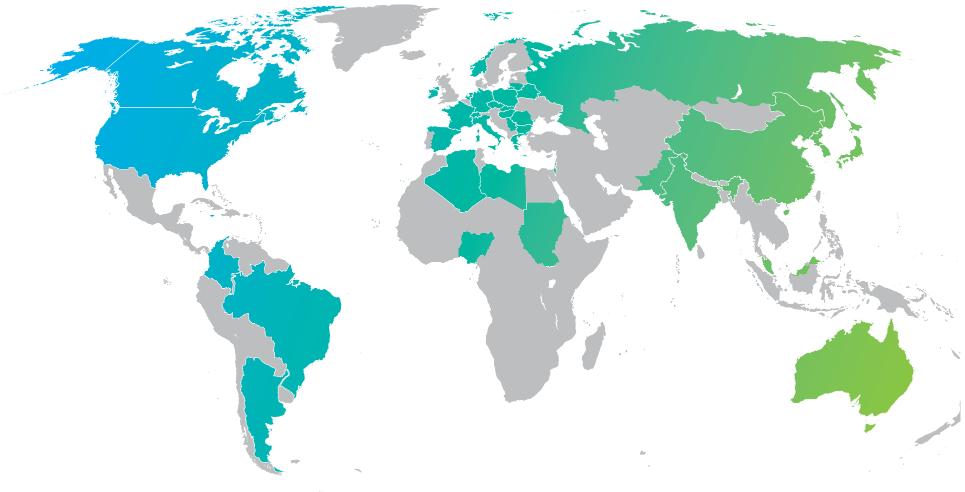
BREAKDOWN OF EUROPEAN CO-AUTHORS

Austria	5	France	16	Romania	1
Belgium	4	Germany	21	Scotland	2
Belarus	3	Italy	8	Spain	7
Croatia	1	Latvia	2	Sweden	6
Czech Republic	1	Netherlands	2	Switzerland	3
Denmark	1	Norway	2	Ukraine	1
England	11	Poland	2		
Finland	1	Portugal	1		

HIGHLIGHTING RESEARCH AREAS OF RELEVANCE (BY % ACTIVITY) FOR CRANN SCIENTIFIC PUBLICATIONS 2004—2010

Materials Science, Multidisciplinary	19%
Physics, Condensed Matter	15%
Physics, Applied	15%
Chemistry, Physical	12%
Nanoscience & Nanotechnology	9%
Chemistry, Multidisciplinary	7%
Engineering, Electrical & Electronic	3%
Optics	2%
Physics, Atomic, Molecular & Chemical	2%
Physics, Multidisciplinary	2%
Engineering, Multidisciplinary	1%
Assorted	12%

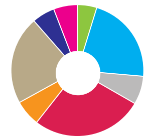
CRANN ATTRACTING RESEARCHERS FROM AROUND THE WORLD



- Algeria
- America
- Argentina
- Australia
- Belarus
- Brazil
- Bulgaria
- Canada
- China
- Columbia
- Czech Republic
- France
- Germany
- Greece
- Hungry
- India
- Ireland
- Israel
- Italy
- Jamaica
- Japan
- Korea
- Libya
- Lithuania
- Malaysia
- Netherlands
- Nigeria
- Northern Ireland
- Norway
- Pakistan
- Poland
- Romania
- Russia
- Serbia
- Slovakia
- South Korean
- Spain
- Sudan
- Switzerland

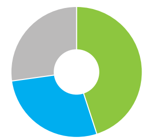
CRANN PERSONNEL FOR 2010

Principal Investigators	18	6%
Post-Doctoral Researchers	87	27%
Researcher	29	9%
Post-Graduate Students	108	34%
Staff	27	8%
Researcher-in-Residence	6	2%
Transition Year	24	7%
Summer Students	23	7%
Total Head Count	322	100%

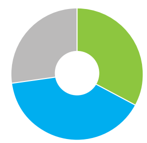


A LOOK INTO WHERE CRANN GRADUATES BEGIN THEIR CAREERS

Graduates stayed in Ireland	45%
Graduates gone abroad	28%
Graduates unknown	27%



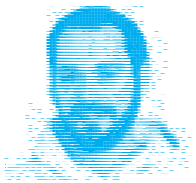
Graduates in industry	33%
Graduates in academia	40%
Graduates unknown	27%



PhD DISSERTATIONS SUBMITTED 2007—2010

2007	7
2008	15
2009	18
2010	16

WHERE ARE THEY NOW?

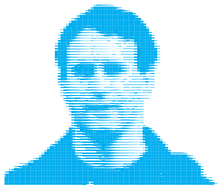


Dr. Tom Fitzgerald

Upon obtaining my Chemistry degree in 2004 I began a PhD research project in nanotechnology under Prof Mick Morris (a leading PI in CRANN) at University College Cork. The project involved manipulating block copolymers to self-assemble into ordered nanostructures which could then be used to create nanowires for use in integrated circuitry i.e. computer chips. The project was carried out through CRANN in collaboration with Intel Ireland. During my PhD I was able to gain access to state of the art technologies at the CRANN facilities at UCC and TCD for creating and characterising polymer nanostructures. Through CRANN's collaboration with Intel, I was able to share knowledge with Intel researchers and travel; making visits to both Intel sites, Kildare and Portland, USA. Upon obtaining my PhD in 2008 I got a job with Intel Ireland as a Researcher-in-Residence again working with CRANN to further my PhD research.

"Through CRANN's collaboration with Intel, I was able to share knowledge with Intel researchers and travel; making visits to both Intel sites, Kildare and Portland, USA"

In 2009, I began working for **Merck Millipore** as a research scientist at their Cork site. I am able to use the skill-set and knowledge obtained during my PhD with CRANN in my current position supporting day-to-day production as well as research into new product development. Since starting with Merck Millipore I have helped in developing a strong relationship between Merck Millipore and my PhD supervisor Prof Morris, which has subsequently led to collaboration with CRANN. My current role now involves supporting a new product research project being carried out in CRANN in collaboration with Merck Millipore.



Dr. Robbie Gunning

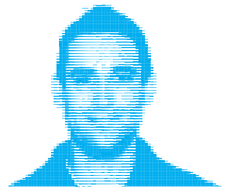
I studied for my undergraduate degree in Theoretical Physics in Trinity College. I took an internship in the summer of 2001 as an undergrad in Prof. Mike Coey's group as a summer student while the precursor to CRANN—the "SFI Chemistry Extension" was being set up. I stayed on to do my PhD in the School of Physics while CRANN was being built, and when I finished, I moved to the newly finished CRANN as a post-doc in 2006/7; I've been around CRANN for almost every part of its inception, construction and implementation!

"My time in CRANN allowed me to leave with a diverse and advanced skill-set, with access to a panoply of state-of-the-art equipment..."

After finishing in CRANN, I moved to the **University of Limerick**, and then on to the **University of Oxford**, where I am currently a post-doc in the Optoelectronics and Photovoltaics group here. My post involves using a wide range of characterisation techniques to help improve the performance of solar cells.

My time in CRANN allowed me to leave with a diverse and advanced skill-set, with access to a panoply of state-of-the-art equipment, coupled with the ability to interact with experienced international researchers. As a result of this technical competence, I've been able to integrate quickly with any research group I have joined. I've even taught courses in TCD, Limerick and Oxford on experimental techniques that I learned in CRANN.

I'm at the stage where I'm looking to apply for my own funding, in order to build my own research group. Having a background based in a high quality institute such as CRANN gives me a distinct advantage in applications. It's also great to know that my home country has an advanced lab to work in, should I choose to return and continue my research in Ireland.



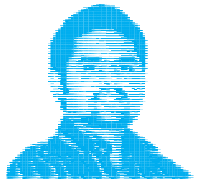
Dr. Niall Kinahan

I have been a researcher with CRANN since its foundation in 2003, both as a PhD student and now as a Postdoctoral researcher. Since then, CRANN has evolved at a staggering pace and is regarded as a global leader in both fundamental and applied nanoscience research. This drive, spearheaded by Prof. John Boland and a dedicated team of Principal Investigators (PIs), has been made possible thanks to extensive funding and support from Science Foundation Ireland (SFI). My current research is focused on the theme of nanoelectronics. This work involves the fabrication and characterisation of nanoscale electronic components destined for incorporation into next-generation consumer devices.

These devices are generally expected to be smaller, faster, and cheaper than their predecessors. Nanowires—and molecule-based electronic systems, in particular, show great promise in delivering on these expectations and making next-generation devices a reality. The investigation of such systems is, however, an extremely challenging and complex undertaking, requiring state-of-the-art equipment, facilities, technical expertise, and a great deal of scientific and industrial collaboration, all supported by significant and consistent financial investment. CRANN provides an environment which uniquely satisfies these requirements and enables my research to be take place at the highest level.

"CRANN provides an environment which uniquely satisfies these requirements and enables my research to be take place at the highest level..."

The education, skills, and experience I have gained during my time here have opened many doors to me, even during these difficult economic times. I have recently been offered and have accepted a position with **Intel Ireland** based on the strengths I have developed while at CRANN. I look forward to a bright future with what is perhaps Ireland's most successful and best known multinational company.



Dr. Peter Nirmalraj

I came across Prof John Boland's research group in a conference in Sweden in 2005 where I was doing my masters in KTH and I was very much interested with his line of research work. Due to similar research interests in novel scanning probe microscopy techniques, I approached Prof. Boland and expressed my interest in joining his group. I joined CRANN then in April 2006 as a PhD student and completed my doctoral thesis this past April. Since then I have been working here as a research associate on scanning probe microscopy related projects.

The core area of my PhD studies was focused on investigating the electronic behaviour of diverse 1-D and 2-D nanoscale materials such as carbon nanotubes and graphene for applications in flexible electronic devices. Atomic force microscopy was my principal technique which I used to locally probe the electronic properties of these materials of reduced dimensions. We have generated significant proficiency and know-how in this challenging area and published our results in high impact factor journals thereby reflecting the quality of the research work that we carried out as a team here in CRANN.

I will be moving on to **IBM, Zurich** from April 2011, with a Marie Curie fellowship. My research project will be on probing the conductance of molecules using a scanning tunneling microscope where the molecules will be present in a liquid environment. This is a challenging project which also involves studying metal-molecule-metal contacts. This is key to developing molecular scale electronics devices.

As a researcher in CRANN I had the scope and possibility to explore new ideas and I thoroughly enjoyed the scientific space given to me. I was able to sharpen both my research and communication skills as I interacted with people from a very broad spectrum, spanning from scientists from various leading institutions to secondary school students. I also learnt the significance of coordinating a collaborative research project and achieving the set goals within the set time frame. Overall it has been a very stimulating experience working in CRANN and it provided me with the right platform to shape up my career.

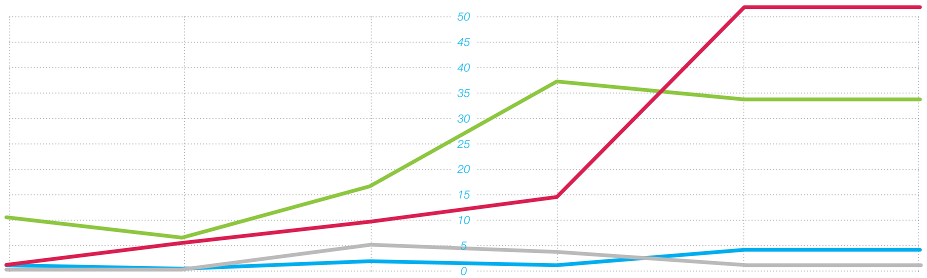
MEDIA FROM 2006—2010

CRANN IN THE NEWS

CRANN is focused on ensuring that the outputs and benefits of nanoscience research are communicated through a range of mechanisms and over the last five years has increased significantly the amount of media coverage across television, radio, print and web. Compared to 2006, CRANN achieved more than seven times the number of media hits across these channels in 2010 (See Graph below). Maximum media exposure is sought for news items such as new industrial engagements, awards received and events like Nanoweek and the opening of the AML. The launch of Nanoweek 2009 featured on RTE's Six One News, and there were 15 articles in both national and local newspapers and 14 online articles as a result of the week. The opening of CRANN's AML in April 2010 generated nine media hits, four in newspapers, four online and one piece on RTE's 9 o'clock news.

TYPE OF PUBLICATION

2006 *2007* *2008* *2009* *2010*



	2006	2007	2008	2009	2010
Paper	*10*	*7*	*16*	*37*	*33*
Radio	*1*	*0*	*2*	*1*	*4*
TV	*0*	*0*	*5*	*3*	*1*
Internet	*1*	*5*	*8*	*13*	*51*
Total	*12*	*12*	*31*	*54*	*89*

INDUSTRY PARTNERS

CRANN has formal engagements with 74 companies.

2004	SME : 0	MNC : 2
2005	SME : 1	MNC : 2
2006	SME : 3	MNC : 2
2007	SME : 4	MNC : 3
2008	SME : 5	MNC : 5
2009	SME : 18	MNC : 16
2010	SME : 46	MNC : 28

INTELLECTUAL PROPERTY & COMMERCIALISATION

Patent Applications	2007	3
	2008	5
	2009	8
	2010	9
Patents Awarded	2007	1
	2008	2
	2009	4
	2010	0
IP Disclosures (IDFs)	2007	5
	2008	9
	2009	11
	2010	17
Licensing Agreements	2007	0
	2008	1
	2009	1
	2010	1
Spin-out Companies Produced	2007	0
	2008	1
	2009	1
	2010	0

CRANN RESEARCH

Over the past two years CRANN has successively leveraged its research expertise and world-class infrastructure to further expand its industry engagement while at the same time delivering breakthroughs in fundamental research that are pushing the boundaries of nanoscience into exciting new areas. The core interests of CRANN are the properties of small matter, and how materials at ultra small scales can be exploited to create new types of devices and sensors.

CRANN has particular expertise in magnetic materials and is using this knowledge to enable Intel to develop new types of non-volatile memory that retain information, after the computer is shut down. Researchers at CRANN are also extending these same concepts to organic materials, which may allow the development of ultra-cheap magnetic sensors. In this drive to create ever smaller materials, we are also developing methods to fabricate vast arrays of carefully assembled nano-materials, in the hope that this will provide an inexpensive route to ultra high density computer chip manufacturing.

The opportunities provided by nanoscale materials are becoming increasingly diverse. We have demonstrated world-leading expertise in the assembly of nanoscale materials to create macroscopic materials with unique properties. This has resulted in a range of material technology platforms that are being evaluated by Hewlett-Packard for electronic paper applications. CRANN researchers are now exploring the possible use of these same materials for sensor and energy applications.

The development of new kinds of nanomaterials is an important CRANN focus. Instead of the synthesis of expensive small materials, CRANN researchers have discovered new ways to make nanomaterials by controllably breaking down inexpensive macroscopic materials into nanoscale components. This important discovery is now providing access to whole new classes of materials that would otherwise be unavailable, thus opening up significant opportunities into energy storage and harvesting.

CRANN researchers have also made significant advancements in the application of nanoscale sensing elements to biological problems. Using specially designed mechanical devices it is now possible to detect the growth of micro-organisms or even the presence of a single virus particle. The enhanced sensitivity of these devices enables rapid screening, reducing the detection time of MRSA to a few hours as opposed to several days. These world leading technologies are now being developed in partnership with pharmaceutical companies such as Novartis and Roche.

The value proposition is clear: **Research excellence drives everything that we do.**

Our investment in advanced microscopic capabilities is continuing to open up new research opportunities for CRANN. Surfaces and interfaces are important in any device, and CRANN researchers are now becoming increasingly involved in studies of the properties and performance of medical devices. We are now starting to look at a different type of question; how to better control the adhesion of the drug-containing polymer coating on arterial stents and/or to facilitate the uptake of a drug delivered via aerosol?

This last two years marked a period of great productivity and growth. CRANN has generated 270 publications in high impact journals and during this same period has used its expertise and facilities to increase the number of industry partners to 74. The value proposition is clear: research excellence drives everything that we do. It validates CRANN as an internationally leading research institute and enables us to compete and engage with industry across the globe.

INDUSTRY ENGAGEMENT & COMMERCIALISATION

Over the last two years, CRANN has been highly successful in building upon the strong relationships with our core industry partners, Intel and Hewlett-Packard, and in developing new industrial engagements with a wide variety of national and international based enterprises.

CRANN now engages in basic and applied research activity with industry spanning all the key sectors for Ireland —ICT, Energy, Medical Devices and Pharmaceuticals. With the continual development of our research strategy and direction, CRANN seeks to align our core research, new pathfinder research initiatives and strategic investments in infrastructure to address these commercially vital sectors.

In late 2009, CRANN placed significant emphasis on rolling out a new industry engagement model. In the past twelve months CRANN has significantly increased the number of companies with whom we engage and, most importantly, increased the value we offer to all our partners.

To date, we have active interactions with 74 companies; nationally and internationally. Engagements range from multimillion euro collaborative research to industrial training programmes to materials analysis for direct manufacturing support.

CRANN's diverse researcher base, international reputation and world class infrastructure are seen as key enablers for industry. These provide a company with an extremely flexible, configurable resource that is externally managed but targeting the company's needs. Key elements in place to enable this are strong institute governance with industry board members, a practical IP management strategy to quickly exploit success, expertise in funding identification and sourcing, internal financial and administrative management structures and the availability of industrially experienced staff to manage the engagement process under direct company oversight.

In supporting Irish industry's immediate production and development requirements, we offer technical expertise and operate an industrial interface for companies to get direct access to equipment and test facilities. In 2010, CRANN partnered with 20 companies (11 MNCs and 9 SMEs) addressing their immediate requirements.

Longer term research programmes have also seen considerable success with the licensing of technologies and continued commitment of additional funding from industry to fast-track key development areas. Industry researchers are directly placed in CRANN to participate and guide the research whilst researchers from CRANN continue to find employment in industry.

CRANN participates in the EI/IDA Comp-etence Centre initiatives, co-hosting the Competence Centre for Applied Nanotechnology (CCAN) with the Tyndall National Institute which involves six Irish based companies. CRANN Principal Investigators are directly involved in three CCAN research projects and also contribute as a knowledge provider in the Centre for Bio-Refining and Bio-Energy (CBB) which involves seven Irish industry partners.

Engagements under the more established EI programmes, such as the Innovation Partnership and Voucher schemes has seen CRANN identify new opportunities for over 11 companies, sourcing funding, co-developing the research agenda and successfully managing the project submission and grant awards.

In the European context, CRANN currently coordinates two European FP7 frameworks and partners in seven other consortia. We have provided networking links and introductions for Irish companies to actively participate in high impact international collaborative research. Currently, CRANN has established research programmes with 17 MNC and 24 SME partners in 13 European countries.

As we look to the future, CRANN is committed to providing every industry partner with a professional and valued engagement. We are in the process of establishing an industry affiliate's programme, as a key next step to fostering sustained industry engagement. This will drive the clustering of core expertise critical to industry within CRANN, maximising the available resources to each company and ensuring the return of state investment to the economy.

In addition to industry engagement CRANN has also placed increased emphasis on commercialisation of intellectual property. At present there are thirty technologies available for commercialisation within CRANN and we are continuing to show a strong pipeline of new technologies coming through. Much of this technology is patented; this process is supported by the Trinity Research and Innovation office. These technologies have applications in semiconductors, medical devices, sensors, energy and optics.

In the last 12 months CRANN Technology has been showcased to over fifty companies and a wide range of experts from the academic and venture capital communities. This has secured interest from a variety of industrial partners in a number of projects. CRANN has successfully licensed two pieces of IP during the last 12 months. In addition, CRANN PI, Prof. Igor Shvets, co-founded a new medical device company Miravex which was awarded the first Eircom University Challenge Award at the Irish Technology Leadership Forum (ITLG) event. CRANN is focussed on developing a commercialisation supportive eco-system to enable the successful exploitation of our key technologies.

CRANN over the last two years has evolved from a world leading research institute to an institute which also can provide measurable value to industry through collaboration and commercialisation. This combination of cutting edge research and industry support has resulted in an effective institute which provides real value to Ireland.

One of CRANN's eight Researcher-in-Residence, Chris Murray, INTEL, working on a SEM in the AML.

EUROPEAN ENGAGEMENT

Supplementing exchequer funding with new income streams is an important element in CRANN's strategy for sustainable growth in the coming years. The EU seventh framework programme (FP7) has been targeted as an important source of both research funding, which will underpin this strategy but also international validation of the quality of the research programmes at CRANN. FP7 is a 7-year programme of research funding (2007—2013) which is available via international competition, and CRANN has adopted an ambitious target of increasing the funding from FP7 sources by 100% from 2009 levels by programme end. This goal will be met by increasing both the number and quality of proposals, and a strategy for meeting these goals has been set out:

1. An EU Programmes office has been established to monitor and capture funding opportunities.
2. CRANN will provide on-going training and awareness building in relation to EU programmes—programme management, reporting, finance etc, for both PIs and core staff.
3. CRANN is building close relationships with EI FP7 staff and EU commission project officers.
4. Raising the profile of CRANN within European research networks by participating in conferences, partnering events and European Technology Platforms.

An FP7 news page and calendar has been established on CRANN's internal information platform—CRANNshare, where all funding opportunities will be disseminated to the PI cohort and core staff. Regular mapping actions are also carried out in order to map CRANN research onto FP7 work programmes and call topics. We also liaise regularly with the national delegates for the various programmes in order to ensure CRANN research is represented in future FP7 calls for proposals.

In addition to funding diversity, FP7 project participation brings benefits in terms of networking with Europe's leading institutes and companies, allowing CRANN staff to benchmark their work with the best in Europe and beyond. CRANN PIs are currently involved with 15 projects in a range of programmes in Europe, partnering with forty companies and 155 universities/ institutes. The maps on the facing page illustrate the scale of the network already established by CRANN.

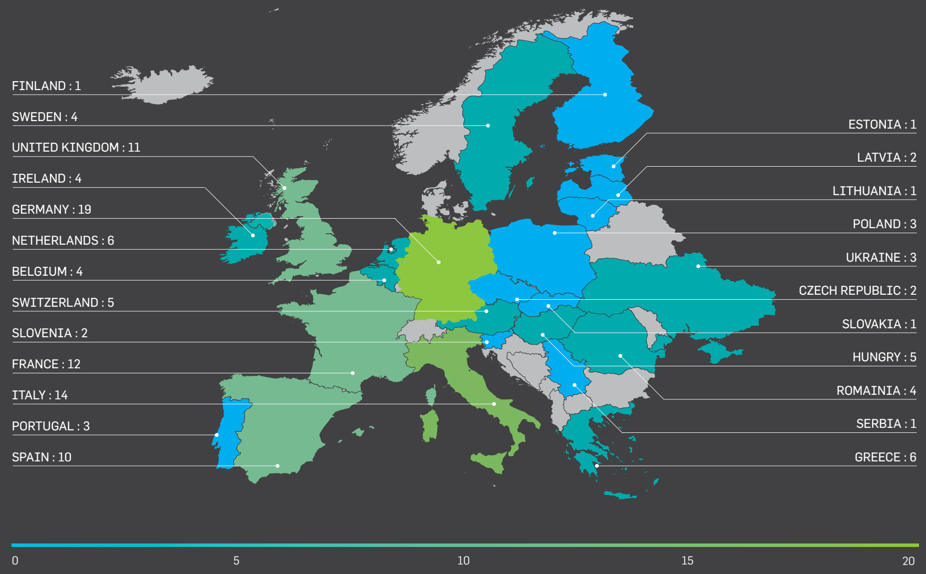
Achievements

The increased focus on framework programmes at CRANN is represented in the outputs for the past year (see Graph pg.56 of FP7 funding awarded by Year). A number of awards deserve special mention:

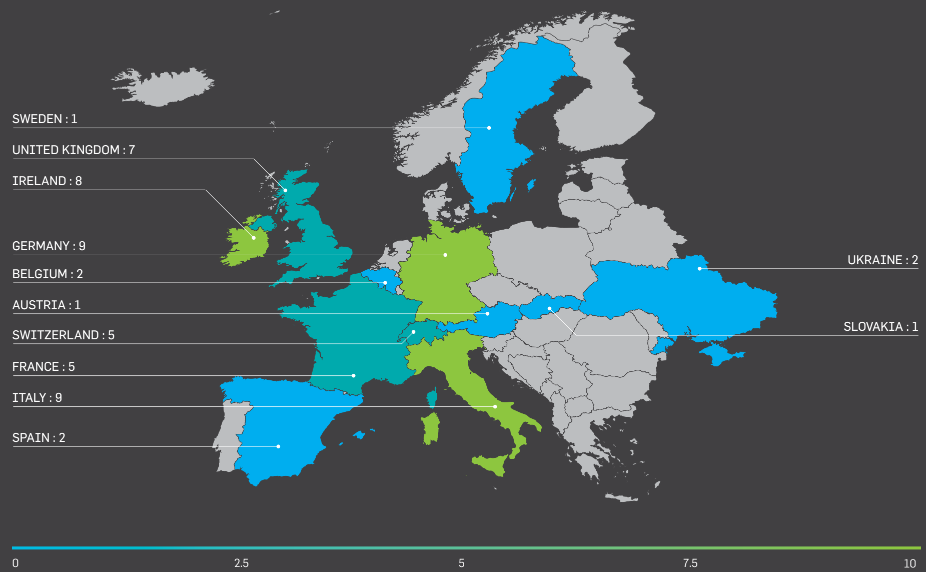
Prof Jonathan Coleman was the recipient this year of a prestigious European Research Council (ERC) Starting Grant, which recognises Europe's leading young scientists. This grant will help to advance Prof. Coleman's work in production of atomically thin layers.

The projects LAMAND and NAMDIATREAM commenced in 2010. Both are led by CRANN PIs—Profs. Michael Morris and Yuri Volkov, respectively, and involve between them 28 international partners and bring a total of over €2.5M non-exchequer funding into Ireland.

CRANN EUROPEAN ACADEMIC COLLABORATORS



CRANN EUROPEAN INDUSTRIAL COLLABORATORS



INFRASTRUCTURE

CRANN Central Equipment Facility

In 2010 CRANN established a Central Equipment Facility (CEF) with two primary objectives. Firstly, to enable world leading research into nanotechnology by providing access to advanced instrumentation. The facility greatly enhances the research capability of our PIs and provides the infrastructure necessary for them to carry out world leading research. As part of this goal there is significant focus placed on training our Graduate students and Post-Docs to the highest level on the latest technologies. This ensures CRANN will continue to attract the best researchers and in turn be recognised for the quality of the researchers it produces.

Our second objective was to establish the facility as a national asset. The facility is open to all users from academia, and importantly, to industry. It operates on an open access policy, with the clear focus of demonstrating and developing the economic value of nanotechnology. The CRANN CEF operates a unique “self service” access program that enables industry to use the CEF as a virtual extension to their in-house capabilities. This is achieved by providing high quality training enabling self driven users and world class analysis equipment and techniques.

In addition, the CRANN CEF aims to proactively increase the use of advanced microscopic techniques and nano-fabrication processes within the Irish research and industrial communities. This will occur through collaborative research programmes and participating in outreach programmes.

Infrastructure:

- » Advanced Microscopy Laboratory
- » Photonics Laboratory
- » Clean Room

The Advanced Microscopy Laboratory (AML) is a custom built, state of the art 600m^2 facility, located in the Trinity Technology and Enterprise Campus, in Central Dublin. The equipment includes a Carl Zeiss Helium Ion Microscope [HIM], an FEI Titan Transmission Electron Microscope [TEM], and five other high specification scanning electron and focused ion beam microscopes. The centre offers custom designed ultra-high specification microscope operating environments, dedicated wet and dry sample preparation labs and a high specification electron beam lithography capability with an integrated clean-room, and resists processing facilities on-site.

The CRANN CEF Photonics Laboratory provides techniques for the optical characterisation of nanostructures and nanodevices. CRANN’s unique ultrafast laser laboratory investigates the dynamic processes in materials and the interactions between these materials and lasers, principally in nano-scale materials such as quantum dots. The equipment includes an Ultrafast Laser System (femtosecond) which can provide an understanding of fast photodynamic processes in physics, chemistry and biology. The SNOM (Scanning Near-field Optical Microscopy) platform simultaneously performs Raman/fluorescence spectroscopy and surface topographic analysis.

The Clean Room is equipped to produce device structures on wafers up to 150 mm in diameter. The specification is from class 10 in the lithography area to class 10,000 in the metrology and deposition areas. The clean room houses a variety of deposition, metrology, lithography and etching processes. The clean-room has been set up to operate in a flexible manner and it allows a broad range of material systems to be used under a controlled environment.

Since its establishment in January 2010 we have seen exceptional engagement. The facility has trained 150 researchers and has enabled engagements with 20 companies. The infrastructure has supported the publication of more than 50 research papers, three invention disclosures and one patent application. The facility has already become a unique and prized national asset which enables both our researchers and our companies to access the world leading infrastructure which is required to compete internationally.

Our aim is to develop **innovative programmes** that will communicate the value of nanoscience to the general public, and not just to those within the formal education system.

CRANN

OUTREACH AND COMMUNICATIONS

Nanoscience is a critical component for successful new technologies which will have major societal impact—from the next generation i-pad to more sensitive medical diagnostics, so it is important that we generate a culture in Ireland whereby nanoscience researchers are willing and able to communicate the value and societal context of their work. This helps build public trust and respect for scientists, which in turn inspires the next generation to take up scientific study.

CRANN ensures outreach and public communications obtains significant focus. Our aim is to develop innovative programmes that will communicate the value of nanoscience to the general public, and not just to those within the formal education system. We have engaged in a wide range of activities targeting a number of audiences.
By working with audiences across many life stages, our aim is that nanoscience becomes part of the natural discourse and recognised as a means of enabling every-day technologies and providing a passport for highly-trained PhD graduates to secure employment in high-tech industry and research centres.

Nanoweek and NanoNet Ireland

Launched officially in January 2011, NanoNet Ireland brings together leading nanoscience researchers and representatives from industry into a single body designed to represent and promote awareness of nanoscience in Ireland and the contribution it makes to the Irish economy. This network combines two major nano-related consortia. INSPIRE, funded by the HEA, is comprised of researchers across ten third level institutions and coordinated by CRANN.

The Competence Centre for Applied Nanotechnology (CCAN), funded by Enterprise Ireland and the Industrial Development Agency, includes both leading multi-national companies such as Intel, Analog Devices and Seagate and indigenous Irish companies such as Creganna and Proxy Biomedical.

Members from NanoNet Ireland have previously come together to organise Nanoweek, a national campaign designed to raise awareness of the contribution that nanoscience makes to society and the Irish economy. The inaugural Nanoweek took place from 30th November until the 4th December, 2009. The event was a success in bringing together political representatives, large audiences from the academic and business communities, and in generating significant media attention around events such as academic workshops, public lectures and schools' visits. Following the success of Nanoweek 2009, the second nanoweek took place from 31st January until 4th February 2011.

Nanoweek 2011 was officially opened with the launch of a DVD on nanoscience produced by CRANN for secondary school students. A two-day academic/industry conference during the week brought together international speakers with direct experience in building technology companies from world class nanoscience research and representatives from Irish industry, research and investment communities to share experiences in the commercialisation and application of nanotechnology.

Nanonet Ireland aims to coordinate the largest Nanoweek yet for 2012, to fit into Dublin's City of Science calendar.

Post-graduate Students

We can contribute to a supply of articulate and confident scientists in Ireland by providing CRANN students with experience in presenting their work to a range of audiences. While a series of postgraduate seminars each year allows students to present their work to their peers, other means are required to develop skills that will enable them to explain their work in simple terms to a more general audience.

Thesis in Three

CRANN organised a "Thesis in Three" competition in September 2010 whereby PhD students had to present their work to a general audience using only 3 slides in 3 minutes. The event took place in a local pub, creating a relaxed atmosphere but with added pressure on participants to communicate well and entertain the audience, many of whom were "non-scientists". The winning three presenters went on to represent CRANN in a CSET-wide Thesis in Three, coordinated by CLARITY (UCD) and CNGL (DCU) as part of Innovation Dublin and held in November 2010. CRANN was delighted that the overall winner of this event which had 19 participants from 6 different CSETs was Karen Young, PhD student with Prof Jonathan Coleman in CRANN.

3rd level students

Until recently students were really only exposed to focused study in nanoscience if they chose to undertake a PhD. There was clearly a need to introduce this study earlier in the academic lifecycle. In 2010, CRANN was actively involved in the development and promotion of a TCD undergraduate programme focusing on nanoscience. Nanoscience—Physics and Chemistry of Advanced Materials (N-PCAM) commencing in September 2011 will be run jointly by TCD's Schools of Chemistry and Physics. Students will gain a solid grounding in physics and chemistry with specialisation in nanoscale materials and some laboratory training provided in CRANN in the final two years.

School Students

CRANN's long term objective is to influence and assist in the development of educational modules which will impact both the primary and secondary curricula.

Nanoscience DVD

Students are more likely to understand and become interested in science when it resonates with their daily lives. In 2010, CRANN developed "Nano in my Life", a DVD aiming to excite and engage second-level students about the basics of nanoscience, and its applications in their everyday lives, from sports equipment to cosmetics products, mobile phones to new music technologies.

"Nano in My Life" comprises ten short chapters of 3-6 minutes in length. Each chapter provides insight into the range of new technologies and materials that nanoscience is enabling, from faster laptops to more sensitive medical diagnostics. An offline edit of the DVD was piloted in six schools in November 2010. Final editing was completed based on feedback from students and teachers and the finished product was launched in January 2011 at the opening of Nanoweek.

The intention with CRANN's DVD is to provide teachers with an easy-to-use resource which introduces students to an important scientific topic not yet included on the formal curricula, but at which Ireland is excelling on the international stage. The DVD will be accompanied with support materials for teachers to enable them to conduct a number of Transition Year modules on nanoscience.

Debating Science Issues

Debating Science Issues (DSI) is a dynamic debating competition which invites senior cycle secondary school students to engage in debate on the cultural, societal and ethical implications of advances in biomedical topics including nanotechnology. It is funded by the Wellcome Trust and coordinated by REMEDI (National University of Ireland, Galway) in conjunction with seven science centres throughout the republic and Northern Ireland. CRANN has been involved with this competition since its inception and in 2011 provided workshops to four schools in Leinster prior to coordinating the first round of debates.

Transition Year Placements

In 2010, CRANN established a structured week-long placement programme for Transition Year (TY) students. This runs twice yearly, once in the Spring, the second in the latter part of the year. Twenty-four TY students from 18 different schools throughout the country took part in the programme during 2010. They were exposed to the range of nanoresearch that takes place in CRANN, by spending time with postgraduate students and postdocs from a range of PI groups, attending presentations and tours e.g. to Intel, St. James's Hospital.

CRANN also works closely with TCD's School of Physics, sharing resources between CRANN's TY programme and the Transition Year Physics Experience programme (TYPE).

Over the course of the week each student was requested to write a response to what they experienced during their time with CRANN. The following two stories were written by two Transition Year students who participated in CRANN's TY programme in November 2010.

My Trinity College Dublin / CRANN work experience: A place filled with history where I saw the future.

By Calum Hendler, *Our Lady's Secondary School, Castleblayney, Co. Monaghan*

We live today in a world created by people like Ernest Walton, for his work on the atom and mathematician William Rowan Hamilton, who discovered Quaternions. They created our present and now its CRANN's turn to set about creating a better future. A future where Ireland plays a strong role in nanoscience. Ireland's role in nanoscience will strengthen our economy and help create a sense of optimism. Ireland must position itself to catch the nanotechnology revolution and CRANN is a central player in this.

My reasons for applying for the TY programme at CRANN are simple. A deep love of science and I felt that CRANN's TY programme could expand my continual want for learning and understanding of how things work. I also wanted to meet new people who are excited about how the world around them works. And this programme has succeeded in fulfilling my expectations and much more.

In CRANN, I experienced optimism, team work, support, and encouragement. The people I met in CRANN showed many attributes that I admire and will strive for in myself.

I have an optimistic personality which is my attraction to science and why I believe in the importance of science. My experience in CRANN has reinforced my optimism. I learned that team work, cooperation, friendship, and supportive advice are how problems are solved. My fellow TY students and I gained life-long skills such as problem solving through setting goals, identifying alternative actions, and anticipating consequences.

Through the friendships I have made, I have gained an understanding of the perspectives of others, shared positive experiences, and learned a lot about myself and where I would like to see myself in the future. Through team work experiences, cooperation was at the heart of problem solving and enjoyment.

Throughout the week, not only did we learn a multitude of information and skills, we also had great laughs and fun along the way. I also was given a glimpse of university life which I cannot wait to participate in.

During this week, I was introduced to the science of the really small. I have learned that nanotechnology is the study of controlling matter on an atomic and molecular scale. The thought of things this small just takes a while to get your heads around but when you finally do, you begin to understand the vast magnitude and multitude of applications this science has for every day life.

Activities that I found memorable were the guided tour of Trinity College, our trip to the AML, Intel, and St. James Hospital. The tour of Trinity College was very informative and gave me a better insight into college life and what TCD has to offer. The trip to the AML was fascinating as we were allowed to use the SEM and TEM to view specimens in a magnification much greater than that of a light microscope. The trip to Intel was impressive due to the scale of the factory and through the tour of the factory floor I gained insight into the manufacturing and applications of microchips. In St. James Hospital, we were introduced to their investigations into the safety of using nanotechnology in the human body and the environment. I was also very amazed at CRANN's facilities in the Naughton Institute, Trinity College.

A quote by Antoine DE Saint-Exupery, "The Little Prince", sums up my feelings of the week, 'It is with the heart that one sees rightly; what is essential is invisible to the eye'. At the heart of my experiences are the friendships I made, the memories I have, and the reality of nanotechnology. These are individually invisible to the naked eye but yet have the possibility of such profound effect. My experience in CRANN was a very memorable and fun one.

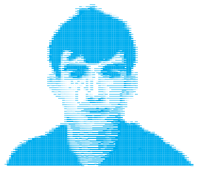
> *"I have gained an understanding of the perspectives of others, shared positive experiences, and learned a lot about myself... "*

CRANN has stimulated and increased my interest in science and the role science plays in Irish and international life. I hope I can share my positive experiences with my friends in school to further their interests in science.

I would like to express my thanks to Mary Colclough and everyone else who made my TY work in CRANN possible. I really appreciated the time and effort they put into the programme giving us an insight into what they do and what CRANN is trying to achieve for the future. I would also like to thank the Principal Investigators and researchers for all their kindness.

CRANN's Experience Nano TY Programme.

By Oisín Moran, Transition Year, *Presentation College, Bray*



Monday, the 1st of November, was filled with excitement in CRANN's reception. Twelve lucky TY students who had got their place in CRANN's "experience nano" programme, were busy getting to know each other. I was lucky enough to be one of these and my anticipation, along with others, was filled with the unknowingness of what the week ahead had in store. We were warmly greeted by Mary Colclough, The Communications and Education manager, who brought us up to the boardroom. Here we were introduced to Nanotechnology and each given a timetable of what was to be an amazing, innovative and eye opening week! I have been interested in science for as long as I can remember. I grew up reading about things that should have been way out of my depth. I wanted to come to CRANN as I knew little about nanotechnology but what I had heard was astounding.

On Monday afternoon we got our first real taste of what work is done with nanotechnology. We visited the clean rooms in CRANN; learning about the varying degrees of cleanliness and the operations performed there.

We saw machines for all sorts of operations on the nano scale including one, which cost "about a few Ferraris". We all got to take home a piece of Silicone, which is commonly used as a substrate layer in computing.

Tuesday saw us in the AML where we witnessed different approaches to viewing material, which normal optical microscopes cannot see. The reason for this is that light has a wavelength of about 400—700nm (depending on the colour) so viewing things smaller than this gets tricky and then becomes impossible. Two methods we saw were SEM and TEM that, put simply, fire electrons at the material to be viewed and pick up what bounces off or passes through.

Later we went to our assigned PI groups who kindly took us around their labs and showed us what they do. This week has succeeded in teaching me a lot about an area I knew little about and I am glad of this. One of the most important things I learned was how vitally important nanotechnology is not just for Ireland and its economy but also for the world. It is one of the most interdisciplinary areas of study I have come across and ranges from Physics to Chemistry to Biology and everything in between and beyond.

> *"Nanotechnology is the future of almost every aspect of your daily life and it's about time you knew it. It will make computers faster... walls warmer, enable people to climb walls like Spiderman... it will destroy ailments and this is just the beginning."*

On Wednesday we made a trip to Intel to find out about the commercial impact of nanotechnology. What we saw in CRANN was multiplied one hundred fold in Intel with approximately €7bn of investment and clean rooms that spanned hundreds of metres. I found it funny how such a massive structure of buildings was responsible for manufacturing the smallest parts of modern technology! Later that day we learned about commercialising nano and then had a tour of CRANN's Nanobio lab.

St. James Hospital facilitated us Thursday morning and showed us their equipment and research. At the end we composed a 3D image of a pollen molecule by using lasers.

Nanotechnology is the future of almost every aspect of your daily life and it's about time you knew it. It will make computers faster and smaller, walls warmer, enable people to climb walls like Spiderman, jump 5 times their normal height, it will destroy ailments and this is just the beginning. I feel nanotechnology needs to get out there and show the world what it can do. "Just say nano"!

Smeagol— A Calling Card for the World

Software developed by **Prof. Stefano Sanvito's** group has put **CRANN** on the map for computer simulation of materials at the nanoscale, opened up collaborations around the world and drawn in non-exechequer funding of €2.5 million to date.

Getting a picture of what happens to materials at the nanoscale often isn't easy but Professor Stefano Sanvito's group has developed a computer programme that can act as those eyes, simulating and predicting how materials and devices act at the atomic level. The software, Smeagol, can aid in the design and understanding of experiments, and has also opened up opportunities for Prof. Sanvito's group to collaborate on international projects.

At home in CRANN, Smeagol is used for a number of applications, he explains: "In materials modelling we simulate in a computer either the properties of existing materials that people are making and growing in CRANN, or we predict new materials or a property of a known material."

Meanwhile the software also offers insights into electron transfer, a process at the heart of electronic devices. "In any mainstream electronic device like a laptop, ultimately the information that is read is the variation of an electrical current," says Prof. Sanvito, who is a CRANN PI and Lecturer in the School of Physics. "So we construct models for devices at the atomic level and calculate the current and the response of a current to external stimuli."

Prof. Stefano Sanvito's group at CRANN has developed Smeagol, software to model interactions of materials at the atomic level. The code is being used by around 140 groups around the world and CRANN is using it as the basis of international collaborations that look at smarter transistors, DNA sequencing and solar energy efficiency.

Using software to model materials and simulate processes can help improve access to information, predict outcomes and potentially avoid costly experiments. And the benefits of Smeagol—which has been in development at CRANN for over five years now—have not gone unnoticed in the international community.

Around 140 centres use the software now, according to Prof. Sanvito, who calls up a map on his computer screen that displays dots from the US and Europe to the Middle East and Japan. "It is a code that is being used quite a lot," he says, noting that one of the factors in its success is that the algorithms are designed to be as general and flexible as possible and so are widely applicable.

"At the moment we run essentially on anything from a laptop to supercomputer, and the code is easy to use, it's robust. So now the range of users maps on an equivalently large range of problems."

Issues being tackled using Smeagol include modelling sensors for biological agents, developing magnetic sensors and transistors and simulating scanning tunnelling microscopy, and the groups using the code are scattered around the globe from the US, through Europe, the Middle East and Japan to Australia.

The program itself also acts as a calling card for the CRANN group, and it has opened many doors, says Prof. Sanvito. "The code has been very useful to engage with the outside world, we are extremely visible on the international stage, people know us well," he notes. "The network is very big and it has opened the possibility to fund research."

So far the code has paved the way to secure around €2.5 million of non-exchequer funding, mainly through collaborative projects under the EU framework. One of those projects saw CRANN partner with centres in the Netherlands, Germany and Italy, explains Prof. Sanvito. "The idea was to construct a transistor that operates as a bit of memory, and it's non volatile, the information will be there as long as you need it. The concept was to do all this using organic materials," he says, describing how the initiative resulted in a prototype. "We demonstrated that we could make one of these devices, something that could operate both as a transistor element and memory."

A step on from that project is underway, this time seeing CRANN working with European partners on engineering interfaces between magnetic and non-magnetic materials, optimising the surfaces for spin, which is linked to memory. Another EU-funded project is looking at the process of DNA sequencing, which can offer important information about diseases. The idea is to develop a more rapid and affordable sequencing method, and Prof. Sanvito's group is modelling the process, which involves 'threading' strands of DNA through a pore in a nanotube and reading the signature of the electrical current as it moves through.

Meanwhile, Prof. Sanvito leads another major collaborative project between the EU and India to look at functional metal oxides, which are notoriously tricky to model but they have important industry applications. "A lot of them are starting to be very important for energy," he says.

Energy is also a central part of a new collaboration between CRANN and Saudi Arabia, where the Smeagol software will help in the search for more efficient solar-power systems. The collaboration will see Prof. Sanvito's group gaining access to staggering amounts of resources from Saudi supercomputers: "We have already received about 20 million CPU hours to use in the next six months," he says. "The amounts of hours we are receiving from them is about two to three times the total amount available for the entire country of Ireland." At the moment Smeagol can simulate up to roughly 10,000 atoms, and the increased computing facilities will help achieve the goal of simulating 100,000 atoms—around the number you find in a transistor, he adds.

The Saudi collaboration will also look at the behaviour of molecules in solutions and aims to describe strong electron-electron interaction. "The main application we have in mind is to look at the problem of electron absorption in solar cells, which is of interest in Saudi Arabia," says Prof. Sanvito. "If you cover 10 per cent of the Arabic peninsula with solar cells at 10 per cent efficiency you will meet the present demand worldwide for energy. And if someone can break through to the 10 per cent efficiency level it could be a fantastic turnaround of the entire economical landscape."

"At the moment we run essentially on anything from a laptop to supercomputer, and the code is easy to use, it's robust. So now the range of users maps on an equivalently large range of problems."

— Prof. Stefano Sanvito, CRANN

A Fine Balance— Attracting the best in biological sensing

CRANN has attracted some of the world's leading researchers in their fields to work here. **Prof. Martin Hegner** relates how and why he moved his group from Switzerland to Trinity to continue his work on biological sensing.

Professor Martin Hegner was first into the new CRANN building in 2007. His boxes arrived from Basel in Switzerland just in time to move into the Pearse Street facility, where he has been working ever since on developing tiny cantilevers, or springboards, to detect specific biological entities in samples.

A biologist and a native of Switzerland, today Prof. Hegner's group is working on industry—and clinically-relevant problems: they include sensing contamination in liquid medication samples, identifying advanced targeted therapies in cells and even monitoring the progress of vaccinations.

His interest in working at the nanoscale was piqued from early in his career, first in Switzerland and then while working on optical tweezer techniques at UC Berkeley in San Francisco in the 1990s. Next he moved back to Switzerland in 2001 to a post at the University of Basel, a national competence centre in nanoscale science. Being the "lonely biologist in a department of 200 physicists" there gave Prof. Hegner not only the opportunity to work in the converging field of biophysics, but he also added the language of physicists to his vocabulary.

His research took an innovative approach to sensing biological entities, by directly measuring the forces when biological molecules interact. This kind of probe can offer insights into important reactions, such as understanding how well drugs bind to targets, as Prof. Hegner explains. "You would like to have a drug which is binding firmly to a receptor and inactivating it. So we were measuring on a molecular level, probing the forces which are occurring when DNAs or proteins are interacting with each other," he says.

Prof. Hegner's group became recognised as leaders in this field, using arrays of micro-cantilevers that are akin to diving boards: if a molecule binds to the surface of the cantilever it causes a vibration that can be measured. The key is to scale the sensors correctly, he explains. "If you shrink down these sensors to microns and sub-microns, all of a sudden you get access to this mechanical interaction on the surface. The sensor is soft enough that you can convert the binding signal into a mechanical signal which you can then read out with a computer."

Prof. Hegner's work has been using cantilevers that may be only a few hundred nanometres thin, and they are custom made in-house. "I have physics students in the group who love to build and make machines instead of opening up a catalogue like 20,000 researchers worldwide who buy a product," he says. "But if you are able to make your own device you are able to surpass the others because your machine is more sensitive."

"We shrink down the sensor and so we are able to see when something changes on the surface. If something grows we pick up weight and weight is the growth of viable biomass." — ***Prof. Martin Hegner***

Yet even though this group was leading the charge in this field, the climate in the Basel department was becoming less hospitable for a biologist as the trend moved towards low-temperature physics. Prof. Hegner started looking for a new position, and he had no shortage of invitations, with offers from Denmark, Canada and other parts of the world, but ultimately CRANN was the most attractive option. And so he moved into the new building in Trinity in the summer of 2007 while the snag lists were being completed.

But it wasn't just the equipment and group of expert researchers that Hegner brought with him to Dublin, it was also the industry relationships that he had built up in Basel over his years there.

Today, as a CRANN PI and Lecturer in Trinity's School of Physics, he maintains those collaborations. One, with Novartis, uses silicon cantilevers to rapidly screen liquid eye drops to see if they are sterile. The conventional way of testing for contamination is labour-intensive and time consuming, as Prof. Hegner outlines: "They fill plates with nutrients, agar plates, and they put their eye droplets on to the plate, then they wait a day or a week and if something grows they know it is not sterile," he says. But the cantilevers can speed up this process by around a factor of 10, quickly and sensitively detecting the growth of bugs in the solution. "We shrink down the sensor and so we are able to see when something changes on the surface. If something grows we pick up weight and weight is the growth of viable biomass."

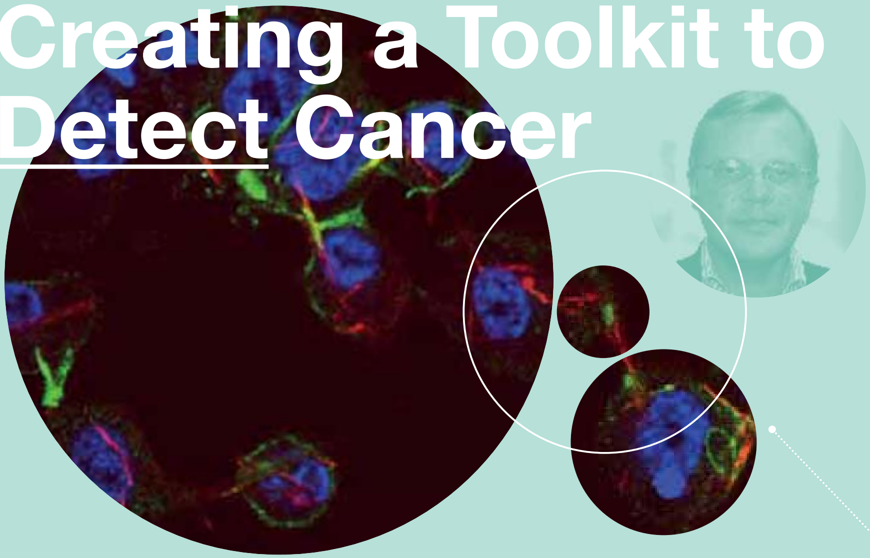
Another collaboration, this time with Roche, senses specific lengths of a type of molecule called RNA in cells, which is a hot target for new drugs. Getting RNA-based drugs into the right compartment of a cell is a challenge, but the cantilever sensors can track progress. "We would like to measure on a sensitive level can we shuttle the RNAs into a cell," says Prof. Hegner. "So we developed with Roche four or five years ago an assay where we can detect small pieces of RNA in a genomic background without any labels."

Prof. Hegner also links in with the Swiss Tropical Institute to work on monitoring the biological impact of a malaria vaccination programme in Tanzania, using the cantilevers to analyse tiny samples of blood taken from vaccinated infants. He adds that the platform could have wider applications in measuring other important biological indicators, such as the presence of viruses and biomarkers associated with disease.

The ability of CRANN to attract overseas researchers of Prof Hegner's calibre and international standing is a sign that the Centre can compete on a global stage, and reinforces that excellent researchers are the enablers of its continued success.

Prof. Martin Hegner moved from Basel to CRANN in 2007, and continues to carry out world-class research on tiny cantilevers that can be engineered to sense specific biological entities. Industrial applications include screening products for contamination and improving drug discovery and development processes.

Nanomedicine—Creating a Toolkit to Detect Cancer



Investment in basic research into nanodiagnostics at Trinity College School of Medicine and CRANN has led to the development of a major European initiative to detect and monitor signs of cancer in the body.

In cancer, early detection can be a matter of life and death. Identifying 'biomarkers' of the disease in the body can potentially flag a brewing problem early on, and inform the most likely treatment regime to kill the tumour cells. Or, if a person has already been diagnosed with cancer, it's valuable to be able to gauge whether a treatment is having an effect, and one way is by tracking relevant tumour biomarkers in the body.

Ideally, the way to screen for these biomarkers would be in pinpricks of blood or other easily accessed samples from the person being tested, and recent years have seen a push in diagnostics towards 'point-of-care' devices that can quickly analyse samples at the clinic.

So where does nanotechnology come in? Tiny agents such as nanowires can be engineered to bind to and highlight the presence of key molecules in biological samples, and TCD's School of Medicine and CRANN PI Professor Yuri Volkov is leading a major European initiative to explore such approaches.

The aim of the EU-funded project, which involves 22 partners from 9 European countries, is to develop a toolkit for picking up markers of cancer rapidly and with minimum fuss for the patient, explains Prof. Volkov.

The initiative has its origins in Science Foundation Ireland-funded research at CRANN by Prof. Volkov, Prof. Yurii Gun'ko and Prof. Michael Coey. "The pilot research project was on the interface of medicine, physics and chemistry," explains Prof. Volkov. "The project was focused on trying to apply the advances in synthesis of new materials, such as nanowires, and with subsequent functionalisation or coating with appropriate biomolecules to enable them to capture the markers of disease in the blood or serum of the patient." Above all, the technology would have to be not only informative but convenient too, he adds.

"We wanted to do these things in a very small volume of blood to make sure that it is minimally invasive for the patient. So it's less pain, faster and informative, that was the general concept."

CRANN's approach was to develop 'barcoded' nanowires consisting of different nanomagnetic segments. And just like a barcode on a supermarket item, the information could be engineered to relate to a specific biomarker and so bait it in the patient sample.

"In the same way as the barcodes in the supermarkets have black lines and white spaces in between them, that would be "on-off" readout sequence on the wire," says Volkov. "That was the idea. If your target interacts with the wire then you read it out and you get an idea of what you are reading at the moment. So it's a kind of barcoded tagging of biological targets."

The approach offers plenty of potential, he notes: "If you can synthesise those wires in a properly controlled fashion you can use as many segments as possible, so the amount of information which could be encoded in these wires would be practically unlimited."

"We wanted to detect disease in a very small volume of blood to make sure that it is minimally invasive for the patient. So it's less pain, faster and informative."

But reading the barcodes means orienting the nanowires correctly, and CRANN worked with Cellix, originally a Trinity spin-out, to develop a prototype platform using microfluidic technology. Their experiments showed that you can channel the flow of samples so the barcodes can be read by magnetic sensors.

And with that experimental system in place at CRANN, they went to Europe and invited partners to work on a range of platforms and nanomaterials for detecting cancer.

As a result, CRANN now leads the pan-European NAMDIATREAM project, which kicked off in July 2010 to develop a range of platforms for super-sensitive lab-on-a-bead, lab-on-a-chip and lab-on-a-wire nanodevices designed to pick up specific biological signs of lung, breast and prostate cancer in patient samples.

"Out of four technology platforms, either all of them will be successful or they could be complementing each other," says Volkov, describing how the project will look at the most appropriate options. "And after four years we deliver the prototype for the European community, and Irish patients likewise."

It's an example of fundamental SFI investment blossoming into an initiative that is drawing down €12m of European investment, around a third of which goes to Ireland, he notes.

And it's not the only instance of Prof. Volkov's expertise being sought at a European level: he is also to lead work in a separate four-year EU-funded project looking at technology at the interface of devices and medicines to diagnose and treat disease. The €10 million project is scheduled to start this year.

TCD School of Medicine and CRANN leads the EU-funded project NAMDIATREAM, which aims to develop nanodevices and platforms for detecting the monitoring of cancer in the body. The consortium consists of 22 partners from 9 European countries, including seven high-tech SMEs (two of which are based in Ireland—Cellix and Radisens Diagnostics) and two multi-nationals (Beckton Dickson and Nikon). Of the 13 academic institutions, two are in Ireland (TCD and University College Dublin).

CRANN and Hewlett-Packard— Flexible Friends

“It’s all a natural ebb and flow of business in a large company like **HP**, which has such a diverse portfolio of products. The foundation on nanotechnology gives it that future proofing.” *— Dr. Graeme Scott, HP*

Flexibility is a desirable quality in business. And if you are pioneering research into next-generation technologies, being able to flex and meet the demands of emerging markets or incorporate new discoveries is even more valuable.

But to be flexible you need the right connections, expertise and confidence, and CRANN’s partnership with Hewlett-Packard is a case in point. The collaboration started around four years ago, explains Dr. Graeme Scott, a senior member of technical staff in the electronic Technology Development team at HP. “The gem of it is really in the development of the HP site in Leixlip, HP (Manufacturing) Ltd,” he says.

“Within the manufacturing framework we developed some novel processes and started off down a development path, eventually trying to increase the value-add to the site’s R&D activities.”

CRANN and HP are working together on the use of silver nanowires in flexible, transparent, conductive displays for electronic devices, such as portable e-readers. The collaboration, which is raising the research profile of both CRANN and HP, has now also diversified into the area of wireless sensing.

The focus of the initial collaboration with CRANN was to look at issues around e-reader technology, with the aim of making displays sharper and more flexible. “There’s a well known problem with your normal displays, which you have in your laptop and television at home,” explains Dr. Scott. “They are still very expensive to make, they require a semiconductor-type fab and clean rooms. There’s only a small number of companies that do it because the barrier to entry of the market is so high.”

HP envisaged a solution to lower costs with a game-changing approach: “One plan was to have a very disruptive technology that would be produced in roll-to-roll equipment like a paper mill and to do that you need a flexible substrate and flexible technologies.”

Working with the group of CRANN PI Prof. Jonathan Coleman, the team turned to nanomaterials to find a solution for electrodes in electronics displays that would be not only transparent and conduct electricity, but ideally they would bend too. “You can make a metal film very thin and it becomes transparent, and if it’s a very conductive metal it will conduct electricity,” explains Prof. Coleman. “But the problem is that thin metal films are very brittle, and if you want it to be flexible, you can forget it. Where nano comes in is rather than having a metal film you have a load of little rods and you sprinkle them on a glass surface so they are all touching each other.”

The network of conductive rods is now thin enough to be transparent, and the configuration means there’s some give: “If it’s on plastic and you try and bend that plastic, because the rods are only touching they can flex a little bit and when you bend it it doesn’t break.”

The team started making the conducting transparent films with networks of rods in the form of carbon nanotubes, which conduct electricity well. “We managed to get results that were as good as anyone else in the world, but it became apparent very quickly that this wasn’t good enough to fulfill industry’s requirements,” says Prof. Coleman. “Then we realised after a while that instead of carbon rods we could use metal rods.” Phase 2 of the CRANN-HP collaboration is now looking at using networks of silver nanowires to improve the quality of the conductive films.

Meanwhile the trust built up between the partners has fostered another area of research into nanomaterials, this time with an application in wireless sensing, which is an emerging area for HP. “It’s all a natural ebb and flow of business in a large company like HP, which has such a diverse portfolio of products,” says Dr. Scott, who notes that the research capability at CRANN allowed the collaboration with HP to flex in the new direction that emerged. “The foundation on nanotechnology gives it that future proofing.”

The close links between researchers in CRANN and HP in Ireland—who have formal monthly meetings and who travel to the US annually to discuss opportunities—are important for more generally raising the profile of research at HP, which is increasingly being seen as an important activity to flag.

“There has been a realisation that you have to go externally and leverage the world to make some of these new technologies happen, and to do that its best that people know you are there,” says Dr. Scott. “So having gone from a culture where publication and conference presentations were not really thought about, this has taken on more importance as HP tries to build a public face and we are now looking towards European funding for projects.” He comments that the calibre of both the people and the publications within CRANN are helping put HP on the map for research, and he is supportive of CRANN achieving outputs based on State investment through Science Foundation Ireland. “Nothing would delight us more than for CRANN to have a piece of foundational IP and we could go to them,” he says.

Commenting on HP’s commitment to the collaborative research programme, CRANN’s Executive Director Dr. Diarmuid O’Brien notes that HP funding was recently allocated to the partnership that would otherwise have gone to a major US university, which he sees as a sign of Ireland beginning to compete internationally in this field. “There’s no question that the collaboration has raised the profile and the internal company view of what can be delivered from Ireland,” he says.

Getting to the Point of Commercialising Research

CRANN PI **Dr. Graham Cross** is commercialising high-resolution diamond-patterning technology that grew from asking a fundemental scientific question.

Sometimes asking a basic scientific question can open up a new way of doing things. For Dr. Graham Cross, looking into the science of how materials deform during nanoimprinting has spawned an etching technology to help control the process. And once commercialised, the approach could have wide application, from research tools to manufacturing consumer electronics.

The discovery centres on the field of nanoimprint manufacturing, explains Dr. Cross, who is a CRANN PI and lecturer at Trinity College Dublin's School of Physics.

"Nanoimprint manufacturing is all about cost-effective manufacture of nanostructures for all sorts of applications, ranging from bio to IT—semiconductor to magnetic storage to optical devices," he says.

Understanding how materials physically react to being imprinted or deformed at the nano-level can help to identify ways of improving the processes, and Dr. Cross and colleagues at CRANN, including Prof. John Pethica, have been focusing on the 'squeeze flow', or how polymers flow beneath the stamps during imprinting.

"That limits the throughput during the manufacturing process. It basically tells you how fast you can do it," he explains. "We viewed it as an interesting scientific challenge and we got a nice publication out of it [in Science]."

That scientific insight also has commercial potential, he adds, because their work highlighted a new method to pattern diamond and improve the manufacture of dyes.

"From the overall commercial perspective of nanoimprint as a viable, commercial activity, the limitation is actually in the production of the stamps, of the dyes. So in terms of a commercial opportunity there, it's in making a contribution to the production of the dyes," says Dr. Cross. "And we discovered that we had a new way to pattern diamond which ticks a whole bunch of boxes in terms of what you want for a nanoimprint dye."

Currently, electron beam lithography is used to pattern diamond at high resolution, but Dr. Cross and his team have found they can use a newer technique to tightly control the etching process: focused ion beam technology.

"It uses ions instead of electrons, which changes the physics—the way the beam interacts with the surface of the materials that you are looking at with that beam is different," he says.

"The beam will interact with the diamond surface and create what is called a mask, and that mask is very high performance, high resolution and resilient. Then we can use that mask in a process called reactive ion etching. So basically the focused ion beam paints the picture on the diamond surface and a broad reactive ion process then creates the relief, it digs down into all the places that are not protected by the mask. It's an etch process where we have a nice way to lay down a mask and then we can create high aspect ratio, high resolution structures."

Ultimately Dr. Cross sees a wide spectrum of applications for the technique, but some are more tangible than others at present, and that is guiding how the research is being commercialised and matured.

And while the technology for producing high resolution diamond structures may have larger and more lucrative applications at a later stage, for now the commercialisation focus is on market entry.

"We set up relationships with these companies and we have regular business meetings now with the ones who are interested. It's a partnership process now as we guide our final prototypes into what they need." — **Dr. Graham Cross**

"Because this is a fledgling technology and because we would like to grow a business out of this, we have tried to pick an application which is a good technical fit and a reasonably easy one for us to do," he says.

That application is in creating high-performance tips for an atomic force microscope (AFM), a widely used method to examine materials at the nanoscale.

"We have been working with various partners from industry to develop our products," says Dr. Cross, who envisages sales in 2011. "We identified that our technology would assist these companies to do what they are doing right now. We went out and physically engaged with them, we flew to California where most of them are based, we went into their offices and talked about what we were doing. We set up relationships with these companies and we have regular business meetings now with the ones who are interested. It's a partnership process now as we guide our final prototypes into what they need."

"We view it as a multi-tier strategy where we quickly develop a commercial presence and then develop into larger markets. And Adama Innovations will be the company that we anticipate will take the licence out to perform the commercial transactions," says Dr. Cross, who also notes the importance of support from Science Foundation Ireland, Enterprise Ireland and Trinity College Dublin in moving the concept from research through to market.

We discovered that we had a new way to pattern diamond which ticks a whole bunch of boxes in terms of what you want for a nanoimprint dye.

Looking to the future of electronic devices with Intel

"When **Intel** is interested in a new topic it needs to go and get expertise on that. And the way we start is to go to best university we can find and we work with them and learn about the technology."

— Leonard Hobbs, Head of Research at Intel Ireland in Leixlip.

Think about how rapidly consumer electronics have changed in the last decade. At the turn of the 21st century, we punched keys on our mobile phones rather than swiping screens, TV images lacked high definition and laptops were large and clunky compared to today's zippier notebooks and tablets.

So what's coming next? Whatever form future devices take, they will most likely be smaller, faster and more powerful. And CRANN is working with Intel on developing materials and processes that will support ever tinier chips at their hearts.

Such smaller devices can enable functions such as high quality video streaming, three-dimensional TV and improved security, explains Professor Michael Morris, a CRANN Principal Investigator and Professor of Chemistry at University College Cork.

Currently, lithography processes are producing 22-nanometre chips for consumer goods, but the future will demand much tinier scales of around four nanometres, he notes.

"This is looking eight to ten years into the future, Intel are trying to solve how they can do that, because today's optical lithography is unlikely to work at these levels," he says. "At the moment the current size for the brand new devices is 22 nanometres and as the required dimensions approach the 10nm region and lower, new breakthroughs on how patterning is performed will be required."

So fresh thinking is needed to break through to four nanometres, and CRANN is working on a possible approach.

"In this industry you can't stop, you have to be constantly innovating and researching, looking for new things, breaking new boundaries." ***— Prof. Michael Morris***

"There are various solutions to get to four nanometres but the most promising for very small feature sizes is some form of molecular self assembly and that's what we are doing," says Prof. Morris.

Working with Intel, CRANN is developing carefully engineered polymers that consist of two different blocs—A and B. The polymers can self-assemble into periodic structures, which are transferred onto a wafer. One bloc (A) can be selectively dissolved away, while the other bloc (B) remains as a mask that protects the wafer material during etching.

"We can create patterns at the moment of down to about five nanometres and we have electrically characterised them," says Prof. Morris, who explains that through a transfer agreement Intel can examine the findings and decide if the company wants to move forward with it.

The ongoing relationship between CRANN and Intel involves close contact between researchers at Trinity and UCC both with Intel Ireland in Leixlip and also Intel's research group in Portland, Oregon.

And it's not only CRANN's research background and expertise that is seen of value, it's also the facilities, as Prof. Morris explains: "To some extent we can do most of the things they would like to do within our own clean rooms, we can test things out and prove the technology."

Overall the engagement with Intel offers valuable insights for the CRANN researchers, highlighting areas where industry has an interest and also how research knowledge gets developed and transferred, he adds.

From an Intel perspective, the relationship with CRANN offers the benefit of expertise in new areas, as well as building up local competence in the area of nanotechnology.

"It does add a lot of value to Intel," says Leonard Hobbs, Head of Research at Intel Ireland in Leixlip. "When Intel is interested in a new topic it needs to go and get expertise on that. And the way we start is to go to best university we can find and we work with them and learn about the technology."

That learning phase is where the collaborations with CRANN stand at present on the emerging technologies of self-assembly (with Prof. Morris) and magnetic spin (with Prof. Michael Coey at CRANN and Trinity College Dublin).

And while the relationship between Intel and CRANN has been building for several years, in the research timeline the collaboration is still relatively new.

"When you are working with Intel you are working with the most advanced manufacturing company in the world in semiconductors so your stuff really has to be world class," says Hobbs.

"And even locally, connecting the research with the right people with Intel and making that link with the internal decision makers and roadmap takes time as well."

However, it's time worth spending for Intel Ireland, according to Hobbs.

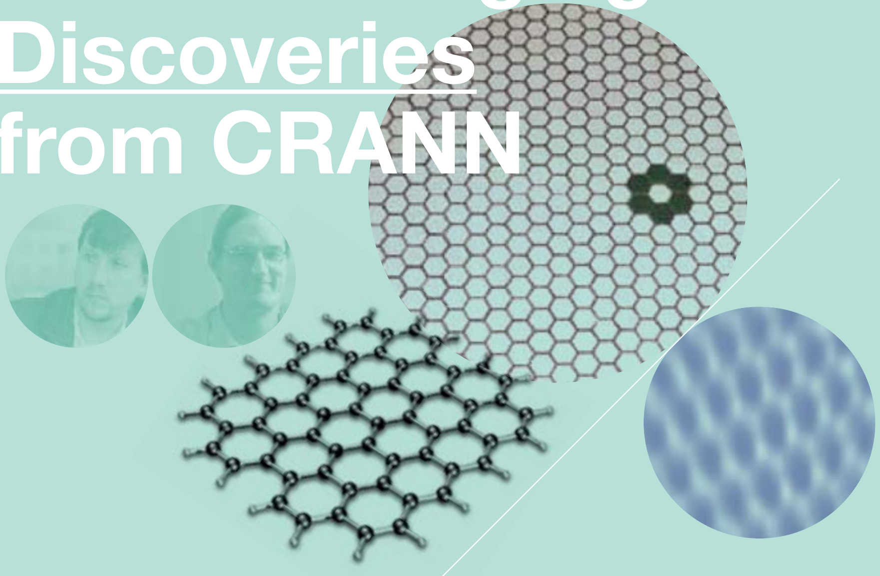
"We also use the programme to develop our own people internally—I have five people seconded to CRANN, learning about advanced technologies. This provides Intel Ireland with a unique opportunity to gain an insight into and contribute to technologies which one day we might use in high volume manufacturing at Leixlip. The programme also enables us to contribute positively to the academic community in Ireland and Europe while establishing meaningful collaborations with our Intel colleagues in Portland Oregon who own the future technology decisions for the company.

A nanotechnology cluster is developing in Ireland through the expertise being built up at Intel, CRANN, Tyndall National Institute, Dublin City University and University College Dublin, according to Hobbs, but he cautions that it's not an area where anyone can rest on their laurels.

"In this industry you can't stop, you have to be constantly innovating and researching, looking for new things, breaking new boundaries," he says. "You have to be out there all the time trying to get ahead and stay ahead of industry and developing roadmaps for industry to follow."

Overall the engagement with Intel offers valuable insights for the CRANN researchers, highlighting areas where industry has an interest and also how research knowledge gets developed and transferred.

Game-changing Discoveries from CRANN



"It was one of these rare cases where you try this really beyond the end of the envelope experiment and it works for the first time. We were rather pleased there."

— Prof. Jonathan Coleman on generating large numbers of graphene sheets in a liquid

A scientific breakthrough can do many things. By definition, it advances human knowledge about the universe we live in. By its nature, it can also raise new questions to ask and flag new avenues to pursue. And sometimes, getting a new and fundamental insight can be a game-changer in industry.

Two recent discoveries by CRANN researchers tick all three boxes, highlighting how basic research can hold the potential for economic consequences, particularly for scaling processes in industry.

One discovery centres on how to harness graphene—a material of such significance that the Russian scientists who isolated the atom-thick sheets of carbon were catapulted from published experiment to Nobel prize in just six years.

We are all familiar with a form of carbon called graphite, the 'lead' in pencils. Graphite is made up of two-dimensional layers of graphene, and since the 1940s it was believed that those chicken-wire-like sheets of carbon could not exist in isolation, according to Prof. Johnathan Coleman, a CRANN Principal Investigator and an Associate Professor at Trinity's School of Physics.

"It was thought that if you took a sheet of graphene away from the graphite crystal that it would just fall apart, and there were good thermodynamic reasons to believe that," he explains.

That changed when Andre Geim and Konstantin Novoselov managed to peel individual and stable layers of graphene from a crystal of graphite using adhesive tape.

"They showed that graphene could exist and they went forward to show that it could be useful in loads of different areas," says Prof Coleman.

Those areas include electronics, photonics and making lighter, greener plastics—but the key is to be able to generate large numbers of graphene layers.

"It's the most exciting material that the 21st century has shown up," says Prof. Coleman. "But the problem was that the people who were making graphene at the start were making one layer at a time. They were developing methods to peel individual layers of graphene off a crystal of graphite. And companies like Intel are never going to make an electronic product based on making one thing at a time, they work with billions of things at a time."

Prof. Coleman's lab was looking at how to separate carbon structures called nanotubes (which are like cylindrical, rolled sheets of graphene) and had worked out how this can happen in certain liquids.

"The nanotubes bind more strongly to the solvent than they bind to each other, so it's favourable to them to be surrounded by solvent than surrounded by other nanotubes. We showed this experimentally and critically we worked out the theory behind it," he explains.

"The theory suggested that the same thing should apply to graphene and the theory told us exactly how to proceed and how to exfoliate the graphite to give individual sheets of graphene, not by the one or two but by billions at a time."

So the CRANN team tried it out in the lab and characterised the graphene sheets that were produced.

"It was one of these rare cases where you try this really beyond the end of the envelope experiment and it works for the first time. We were rather pleased there," recalls Prof. Coleman of the finding, which was published in the journal Nature Nanotechnology in 2008.

"This is one of the major contributions we felt we have been able to make to the field." ***— Dr. Graham Cross on insights into how materials behave when imprinted at the nanoscale***

Being able to produce graphene in a liquid is key, he adds, because it offers opportunities to scale and apply in industry.

"Once you have the graphene flakes dispersed in a liquid, you can make loads of things really easily," he says. "You can make thin films of just overlapping graphene sheets from solutions—thin conducting transparent films are immediately possible and we have done that."

Prof. Coleman's lab has now secured funding from the European Research Council to apply the solvent-based technology to separate other important materials into individual layers.

Another CRANN breakthrough relates to scaling of processes from the micro to nano-scale, and has boosted our understanding of how polymers react to 'nano-imprinting', or stamping patterns into the surface of materials at the nano level. "It's basically a nanoscale version of traditional embossing processes. It's rapid, it allows you to pattern over large areas, and it allows you to do that all the way down to the molecular scale," explains Dr. Graham Cross, a CRANN PI and a lecturer at Trinity's School of Physics. "You start with a target material and then you push a pattern stamp in, which causes deformation and if everything goes well you get replication in negative relief."

However, things can go wrong, particularly where the flow of the target material is incomplete or uneven, and Dr. Cross and CRANN PI Prof. John Pethica have been looking at how polystyrene target material reacts to the nanoimprinting process.

They looked at the viscous response to the 'squeeze flow', which determines how quickly the imprinting can happen effectively, and saw a difference between the reactions of thick and thin films that they didn't expect, recalls Dr. Cross.

"The viscosity starts to drop off with the size of the molecules, it is very surprising, so it can be easier to squeeze a big molecule into a small gap than into a big one," he says. How can this be? It appears to be down to fundamental changes they saw in the topological layout of polymer chains.

Usually the target polymer material is like spaghetti, and in thicker films it must move by a special kind of "snake in the grass" motion. The molecules get tangled up and are hard to move, says Dr. Cross.

"But when you drop down to the thin films you lose the three-dimensional layer and the molecules can no longer entangle and they sit there as blobs and they are easier to move," he notes.

The findings were published in Science in 2008, and an accompanying piece noted that "how this problem unravels is not only a scientifically intriguing question, but is also of technical relevance as manufacturing processes such as [nanoimprint lithography] evolve to fabricate nanoscale features from relatively gigantic molecules".

The CRANN research increases our understanding of the physics of such scaling, and how the reaction of the target polymer alters with thickness, says Dr. Cross. "This is one of the major contributions we felt we have been able to make to the field."

At the Crucial Interfaces of Medical Technology

Understanding how materials work and react with the body at the nano level stands to revolutionise medical devices—and **CRANN** is helping Irish and international companies to look up close at the surfaces that matter.

Think about it—you or someone you know has most likely benefited from a medical device. It might be a stent that props open a narrow artery to allow blood to flow through it, an artificial joint that restores mobility or maybe even a diagnostic device, like a home-pregnancy test that delivers news which will change a family.

In all these cases, the surface matters. It's the layer of material that interacts with the body or biofluid, and how it functions can make the difference between the device functioning well or poorly.

CRANN understands those surface materials right down to the nano level, and in recent years the Centre has been engaging with companies in the medical technology sector, offering solutions right along the device research and development pipeline.

To set up such collaborations means CRANN representatives literally get on the road and meet with prospective partners, evaluating their needs and how to match them with available expertise, explains Dr. Chris Keely, CRANN IP & Commercialisation Manager.

"The projects vary in size and scope and we try to configure CRANN to suit their requirements—that may be for training and R&D, or other projects may be more product-focused. We promote CRANN as being a toolkit of resources medical device companies can apply to their technical needs—that we have the people and the technologies," he says.

"We identify what their objectives and challenges are and then we go back to CRANN and see if we can address them. We also identify what schemes will help support the collaboration—it's mainly innovation partnerships through Enterprise Ireland or Science Foundation Ireland funding."

Many of the projects focus on the nanostructures of surfaces, and in some cases how agents such as drugs or biological markers adhere to them. The approaches that CRANN takes with partners can be about pathfinding as well as building practical demonstration systems to inform development of future products, explains Dr. Keely.

"A lot of the projects we are focused on are about enabling the medical devices industry to do something," he says. "Some of these companies are not looking for a product next year, they are looking to understand the technology at a deeper level. And some cases it could also reveal whether there major show-stopper for the technology early on."

The fundamental knowledge and expertise at CRANN offers flexibility to meet the emerging demands of the medical devices industry. Meanwhile, engaging with companies helps CRANN to better identify and align its expertise with what industry really wants, according to Dr. Keely.

"One of the key things we have learned about the medical devices industry is that you have to be on their roadmap to make an impact," he says.

"Even if you have a great idea and they all love it, if it's not with their product roadmap or it's not in line with their corporate strategy, with all the will in the world locally you still can't transfer it onto what they are doing."

The recently launched Advanced Microscopy Laboratory at CRANN offers a widely applicable toolkit for industry partners with an interest in surfaces, and medical device companies have been plugging into the facility's world-class instrumentation and technical expertise.

So far the relationships have been building well with industry, notes Dr. Keely. "There have been great results coming out and publications, it's a good validation that what we are doing is world class. We are trying to ensure that people can see what is going on and to open the doors—and we need to be ready to jump when we get the opportunity to work with a company."

The fundamental knowledge and expertise at CRANN offers flexibility to meet the emerging demands of the medical devices industry.

"We promote CRANN as being a toolkit of resources that medical device companies can apply to their technical needs—that we have the people and the technologies."
— Dr. Chris Keely

CASE STUDIES

Boston Scientific

Ireland is a leading global producer of stents, small devices that can be inserted into blood vessels (such as coronary arteries) to help ensure that blood can flow through them. And not only can they physically support arteries, but stents may also be coated with therapeutic agents that are released over time.

Boston Scientific, a multi-national company that produces stents, has a significant presence in Ireland. And while they have their own in-house research and development capabilities in Galway, they are also engaging with CRANN and using facilities at the Advanced Microscopy Laboratory.

Working with Dr. Graham Cross, a CRANN PI and a lecturer at Trinity's School of Physics, the collaboration is looking to characterise the adhesion properties of existing stent coatings and model particular aspects of adhesion.

"The aspiration is that the work they are doing at the moment will inform us for future coatings and stent projects, because the essence of the research they are doing is transferable," says Dr. Fergal Horgan, R&D engineer at Boston Scientific Ireland.

"We are looking at a particular polymer type and a particular stent type, and if they can apply the same criteria, essence and substance from their model to another stent polymer, then that is where the front-end effort is going to be much more applicable for future projects."

Having Trinity and CRANN's expertise and facility in Ireland makes the collaboration more workable, adds Dr. Horgan.

"It's easy to lift the phone to someone who is in the same time-zone as you, and for face-to-face meetings, it is very easy to facilitate the [CRANN] guys coming to Galway or us going to Dublin," he says. "Even for things like publishing data, being able to review things in real time makes it practically a lot easier."

Millipore

Artificial membranes form an integral part of many medical and diagnostic devices, and a project between CRANN and Millipore seeks to improve our knowledge of these important surfaces.

Millipore, a global life science company and a division of Merck KgaA, has a long-standing presence in Cork, and the collaboration with CRANN came about through interaction with Prof Michael Morris, a CRANN PI and professor at University College Cork's Department of Chemistry.

Prof. Morris is also a consultant to Millipore and collaborates with the company on a project, funded by Enterprise Ireland, to develop new membranes and improve the current membrane manufacturing processes.

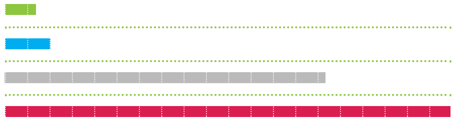
The link with CRANN offers "analytical capability for polymers and membranes which are not readily available" says Dr. Kami Beyzavi, a Technical Manager with Millipore in Durham in the UK.

It's hoped that the eventual outcome of the project with CRANN will include new products and improved processes, he adds.

APPENDICES

FP7 RESEARCH FUNDING AWARDED PER YEAR 2007—2010 (€000'S)

2007	329
2008	485
2009	3,390
2010	4,800



FUNDING DIVERSIFICATION

	ACTUAL 2008	ACTUAL 2009	ACTUAL 2010
SFI CSET Funding	26%	19%	21%
Non-Exchequer/Industry	13%	13%	21%
SFI PI Awards	25%	42%	54%
Other	36%	26%	4%

BREAKDOWN OF 2010 FUNDING

EXCHEQUER INCOME	€'S
Centre Funding	€ 3,797
P I Awards	€ 7,730
Total	€ 11,527

NON-EXCHEQUER INCOME	
International	€ 4,147
Industrial	€ 1,844
Total	€ 5,991

TOTAL	**€ 17,518**

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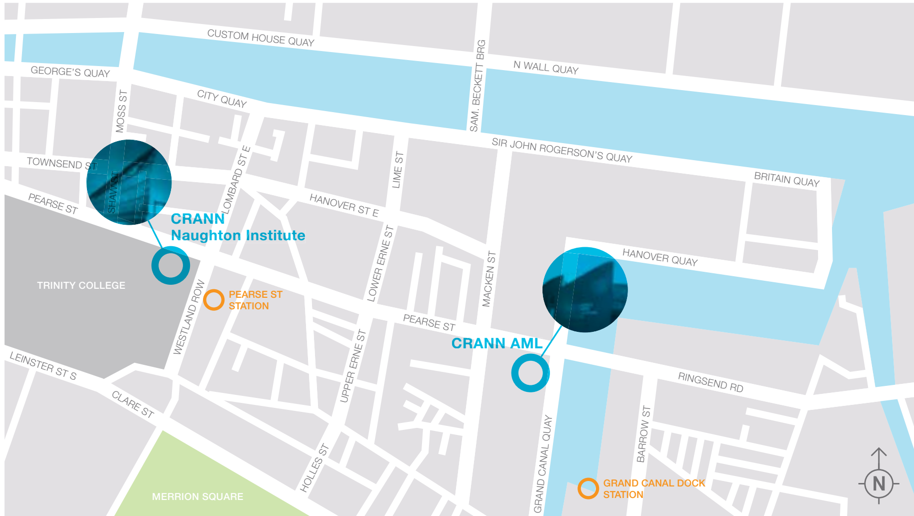

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