



Smart integrated biosensor system

Professor Tony Killard from the University of the West of England is leading a collaborative project to develop and implement smart integrated miniaturised sensor systems

What led to the project's inception?

At the point when I started getting involved in the Organic Electronics Association, I could see the potential for combining the technologies being developed by many of its members with sensors. At that time, nobody was looking seriously at the potential for sensors in this context. I also became involved in the activities of the EU Seventh Framework Programme (FP7), particularly the ICT sector in which

there was a major drive to develop integrated smart systems and smart miniaturised systems employing these technologies.

I chose to perform a relatively simple sensor measurement of either a chemical or biochemical agent, which only required an enzyme, because the concept of integrating all these technologies was sufficiently complex without adding further unnecessary complexity. We chose hydrogen peroxide as we

had a lot of experience with both new sensor materials for its detection and, by extension, developing a cholesterol biosensor, which uses hydrogen peroxide as the basis of its measurement. It was a case of combining the sensor with power, display and control circuitry to make it an integrated system.

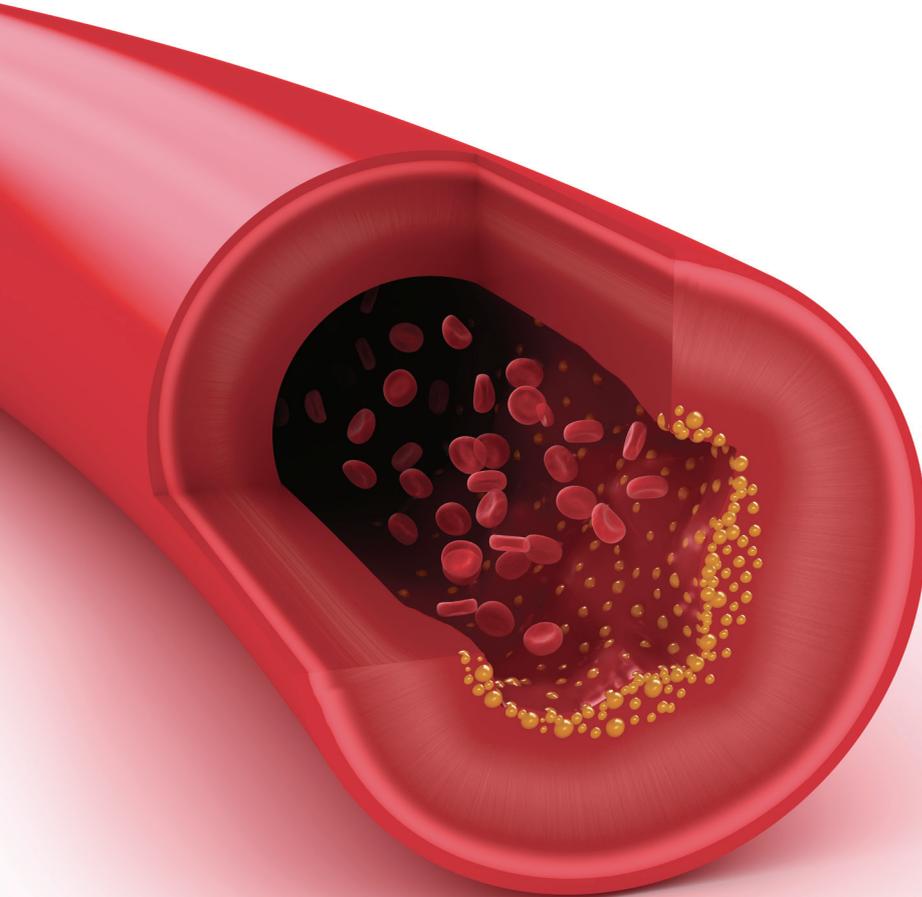
When do you think this product will be market-ready?

There is still a big gap between a laboratory prototype and proof-of-concept to a market-ready device. Its market readiness is therefore better judged in terms of whether we get the right commercial partners to develop and market the technology. Being realistic, even with immediate commercial uptake, you would still be talking at least another three years before a product were ready for the marketplace.

How have you overcome challenges to successfully implement smart integrated miniaturised systems?

Our team is taking a new and imaginative approach to these issues and thinking of new ways of working that would not be typical in microelectronics fabrication. For instance, the organic circuit design needs to be bespoke and cleverly reduced in complexity to meet the minimum requirements of device operation. Similarly, our first choice of display has to give semi-quantitative (rather than quantitative) information to reduce complexity to a level appropriate for the test.

Building in appropriate tolerances and developing new yield optimisation strategies is also being undertaken to overcome the complexity challenge. While our devices are currently approximately credit card-sized, we believe that it will be easy to



shrink device size once we have better understanding and control of these issues.

What are you hoping to be the outcomes and applications of the technology you are developing? How might this technology advance other sectors?

We are entering uncharted territory here. While those of us who push technology can conceive lots of interesting ways our technology could be used, this does not necessarily mean it will be successful. Indeed, the organic and printed electronics (OPE) industry is still emerging and finding how and where its technology can find most benefit. Of course, in the immediate term, there is potential for devices to be used in point of care testing for cholesterol, as well as, for instance, in tests for water quality. However, we will have to perform more extensive clinical and commercial validations of these opportunities to be certain. Such devices would give users and patients greater freedom and control over the testing process. The developing world is an obvious area that could benefit, as these devices don't require any support infrastructure and can be used anywhere and at any time.

Could you outline what aspects of the work give you the greatest sense of accomplishment?

In a nutshell, the greatest achievement for me is to go from conceptualisation to actualisation. Through all the challenges of managing a complex, multi-institutional and multidisciplinary project, it gives you a great sense of achievement that what you conceived so many years ago has, with the hard work and expertise of so many colleagues, been turned into a functioning reality. This is certainly the case with the 'Smart Integrated Miniaturised Sensor' (SIMS) project.

Where are you hoping to next take your research?

The project has been extended to February 2014 and, without giving too much away, I'd like to further combine and integrate what I have learned about the development of biomedical diagnostics and integrated organic and printed electronics to start developing a new range of more complex systems.

We are also looking forward to Horizon 2020 to see what will emerge as the key research topics to be undertaken, and I hope our types of technology will be prioritised as being important for the European economy and society.

Combating cholesterol with organic electronics

Testing blood cholesterol levels requires complex and expensive electronic instruments. However, the development of a new integrated device based on organic and flexible technologies could provide a new alternative

TWO MAJOR TYPES of cholesterol are found in the blood – the harmful substance known as low-density lipoprotein and the protective substance, high-density lipoprotein. Maintaining the right balance of each is essential to help reduce the risk of heart attacks and stroke linked with high cholesterol. According to 2011 figures from the World Health Organization (WHO), cardiovascular diseases are the world's biggest killers, claiming more than 17 million lives each year worldwide.

Cholesterol levels are generally monitored via diagnostic testing, but the optimal monitoring interval is unknown and practice varies. Traditional silicon electronic devices used to carry out these tests are considered highly expensive and inflexible. However, a new collaborative research project currently underway is aiming to develop a new disposable device to provide a more agile and less costly method of monitoring cholesterol levels in the blood.

Led by Tony Killard, Professor of Biomedical Sciences at the University of the West of England (UWE), the Smart Integrated Miniaturised Sensor (SIMS) project is creating a device based on organic and flexible electronics, which can be printed onto flexible polymeric substrates and even paper. These multiple technologies can be fully integrated with components such as batteries, displays, sensors and organic electronic circuits, all combined into a single device. Killard believes that this type of technology will be transformative in where, when and how these tests are performed, and he intends to fully demonstrate the concept with the creation of an integrated sensor capable of measuring a chemical analyte in the form of hydrogen peroxide and a biological analyte in the form of cholesterol.

EARLY RESEARCH

Killard first began examining developments in the field of sensor and biosensor technology back in the mid-2000s. "At that time, I felt that the field had grown a little stagnant from the early excitement and wasn't making the sort of progress I expected," he recalls. During the same period, he became interested in functional nanomaterials, such as conducting polymer nanoparticles and, as a result, identified a number of printing methodologies as an increasingly important means for materials fabrication.

Whilst a great deal of research had previously been undertaken in the field of screen-printing sensors, most of this was focused around conductor materials. Inkjet printing, however, emerged to be a much more useful tool for printing such materials, which prompted Killard to join the Organics Electronics Association. Flanked by a group of industrialists, academics and other specialists concerned with driving the development of organic and printed electronics, he began to see the potential for combining the technologies being developed by others and started to look at the potential for using sensors in this context.

This early work and interest in the field developed into the SIMS project, with its primary focus on building a prototype biosensor system for measuring cholesterol in blood. A collaborative project, SIMS drew upon researchers from UWE, Dublin City University, Fraunhofer ENAS, the University of Liverpool, VTT and Alere, among others, to bring together skills across a number of areas including printed sensors, mobile phone communications interfacing, printed battery technology and organic circuit design and development.

INTELLIGENCE

SIMS

SMART INTEGRATED MINIATURISED SENSOR SYSTEMS

OBJECTIVES

SIMS will develop a smart, miniaturised sensing system through the integration of a nanosensor, printed low-cost display, mobile phone interface and printed battery with organic circuitry. Integration will take place on flexible substrates employing photolithography, screen and ink jet printing and lamination.

PARTNERS

University of the West of England

Alere

University of Liverpool

VTT Technical Research Centre of Finland

Dublin City University

Fraunhofer ENAS

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TONY KILLARD graduated with a degree in natural sciences from Trinity College in 1993 and received his PhD from Dublin City University in 1998. He was appointed Chair in Biomedical Sciences at the University of the West of England and Adjunct Professor at the Biomedical Diagnostics Institute, Dublin in 2011.

Together, the team created a cholesterol detection device comprising a biosensor, power in the form of a printed battery, organic circuitry, a printed electrochromic display, and data communications via mobile phone. Integration activity in the prototype took two forms: the integration of multiple heterogeneous fabrication processes and associated materials such as ink jet printing, screen printing and photolithography; and operational integration of these multiple core technologies into a next-generation miniaturised smart system using organic circuits.

The group used this combination of technologies to perform the semi-quantitative measurement of cholesterol. Now in the mid-stage of development, the team has developed an operational prototype that successfully integrates all components minus the organic circuit, on which the team is still working diligently to achieve effective encapsulation.

To date, Killard has been able to test the model with a silicon analogy of the organic circuit and, in his own words, "things are looking good". The project has successfully demonstrated the quantitative measurement of the generated hydrogen peroxide and, on the back of this, has entered an international competition with the prototype, and are awaiting the results this summer.

CHALLENGES

Despite the SIMS early successes, the world of organic materials and printing is a far less precise and reproducible than that of the crystalline materials and photolithographic processes of silicon electronics, and several challenges must still be overcome. Organic and printed materials are less predictable and therefore not as easily miniaturised. Additionally, the properties of these materials mean that there is greater

Multidisciplinary melting pot

SIMS brings together experts in:

- Printed sensors
- Printed battery technology
- Mobile phone communications interfacing
- Organic circuit design and development
- Electroanalytical chemistry
- Materials science
- Device physics
- Production design and engineering
- Electronic and software engineering

variation in their behaviour – the effects of which, for now, must be cleverly designed out of the circuitry to achieve effective functionality. Some of the materials are also very sensitive to oxygen and water vapour and so require rigorous encapsulation and isolation from the atmosphere. To overcome these challenges, SIMS is developing innovative circuit design and fabrication strategies, as well as novel and effective encapsulation techniques.

NEXT STEPS

Moving forward, SIMS will further examine the ability of organic electronic circuits to drive analogue electrochemical sensor devices for quantitative measurement, which requires a higher level of reproducibility than currently achievable. This will be done with a more advanced prototype that will integrate with the organic circuit. Once this is operational, Killard intends to prepare a fully functional prototype for the semi-quantitative measurement of cholesterol.

As the project advances, achievements may not be restricted to the measurement of cholesterol levels. Indeed, Killard foresees SIMS extending beyond its original aims and intentions: "SIMS will be most important in demonstrating what is possible with this type of technology, even if its application ends up being quite different to that envisaged here," he explains. "I could draw the analogy of the early personal digital assistants (PDAs) and smartphones that were revolutionised by Apple, not because they were especially technologically different, but because they had been more effectively targeted at the consumer. We will have to learn how to do that with organic and printed electronics technologies."



Current prototype of the SIMS device exhibited at LOPE-C in Munich, June 2013.

