Institution: Liverpool John Moores University

Unit of Assessment: 13 Electrical and Electronic Engineering, Metallurgy and Materials

a. Context

The main non-academic users of the unit's research include semiconductor and instruments manufacturers (examples: Samsung, Intel, Keithley Instruments), IP-driven circuit designers (Arm Ltd, Cambridge Silicon Radio (CSR) Ltd.) and manufacturers of electric machines, variable-speed drives, and power electronic components and converters (Infineon, Asea Brown Boveri - ABB, Moog).

The main types of impact, relevant to the unit's research are: i) contribution to new product development; ii) improvement of existing products, for example, by extending functionality, reliability and lifetime, or by introducing appropriate novel control algorithms or structures; and, iii) improvement of efficiency, for example, by reducing test time through new techniques, or by improving the design/control of a system and by developing novel loss evaluation techniques.

The unit consists of two research groups, 'Microelectronics' (RG1) and 'Electric Machines and Drives' (RG2). RG1 specialises in testing and qualification of new materials, processes, and device structures. Its main activities are development of new test techniques and research into defect mechanisms and reliability issues in future generations of mainstream technologies, CMOS and Flash memories. The principal collaborators are:

- IMEC, the Inter-University Microelectronics Research Centre in Leuven, Belgium. IMEC is a research and development centre that has most of the world's leading semiconductor manufacturers as its core technology partners. The principal IMEC consortia with which RG1 collaborates are the Memory Devices Consortium and the Logic Devices Consortium.
- Keithley Instruments, a US company based in Cleveland, Ohio. Keithley Instruments is a world-leading supplier of test equipment, particularly noted for its popular 4200 series.

RG2 specialises in advanced control schemes for power electronic converters, variable-speed electric drives and wind electric energy generation systems, with an emphasis on multiphase systems (systems with more than three phases) and reduced-cost power electronic solutions for multi-motor drive systems. The main industrial collaborators are currently ABB-Switzerland and Infineon-Germany in conjunction with the EPSRC project "Vehicle Electrical Systems Integration" (EP/I038543/1), where RG2 is working on novel solutions for on-board integrated EV battery chargers using multiphase machines and power electronic converters.

b. Approach to impact

The main mechanisms, employed by the unit to develop impact from the research, are: i) direct collaboration with industrial partners; ii) collaboration with industrial partners on externally funded research projects (e.g., EPSRC); iii) prioritisation of the allocation of internally available resources; and iv) presentation of the unit's capabilities and current research ideas to industrial partners at various user-oriented meetings, in order to develop research projects of potentially high relevance to industry and high impact. This is accompanied by the wide dissemination of the main research findings in the high quality research journals, thus enabling worldwide access to the results and maximising the potential impact.

The types of impact, discussed in section a), the main employed mechanisms, and the links to research are best illustrated with the following examples:

- Contribution to new product development: the EPSRC project "High permittivity dielectrics on Ge for end of Roadmap application" (EP/I012966/1, £462k; collaborators include ARM Ltd, IMEC, SAFC Hitech, Umicore Electro-Optic Materials; 01/04/2011-30/09/2014); new techniques for material and process selection (IMEC; 01/2008-07/2013, the case study 1); new analysis method for device variability (IMEC; 08/2011-ongoing); new open-end winding and multilevel multi-phase drive structures; new on-board integrated battery charging systems for EVs (EPSRC project EP/I038543/1, ABB-Switzerland and Infineon-Germany; 01/10/2011-30/09/2015).
- Improvement of existing products: new mobility measurement technique for Keithley 4200 analyser (the case study 2; 07/2010-07/2013); new lifetime prediction techniques (IMEC; 01/2008-01/2010); new method for device lifetime enhancement (01/2009-01/2013); winder

drive systems (KTP under development during autumn of 2013 with Cygnet-Tex-Web, part of Cygnet group).

- Improvement of efficiency and reduction of cost: simplification of test procedures (Keithley, 07/2010-07/2013; the Logic Devices Consortium at IMEC, 01/2008-01/2010); cheap test set-up (Keithley, 07/2010-07/2013); reduced test time (the Logic Devices Consortium at IMEC, 01/2008-01/2010; Keithley, 07/2010-07/2013); reduced-switch-count inverter topology for two-motor three-phase drives; improved switching loss evaluation in multiphase drives.

In order to support these industrial initiatives, the School regularly reviews and prioritises its allocation of resources, including funds for capital equipment. For example, the variability of nano-meter devices is becoming a threat to circuit design and the UK has a growing industry in this area. To position the unit in this field, £200k of research infrastructure funding has been invested in equipment by the School/University during the REF period and a new lecturer was appointed in 2012, leading to the award of an EPSRC research grant in July 2013 (EP/L010607/1, £517k). Similarly, remote offshore wind farms have been identified as a future research area for multiphase generator applications. To enable this research strand development and industrial collaboration, the School has invested over £100k in the grid emulation equipment, power electronic converters and instrumentation, and a new member of staff was appointed in 2013.

The engagement with key users takes various forms. These include industrial steering groups within externally funded projects, regular project progress meetings, preparation of reports for industrial partners, and presentations at various industry-oriented events. For example, the major semiconductor manufacturers (including Intel, Infineon, and Samsung) have formed the Memory Devices Consortium and delegate senior researchers to IMEC to carry out joint research. Through participation of the unit's researchers in the progress meetings organised by this Consortium (details in the next paragraph), the interaction with users, feedback on the research, and approach to impact are direct. Similar applies to the EPSRC-VESI project EP/I038543/1, where the unit's academics and the industrial partners regularly attend three-monthly project meetings and there is therefore a regular exchange of ideas and the feedback from the users. Researchers of the unit have also undertaken a number of engagements directly with the users through presentations of current research activities (e.g., RG2 staff in the Basque Chamber of Commerce, Bilbao, Spain, 2012; RG1 researchers at IMEC with participation of Intel, Micron, Samsung, Toshiba, SanDisk, etc. on ten occasions in the period 2011-2013).

The interactions and relationships of the unit with industrial collaborators since 2008 are evidenced by existence of formal collaboration agreements signed by the University and industrial partners (with Keithley Instruments, June 2010 and April 2013; with IMEC's business department, August 2009 and May/June 2012); secondment of the University staff (six months in 2008, six months in the first half of 2014) and PhD students to IMEC (three six-monthly stays in 2010, 2011, and 2012); test samples supplied by industry and other in-kind support for EPSRC projects in the REF period; statements and supporting letters from industrial partners; presentations from the RG1 and RG2 researchers at regular project progress meetings; the industrial steering groups and collaborations in EPSRC funded projects; joint publications with co-authors from industrial collaborators (e.g., ABB, Infineon, Keithley Instruments); and presentations by the unit's researchers at various industrial forums.

The evidence to prove the follow-through from the unit's activities to the resulting impact is in place. For the case studies, it includes statements from industrial partners, the links from partner's website, and highlights from partner's newsletters.

Through direct engagement with world-leading organisations, the unit constantly monitors the latest industrial needs and technology trends. New opportunities are regularly evaluated for new research directions and used in the project formulation. As explained, the agile approach is also supported by the School's staffing policy, priority equipment resource allocation, and secondments. The other mechanisms used in the unit to enable staff to achieve impact from their research are the support for travel expenses to attend meetings with industrial partners, and time allowance for staff to explore potential for achieving impact from the research.

Staff are rewarded for achieving impact through the University's promotional routes. Industrial engagement is a recognised component of academic activity within the conferment

criteria for Professors and Readers in the University. When appointing new academics, priority is given to a candidate's potential and experience in making industrial impact through research.

When undertaking the impact activities, the unit makes use of institutional resources whenever and wherever possible. This includes, for example, University's Research and Innovation Services unit, which has assisted in developing collaboration contracts and in developing Consortium Agreements with industrial partners to cover the IP issues.

c. Strategy and plans

The unit has recognised that the industrial impact plays a central role in the long term viability and vitality of its research. The strategy for achieving impact and impact plan of the unit are based on the following premises:

- Ensure that our research aligns with industrial needs, and use this to select new research projects and inform allocation of School and University resources (staff, equipment and infrastructure) and staff promotion;
- Ensure the relevance of the research to industry by always having industrial partners and steering groups for the research projects;
- Strengthen the links with industry through researcher and PhD student secondment, participation in industrial consortia and project progress meetings;
- Be agile and proactive in looking for new opportunities by closely following the changing needs of industry;
- Continue to publish research findings in journals/conferences of high industrial relevance and the highest quality;
- Use every available opportunity to disseminate research results to the industry at various user-oriented meetings.

The primary goal in relation to future research in the unit is to grow research combining both high academic quality and high industrial impact. The unit has developed and is implementing a clear strategy during this REF period, as the examples in section b) show. The latest two EPSRC funded projects (EP/L010607/1 in RG1 and EP/I038543/1 in RG2) were selected in areas where the UK has a growing industry of high national importance. The first one includes two major UK companies, Arm Ltd and Cambridge Silicon Radio (CSR for the first time in relation to research in this unit) as the project partners (one reviewer of the proposal commented in the report "The project has been configured to generate impact."). The second one has, in addition to other partners, two global companies (ABB-Switzerland and Infineon-Germany) as partners; their support for the project has been secured through this unit.

The plan is to strengthen the links through the joint projects, to understand the industrial needs in-depth, and then to expand the collaboration by designing more mutually beneficial projects. The long term goal is to form a strong inter-dependence between the unit and industry.

d. Relationship to case studies

Two case-studies (CSs) were selected to exemplify the two types of impact of unit's research: development of new technology/product (CS-1) and improvement of existing product (CS-2).

CS-1 shows how the unit's research contributes to new technology/product development by working directly with the Memory Devices Consortium through secondment of the RG1 researchers to IMEC. Using high-k dielectric enabled the memory industry to develop new sub-28-nm products, but the product qualification was a major challenge due to the lack of techniques for probing the defects within high-k layers. The new pulse techniques, developed by this unit, are powerful and essential tools for quickly comparing and screening materials and processes and were/are extensively used by the Consortium members in developing new memory devices.

In relation to the CS-2, the unit recognised that the existing mobility measurement techniques have a number of shortcomings when applied to the advanced transistors developed by the IMEC's industrial partners. A new technique was proposed and demonstrated by the unit. To maximise the reach and impact, the unit worked together with the Keithley Instruments and: i) implemented it on the standard industrial equipment, and prepared ii) the application notes and iii) the control software. This new technique extends the product functionality and the instrument with this feature is now marketed globally by Keithley Instruments.