MEDEA+ Scientific Committee

Executive Summary – Towards and beyond 2015: technology, devices, circuits and systems

INTRODUCTION

As we move further into the era of nanoelectronics where research into new nanoscale devices becomes ever more expensive, Europe faces formidable challenges.

The European semiconductor industry looks to academia for answers about where it should invest its research budgets, but in reality all parties are aware that no one can provide definitive answers. Not because Europe's academia in any way lags behind the rest of the world. In fact the reverse is true. But because the challenges 'Beyond CMOS' – the point in 2015 when scaling of today's silicon-based semiconductor technology will no longer be possible – are simply too great for anyone to accurately predict which solutions will be workable.

Europe has so far maintained world-class semiconductor manufacturing facilities and its semiconductor research institutes are recognised as some of the best in the world. Many of them are actively engaged in semiconductor research for clients in other parts of the world. However, from industries point of view, the necessary investment in new technology needs to be made five to ten years in advance of commercial returns. It means that the issue today is as much about how to create collaboration models and infrastructures that allow academia and industry to jointly identify commercially viable solutions as it is about developing the solutions themselves.

Even with these collaboration models and infrastructures in place, arriving at conclusions will not only present a technical challenge. The European semiconductor industry has never pursued raw computing power for the sake of it. Where it has excelled, and can continue to do so, is in the application of computing power to societally relevant applications – in areas such as telecommunications, automotive, healthcare and security. Identifying the societally relevant applications of the future will require a dialogue not only between industry and academia, but with all stakeholders in the new Europe – capital, labour, politics and the people.

In short, the solutions that academia proposes and industry adopts must be technically viable, commercially manufacturable and societally relevant.

- ***Create and fund communication channels for dialogue between academia, research institutes, industry and the wider community to elaborate what Europe wants to achieve from nanoelectronics research and to identify relevant application domains***

Towards and beyond 2015

The **'Towards and beyond 2015: technology, devices, circuits and systems'** publication, of which this document represents an executive summary, has been prepared by a Working Group of senior industry, academic and research institute representatives at the request of the MEDEA+ Scientific Committee to address future technical and scientific challenges in the field of micro- and nano-electronics.

However, it inevitably also addresses the consequences for European nanoelectronics research if the European semiconductor industry continues on its path to becoming fab-lite or fab-less.

A fab-lite Europe

A fab-lite Europe would see Europe's semiconductor industry with no large-scale manufacturing facilities for leading-edge CMOS technology – the technology that currently underlies the vast majority of high volume applications for semiconductor devices. All that would be retained are pilot-line and small-scale manufacturing fabs, and even those might not be capable of producing the latest CMOS process generations. The majority of manufacturing would be out-sourced to silicon foundries in other parts of the world, such as Taiwan.

A fab-less Europe

A fab-less Europe would result in there being no pilot-line or manufacturing facilities in Europe for the production of leading-edge CMOS technology. Europe's semiconductor companies would commit their research and development resources to developing applications rather than to staying at the leading edge of semiconductor manufacturing. All manufacturing would be out-sourced to silicon foundries outside Europe.

The consequences for research

Wafer fabs are the only places where academic or research institute innovations in semiconductor technology can be proven in a manufacturing environment. They therefore represent a critical link between technical feasibility and commercial practicality. In today's fab-lite Europe, it is already extremely difficult for research groups in academia to access commercial wafer fab facilities. In a fab-less Europe it will be virtually impossible.

A fab-lite situation in Europe will force European research into the difficult position of trying to realise significant technological improvement without significantly changing the underlying semiconductor technologies and processes. This virtually precludes the likelihood of breakthrough developments. A fab-less scenario will lead to even more extreme consequences for European nanoelectronics research, because it will sever the artery of technology transfer from research into industry. By disconnecting academia from industry, it would only serve to reinforce the 'European Paradox' – that what is invented in Europe does not generate wealth in Europe.

One of the questions that therefore needs answering is 'If Europe goes fab-less, should European academia continue to undertake semiconductor research that attempts to keep Europe on-track with the ITRS (International Technology Roadmap for Semiconductors) as far as CMOS is concerned.' Undoubtedly, those European research institutes that work for semiconductor companies outside Europe will continue to do so, but that does not solve the European Paradox.

Building on strengths

In overcoming this hurdle, Europe's traditional strengths in utilising technology to meet societal needs in areas such as biotechnology and healthcare could be its salvation. Although CMOS is likely to remain the preferred technology for adding intelligence to systems, at least until 2015, many of these future systems will require sensors and actuators to interface with the real world. For example, biosensors used for the early diagnosis of disease will require sensor elements that are no bigger than the biological molecules they are trying to detect, plus microscopic pumps to push body fluids such as blood or saliva over these elements. Such applications therefore represent real challenges in an area of nanotechnology often referred to as 'More than Moore' because it adds functionality that cannot easily be implemented in the CMOS technology that promulgates Moore's law. Applications for 'More than Moore' devices can also be found in mobile telecommunications (for example, in cell phones) – another area of European expertise.

The continuation of Moore's Law for CMOS (More Moore) and the More than Moore domain are not separate. In most applications they are complimentary, with Moore More providing ever increasing processing power and Moore than More providing special functionality that cannot be implemented in CMOS. Together they will allow the application-focused development of fully integrated, highly miniaturised, autonomous systems. Such systems, for example, will lie at the heart of Europe's vision of Ambient Intelligence – environments that are aware of people's presence and responsive to their needs.

However, much of the expertise required to realise the More than Moore functionality in these systems lies outside the semiconductor industry in a diverse collection of academic research groups and small to medium-sized companies working in nanoscience and nanotechnology. Because of the size and dispersion of these groups, many remain invisible to the wider community. Their capabilities therefore need to be identified.

- ***Initiate and fund benchmarking studies to identify Europe's strengths in nanoscience and nanotechnology***

Embracing the ultra-small

Europe's wafer fabs are already producing 90-nm CMOS chips in volume and are gearing up to start production of 65-nm CMOS in 2007. Test-chips have already been produced in 45-nm CMOS. What it means is that Europe, for the moment at least, is firmly on track with the ITRS.

However, despite being able to use these technologies to fabricate hundreds of millions of transistors on an area of silicon no bigger than a fingernail, there is much more to embracing the ultra-small than merely being able to manufacture it. You must also be able to make it do something useful by turning it into a system.

Essential though it is, and therefore fully worthy of the funding needed to bring it to fruition, current research on pushing CMOS technology to the end of its scaling limits tends to focus on the physics and fabrication of new transistor structures. Not enough research is currently being done in Europe on how to design ultra-complex systems using these transistors. The so-called design gap, the gap between what you can put on silicon and what you can design onto silicon, continues to grow. The situation is worsened by new design issues that arise as a consequence of next-generation process technologies. They include the management of power dissipation, which threatens to increase rather than decrease for future CMOS generations, and the management of process-induced variability in transistor performance, which increases the chances of design error. There is therefore a real need for more research into the 'system-ability' of future CMOS process technologies – the ability to integrate the technology into functional systems.

There is a similarly urgent need to fund research into the system-ability of candidate technologies that may replace CMOS after the year 2015. While some of these will duplicate existing CMOS functionality, such as logic or memory, others are disruptive technologies that could lead to paradigm shifts in the whole concept of computing and will therefore require completely different design flows in order to exploit them in systems.

The extreme levels of system miniaturisation facilitated by nanotechnology also means that in many cases different nano-devices based on different nanotechnologies and processes will need to coexist within the same operating environment – essentially within the same package. This is a significant shift away from traditional systems where functionality is typically separated into different boxes or packages.

In many cases these new nano-devices will be fabricated directly on top of CMOS silicon chips – for example, to facilitate the massive number of parallel interconnections required between biosensor arrays and their associated electronics. It will require a compatibility of materials and processes far beyond those associated with traditional silicon chip manufacturing. The diversity of technologies that will have to be employed in future nanotechnology-based systems will also require multi-disciplinary research and development teams, because it will not be possible to develop different parts of such highly integrated systems in isolation.

Future European research into nanoelectronics and related nano-devices therefore needs to be carefully assessed for the system-ability of its end results in all domains –

for ultimately scaled CMOS, beyond CMOS and hybrid (heterogeneous) system solutions.

- ***Create and fund multi-disciplinary working groups to create and apply metrics for the system-ability (integration capability) of future CMOS generations and related nanotechnologies***
- ***Establish and fund high-level workshops to evaluate and monitor goals, metrics and progress and to redirect subsequent research as necessary***

Investing in nanoelectronics research and infrastructures

If the European Paradox is to be solved such that the fruits of European nanoelectronics and associated nanotechnology research end up generating wealth and employment in Europe, it will be necessary to engage all players in the innovation chain, from academia right through to commercial product/services suppliers.

It will require the establishment of a collaboration model for industry, research institutes and academic institutions that instils confidence in all players that academic research is both relevant and progressing in the right direction for commercial exploitation. Close ties with academia and direct funding of research by industry are characteristic of the collaboration models in America and Japan – currently accepted as two of the world's most successful countries in nanoelectronics and related nanotechnology research. Establishing a similar model in Europe will encourage the European semiconductor industry to invest more heavily in academic research, and the extra funding open to academia via this route will encourage it to focus on technologies that have greater potential for industry. However, despite being a win-win situation for both parties, it is unlikely that this model will come to fruition in Europe without additional 'kick-start' funding at EU level.

With their ability to bring together national, cross-border and EU development funding, plus their ability to incubate highly innovative start-up companies and to draw in major industrial players, the European 'Pôles de Compétitivité' represent one of the most attractive infrastructures for fostering collaboration between academia, research institutes and industry. On top of this, the establishment of a European Research Area (ERA) for nanoelectronics research would be highly beneficial. By defining and overseeing a set of Europe-wide scientific research programmes, an ERA for nanoelectronics could coordinate national and European-level funding, creating a European common market for research and innovation while also avoiding excessive duplication of effort.

For research into ultimately scaled CMOS, where very expensive wafer-processing and test equipment is required, funding needs to be centred around Europe's large semiconductor research institutes. Funding for research into More than Moore devices will need to be more widespread, encompassing universities, research institutes and even small start-up companies because of the specialist application knowledge required and the multi-disciplinary nature of the research.

- ***Create a collaboration model and infrastructure for nanoelectronics and related nanotechnology research that encourages greater industry investment and greater academic focus by exploiting Europe's Pôles de Compétitivité and establishing a European Research Area (ERA) for nanoelectronics***

Investing in education

The long-term future of nanoelectronics in Europe will not only rely on establishing appropriate collaboration models and infrastructures. It will also rely on a continuous supply of fresh new minds to bring in new ideas.

However, the relatively narrow curricula offered by today's university science and technology degrees is unlikely to produce people with sufficient appreciation of the multi-disciplinary issues involved in taking CMOS beyond its traditional scaling limits, or in developing nanotechnology-based More than More devices. Establishing appropriate multi-disciplinary courses is another area where greater dialogue between Europe's producers of intellectual excellence (academia) and its consumers (research institutes and industry) can contribute to delivering the broader knowledge base needed for the future.

Finally, bearing in mind the essential objective of breaking the European Paradox by making nanoelectronics research not only relevant to Europe's societal needs but also to its wealth and employment, it will be important to educate the public about its progress and benefits. In the long-term, creating greater public awareness and demonstrating success will be crucial to securing ongoing funding.

- ***Develop multi-disciplinary education and training schemes covering the More-Moore, More-Than-Moore and beyond traditional CMOS scaling domains***

- ***Create greater public awareness of the societal benefits of advanced nanoelectronics research and industry in Europe***