BRIEFING No.4

ICT

UNIVERSAL MEMORY

Memory is an integral part of information processing devices and is needed for short-term storage such as when computer programs are being executed or text documents are processed. Currently, three main types of memory exist: SRAM offers very high speed at a high cost, DRAM is average in terms of speed and cost, and Flash memory is a low cost, low speed solution for applications that need to retain the data even when power is disconnected. A group of emerging memory devices called universal memory aim to combine all these features in a single device.[1]

Developments in universal memory devices may eventually lead to the introduction of novel memory architectures that offer increased performance, enable smaller mobile devices, and offer novel features in traditional products such as cars or domestic appliances. Nanotechnology is an integral part of emerging memory research as it is becoming increasingly difficult to enhance the performance of current devices by scaling the technology further. It is unlikely that a single technology will emerge as the universal memory technology; however, the developments in this sector will enhance the energy efficiency and performance of memory devices. Currently, the Integrated Circuit (IC) market is dominated by US and Asia based companies. Universal memory and nanotechnology based solutions could provide an opportunity for Europe to gain ground in the sector.

Background

None of the existing memory technologies provide all of the required properties. The largest application area for memory products is computers followed by communication devices (such as mobile phones), consumer products (TVs, cameras, home appliances, etc.), industrial applications, and automotives. Each of these devices require different properties from memory and combinations of currently available technologies need to be used to achieve sufficient performance and price:

DRAM (Dynamic RAM) is the current choice for low-cost RAM. It is rather low cost and high speed but suffers from high power consumption.

SRAM (Static RAM) is the choice for embedded applications e.g. in automotives and cache memories for enhancing the performance of hard disk drives for example. The memory cells are more expensive and less dense than DRAM. The structure enables very high performance with low power consumption.

Flash memory is the semiconductor solution for storage applications; attractive for USB stick drives, mobile devices, and solid state drives. It features low-cost, very high density, and non-volatility. Its disadvantage compared to SRAM and DRAM is speed.

Features in integrated circuits have halved in size approximately every two years (Moore's law) but we are now approaching the size range (~16-20nm) where existing technologies will not be able progress further.[2,3] New technologies, exploiting nanoscale features of different materials will be needed. Most of the technologies considered in this briefing benefit from exploiting nanoscale features to provide higher memory density and performance.

Impacts

Universal memory technologies have the potential to completely change the current memory architectures for home computing, mobile devices, and server or high-performance applications.

All the technologies described offer **non-volatility; that is they retain the data even when power is switched off.** Other required features include **competitive price, higher memory density, higher read/write performance, high scalability, and lower power consumption.** Currently there is no single leading technology that offers all of these features. It is likely that the division between low-cost, high-speed, and non-volatile storage will remain for the coming 10 years; however, these

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Box 1: A number of approaches offer high-speed non-volatile storage

High nano-intensity technologies use nanoscale features for storing information

- Carbon nanotube based RAM[8] (CNT RAM)
- Nanoelectromechanical RAM[8] (NEMS RAM) and Millipede memory
- Quantum dot RAM (QD RAM)

Medium nano-intensity technologies offer high scalability utilising nanoscale features

Use resistive elements for storing information

- Phase-change RAM[1] (PCRAM)
- Resistive RAM[3] (RRAM)
- Conductive Bridging RAM (CBRAM)

Use magnetic elements for storing information

- Magnetoresistive RAM[1] (MRAM) and Spin Transfer Torque MRAM (STT-MRAM)
- Racetrack memory

Low nano-intensity technologies are similar to traditional technology

- SONOS[6] (Silicon-Oxide-Nitride-Oxide-Silicon), similar to Flash
- Ferroelectric RAM[1] (FeRAM)

universal memory technologies will lead to more lightweight and miniature devices with lower power consumption. Most applications currently require combinations of DRAM, SRAM and Flash technology to provide sufficient performance. Universal memory devices may prove to offer lower total costs in the memory system thus making them a competitive option even if they offer slightly lower total performance.

Economic/Industry

According to the Semiconductor Industry Association, the global semiconductor market was $226 billion in 2009 and this figure is expected to rise to $300 Billion in 2010. According to Databeans Inc., the worldwide memory market accounts for $57 Billion or 22% of their estimate of the semiconductor market ($259B). Furthermore, Databeans projects the memory market will reach $99 billion in 2015.

The market share of memory technologies other than the dominating DRAM and Flash is said to be 5% of the total market (Databeans, 2010). The mobile memory market, largely consisting of Flash, and mobile DRAM is expected to grow to $10 Billion by 2011 according to iSuppli but after this the market is projected to remain stable. The largest increase in future memory demand will be in cloud computing and smartphones according to the Global Semiconductor Alliance.

Huge growth can be projected for universal memory technologies in the future due to the potential to offer high performance non-volatile memory for cloud computing and high performance accompanied with low power consumption to the mobile segment. These sectors require novel features from memory technology thus driving the growth of high performance non-volatile memory.

Technology readiness levels

According to expert feedback[10], **RRAM has the greatest potential** of becoming the universal memory but its greatest challenge is that the mechanism behind it is not yet fully understood. **CNT RAM** scores highly in quantitative assessment but due its early development stage it is difficult to assess if it is able to reach the market. Some prototypes have already been built but it may take 10 years for the technology to enter the market. The nanotechnology based approach used in CNT RAM potentially enables very high performance and scalability.

FeRAM's potential lies in its resemblance to DRAM but the technology will probably suffer from the same scalability limits. Basic MRAM technology itself is quite mature but its greatest potential is in the **STT-MRAM evolution** which is another serious competitor. **PCRAM** is already in the market, sold by Micron and Samsung, and the latest achievements indicate it to be highly scalable at least down to the limits of DRAM. Large scale introduction of **QD RAM** will probably still take some years but Freescale will soon introduce their **QD** enhanced RAM, according to expert feedback.

Figure 1 illustrates technology readiness levels and the future scalability estimates of assessed technologies. An estimation of time to market entry or maturation is also given.

In addition to distinct technologies, development in 3D integration techniques may make it possible to further scale current technologies (DRAM and Flash) and decrease the demand for universal memories. On the other hand, experts say that RRAM currently shows great potential for 3D integration.

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Challenges

As with all integrated circuit manufacturing, higher production volumes mean lower costs. So far none of the universal memory technologies are produced in volumes high enough to compete with Flash technology by price. Current Flash manufacturers have invested billions of Euros in manufacturing capacity, which will be used as long as it is scalable.

Technological maturity is another significant challenge as currently there is no universal memory technology that would deliver all required properties. Manufacturing readiness is also a big question. There are major challenges in achieving reliable processes with high yield because the emerging memory technologies are not directly compatible with existing CMOS processes.

Even though some of the most advanced emerging memory technologies have already entered the market, significant technological developments are still needed for them to challenge existing technologies in cost (DRAM and Flash), in speed (DRAM and SRAM) and in memory density (DRAM and Flash). Due to these challenges, it is most likely that the new technology will first break through in a completely new market segment where traditional memories cannot satisfy the market need. Potential application areas include SIM cards, smart cards and sensors (medical, utilities, security, etc.) where novel memory enables more complex calculations to be performed with less energy consumption.

EU Competitive position

Europe's competitive position in semiconductor technology is challenging, but the industry ranks second in the EU R&D intensity scoreboard after biotechnology. Emerging semiconductor technology intersects greatly with advanced materials, nanotechnology, and micro-/nanoelectronics, which are all considered as key enabling technologies at the EU level.[4] Altogether, the semiconductor industry supports over 115 000 direct jobs and up to 500 000 related jobs in Europe.[5]

The European semiconductor market accounts for 13% of a worldwide market dominated by Asia (53%)[4]. In Europe, the automotive and industrial sector account for a proportionally large part of the semiconductor demand (37% vs. 17% on average). This application-oriented approach could provide a competitive advantage and added-value for European companies[5].

The industry has consolidated greatly during the last few years, leading to Europe's share of production decreasing, particularly in the memory sector. EU based semiconductor companies currently account for only 10% of production.

Semiconductor companies with facilities in Europe include STMicroelectronics, NXP semiconductors, Infineon, Numonyx, Altis Semiconductor, Freescale Semiconductor, and Crocus Technology. STMicroelectronics and Intel-owned Numonyx was recently sold to US based Micron. Infineon created a spinoff company from its memory division to form Qimonda; however, they later filed for bankruptcy in 2009. Altis Semiconductor, a former IBM and Infineon joint venture has also suffered from financial challenges and was sold in 2010 to a new owner.

Due to these developments, there are no standalone memory products offered by EU-based companies currently. High expertise and IPR on memory technologies still exists in universities, research organisations, and companies. For instance, European STMicroelectronics, Altis, and Infineon are still developing embedded memory technologies.[7]

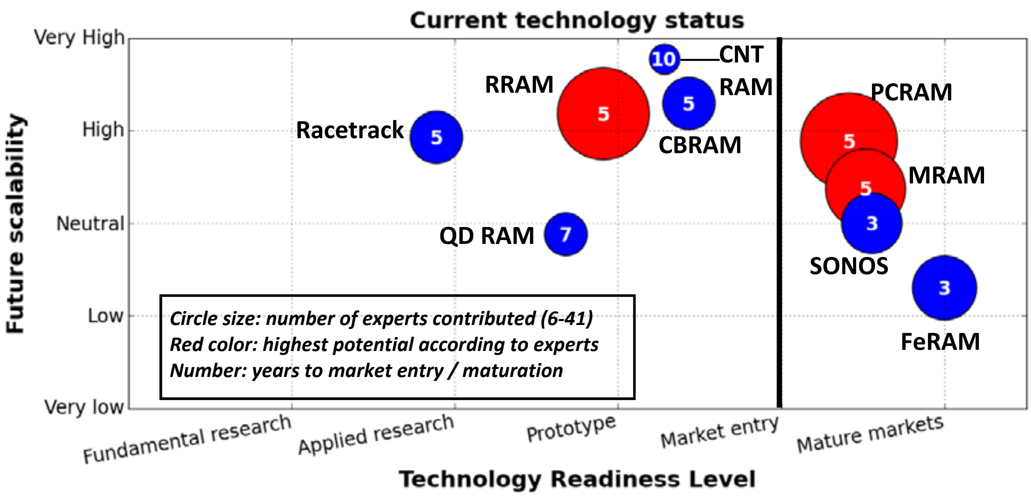

Figure 1: Technology Readiness Levels for Universal Memory technologies

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Micron, IBM and Intel have technology development departments based in Europe and some companies are still fabricating embedded memories in Europe.

The table below demonstrates the dominance of Asian and US companies today on standalone memory products market, which is the largest memory market by revenue.[9]

Company	Based	Flash Q1-10	DRAM Q2-10
Samsung	KOR	38.5%	35.4%
Toshiba	JPN	33.8%	-
Elpida	JPN	-	17.7%
Micron	USA	12.0%	13.3%
Hynix	USA	9.1%	21.5%
Intel	KOR	6.3%	-
Nanya	TWN	-	4.4%
Other	-	0.3%	7.7%
Total	**-**	**$4.36 billion**	**$10.8 billion**

Notable universities and research organisations on universal memory technologies in Europe include IMEC in Belgium, CEA-LETI in France, and Fraunhofer in Germany. Multiple collaborative development projects involving both industry and universities are, and have been, undertaken in the EU. Examples of EU funded projects for memory technology development include:

- GOSSAMER (FP7, 21.5M€, 2008-2010)
- MAGWIRE (FP7, 3.1M€, 2010-2013)
- TRAMS (FP7, 3.4M€, 2010-2012)
- PROTEM (FP6, 9.6M€, 2006-2010)
- CAMELS (FP6, 2.7M€, 2005-2008)
- EMMA (FP6, 4.6M€, 2006-2009)
- NOSCE MEMORIAS (FP6, 4.9M€, 2004-2007)
- FLEUR (FP6, 5.6M€, 2001-2004)

Entering the Flash and DRAM memory market would be very difficult for European players (see table on previous page) and therefore the emerging semiconductor technologies, including universal memory, may enable them to gain market shares. This would require significant investments from both companies and the EU. Furthermore, EU-wide collaboration is required to build a global level playing field.[4] Europe's stature in memory could also be increased by increasing collaboration between the semiconductor industry and companies developing solutions for industrial, automotive and communications applications.

Summary

- No clear winner in the emerging memory segment can yet be identified.
- Scaling down CMOS technology is not possible in future; developments in emerging technologies are greatly needed.
- Cost is the largest barrier inhibiting market share growth of these technologies.
- Investments are therefore needed in all levels of R&D and in manufacturing capability.
- Europe's position in memory technology is challenging — emerging universal memory is a chance to improve the situation.
- Memory is by nature an enabling technology and the concept of universal memory will provide new application possibilities especially in embedded devices and cloud computing.

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[10] Expert engagement and review process with 51 experts