After more than 15 years in development, PCM has finally taken off in stand-alone applications. STT-MRAM will lead the embedded memory race.

**EMERGING NON-VOLATILE MEMORY 2018**
Market & Technology report - November 2018

**WHAT'S NEW**
- Redefinition of embedded market segments, highlighting newly emerging artificial intelligence (AI) applications as well as eDynamic Random Access Memory (eDRAM)/Static Random Access Memory (SRAM) replacement in mobile AP and high-end processors
- Updated market forecast for phase-change memory (PCM), spin transfer torque MRAM (STT-MRAM) and resistive RAM (RRAM)
- Updated analysis of technical trends for PCM, (STT-)MRAM, and RRAM
- Updated analysis of the stand-alone and embedded memory markets
- Updated analysis of China's memory market, and a detailed list of emerging Chinese NVM players
- In-depth analysis of Non-Volatile Dual Inline Memory Modules (NVDIMM) technology and its market
- Analysis of PCM's development history, including the latest news on Micron and Intel's 3D XPoint activities
- Review of materials suppliers and equipment players
- Analysis of 3D XPoint products, and comparison with Samsung’s Z-NAND
- Examination of newly emerging technologies, including Ferroelectric Field-Effect Transistor (FeFET) and Nanotube RAM (NRAM)
- Updated analysis of new entrants and startup funding
- Analysis of memory technologies for artificial intelligence (AI) applications

**EMERGING NVM SALES WILL GROW BY MORE THAN ONE ORDER OF MAGNITUDE IN THE NEXT THREE YEARS, THANKS TO SCM APPLICATIONS**

Ever-growing data generation driven by mobile devices, the cloud, the internet of things (IoT), and big data, as well as novel AI applications, requires continuous advancements in memory technologies. Flash NAND (non-volatile) and Dynamic Random Access Memory (DRAM - volatile) are the stand-alone workhorse options, and will maintain their leading position for another several years thanks to new technical solutions that enable further scalability. However, there exists a large speed-capacity gap between NAND and DRAM, one which must be reduced to improve overall performance of computing systems. Storage-class memory (SCM) serves precisely this purpose and has long been awaited.

Hitherto, emerging non-volatile memories (NVMs) – e.g. phase-change memory (PCM), magnetoresistive random access memory (MRAM), spin transfer torque MRAM (STT-MRAM) and resistive RAM (RRAM) – have been restricted to niche applications because of poor scalability, high cost, and a lack of support from major memory makers. In 2015, Micron and Intel presented a new SCM technology, 3D XPoint, which uses phase-change memory (PCM) materials that the companies researched for more than 15 years. The first 3D XPoint products – Optane™ Solid State Drives (SSDs) and storage accelerators – were introduced by Intel in 2017, and persistent-memory modules (Optane™ Dual Inline Memory Modules (DIMMs)) are expected in 2019. Despite the coming end of the Intel-Micron joint venture (IMFT), Micron has confirmed its continuing strategic involvement with 3D XPoint by announcing its acquisition of Intel’s stake in IMFT, along with plans to introduce its own 3D XPoint products (QuantX™) in 2019.

Over the next three years, 3D XPoint sales will grow by more than one order of magnitude thanks to Intel’s dominant position in the enterprise processor business. Optane DIMMs will be sold in combination with the latest generation of Intel’s Xeon server processors (i.e. Cascade Lake). Moreover, Intel’s new brand strategy for client systems that includes Optane caching pre-installed (Intel Core i+), will support sales growth.

Due to the rise of 3D XPoint sales, SCM is expected to be the dominant application for emerging NVMs in the coming years, reaching more than 90% of the emerging NVM market by 2019.

**IN THE NEXT FIVE YEARS, PCM-BASED 3D XPOINT WILL DRIVE THE STAND-ALONE EMERGING NVM MARKET, WHEREAS STT-MRAM WILL LEAD EMBEDDED TECHNOLOGY**

In the stand-alone business, emerging NVMs will not replace DRAM and NAND but will be used in combination with them inside memory modules, e.g. SSDs, DIMMs, and NVDIMMs. In 2023, PCM will maintain its lead in the stand-alone memory market thanks to the increasing adoption of 3D XPoint as an enterprise and client SCM. It is worth noting that Samsung and Toshiba took a different
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EMERGING NVM PLAYERS WILL USE “TROJAN HORSE” STRATEGIES TO INTRODUCE THEIR TECHNOLOGIES TO THE MEMORY MARKET

In the stand-alone business, emerging NVM brings new features and functionalities, but at a higher price. Thus, new solutions must be found for triggering this NVM’s market penetration. Among big IDMs, Intel has a unique position: it is both a stand-alone memory supplier and a Central Processing Unit (CPU) leader. Intel can combine its 3D XPoint products with its new generation of Xeon processors, which will act as the aforementioned Trojan horse for introducing 3D XPoint into the data-center technology market.

STT-MRAM developers are rather small companies (e.g., Everspin, Avalanche, Spin Memory) that view memory module suppliers (Smart Modular, for example) as the ideal partner for entering the enterprise storage market. These module suppliers are midsized companies inclined to develop niche applications such as MCUs or cache memory. Therefore, it is critical for IP memory companies to convince foundries to be much lower compared to stand-alone PCM due to lower costs, greater fabrication complexity, and challenging scalability.

Compared to stand alone, the embedded emerging NVM market is relatively small, representing ~3% of the emerging NVM market in 2017. The market is dominated today by RRAM, since only a few RRAM-based microcontrollers (MCUs) are available on the market. However, all top foundries are now getting ready with 28/22nm technology processes for STT-MRAM whereas RRAM adoption has been delayed by approximately two years by SMIC and UMC. Therefore, we expect that STT-MRAM will be the first to take-off in the coming years and will lead the embedded emerging NVM market, especially MCUs, which represent the most important embedded segment.

Emerging memory will first replace eFlash, which is facing major scaling challenges due to rising fabrication complexity/costs for technology nodes ≤ 28nm. The adoption of STT-MRAM as an embedded cache memory (SRAM or eDRAM) in high-end processors and mobile AP will occur later due to more strict scalability requirements (≤ 14nm).

AI on the edge is the most innovative application for embedded emerging NVM. Crossbar recently demonstrated various AI applications, i.e. face recognition, through the use of RRAM chips. We expect that such RRAM-based AI devices will enter the market after 2021.

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OBJECTIVES OF THE REPORT

- Present an overview of the semiconductor memory market:
  - NAND, DRAM, NVDIMM, embedded MCU, and mobile AP - main markets, market forecast, and main trends
  - Current technological status and roadmap for the coming years
  - Market landscape

- Provide an understanding of emerging NVM applications:
  - A total of eight application fields - four for stand-alone and four for embedded: total addressable market, market drivers and challenges, technology roadmap, players, main trends
  - Roadmap with time-to-market, by application

- Deliver market forecasts for emerging NVM businesses:
  - 2017 - 2023 market forecast in units, Gb, $US/Gb, and number of wafers
  - Price evolution, by application and technology
  - Forecast for eight applications and three technologies (MRAM/STT-MRAM, RRAM, PCM)

- Describe emerging NVM technologies:
  - Working principle, manufacturing methods, advantages/limitations, development status, price, time-to-market
  - Roadmap with technology nodes, chip-density evolution, and main players
  - Latest product development status for each key market player

- Detail and analyze the competitive landscape:
  - Recent acquisitions and funding
  - Latest company news
  - Recent acquisitions and funding
  - Key players, by technologies and applications

COMPANIES CITED IN THE REPORT (non exhaustive list)


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Yann de Charentenay works as a Technology & Market Senior Analyst for Yole Développement (Yole) working with the Semiconductor & Software division. He is member of the Yole’s memory team and he contributes on a day-to-day basis to the analysis of nonvolatile memory technologies, their related materials and fabrication processes. He (co-) authored more than ten papers in high-impact scientific journals. Simone obtained a PhD in physics in 2015 from École Polytechnique Fédérale de Lausanne (Switzerland), where he investigated novel flash memory cells based on heterostructures of 2D materials and high-k dielectrics.

Simone Bertolazzi, PhD is a Technology & Market analyst at Yole Développement (Yole) working with the Semiconductor & Software division. He is member of the Yole’s memory team and he contributes on a day-to-day basis to the analysis of nonvolatile memory technologies, their related materials and fabrication processes. He (co-) authored more than ten papers in high-impact scientific journals. Simone obtained a PhD in physics in 2015 from École Polytechnique Fédérale de Lausanne (Switzerland), where he investigated novel flash memory cells based on heterostructures of 2D materials and high-k dielectrics.
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