

Collaboration of Giants Brings Great Value

INTRODUCTION

When industry heavyweights join forces, powerful results can happen quickly. Such is the case with the collaboration between IBM and Micron. Over the past year, engineers from both IBM and Micron have been sharing information and collaborating on flash technology, producing a deeper integration between Micron's latest flash chip products and the engineering innovations embodied in IBM FlashCore™ technology. Thanks to the collaborative nature of our relationship with Micron, IBM FlashSystem™ has been able to transition from enterprise multi-level cell (eMLC) flash to Micron FortisFlash™ MLC technology, lowering costs while maintaining industry-leading performance and reliability.

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Micron Technology, Inc., is one of the world's leading semiconductor companies. For more than 30 years, Micron has designed and built some of the world's most advanced memory and semiconductor technologies. Micron collaborates with innovators such as IBM to enable enterprises of all sizes and types to try new things and gain competitive advantage. Through these relationships, Micron is building an ecosystem that promotes connections and co-development efforts that lead to better enterprise storage solutions. High-quality memory and storage are essential components of today's enterprise data centers. This is why Micron is working closely with IBM on flash storage development, integration, and qualification.

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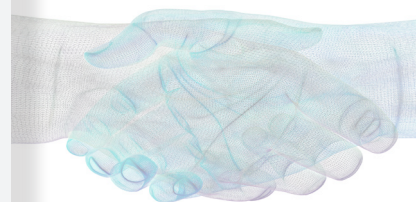


IBM's COMMITMENT TO FLASH

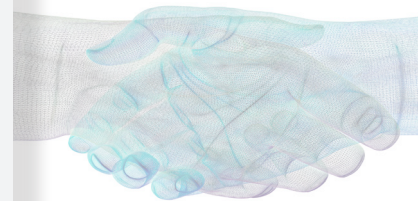
Building on decades of storage innovation and leadership, IBM offers a comprehensive portfolio of integrated, flash-optimized storage solutions to propel organizations into the new era of information technology (IT). These proven, easily integrated flash solutions accelerate critical applications for faster decision making, offer best-in-class reliability, and deliver new efficiencies across the entire business environment for a faster return on investment. IBM FlashSystem storage arrays provide enterprises with the enduring economics and reliability they need for long-term business success.

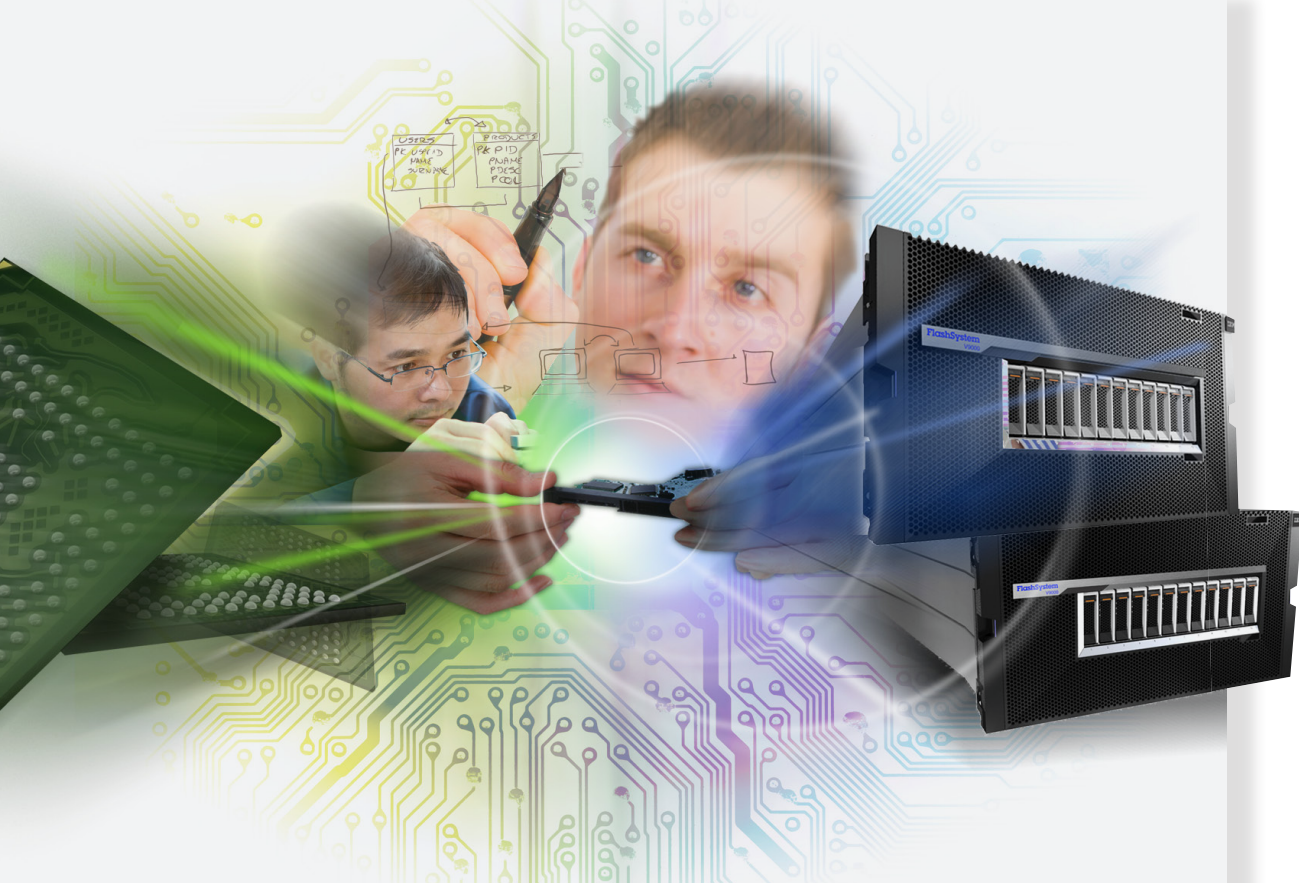
The current IBM and Micron relationship is centered on the IBM FlashSystem family of all-flash storage platforms, including the IBM FlashSystem 900 and IBM FlashSystem V9000 arrays. FlashSystem 900 provides industry-leading performance, reliability, and IBM MicroLatency™ and is designed to accelerate the applications that drive meaningful business insight. Adding to these capabilities, FlashSystem V9000 offers the advantages of software-defined storage at the speed of flash. These all-flash storage systems deliver the full capabilities of IBM FlashCore technology's hardware accelerated architecture, MicroLatency modules, and advanced flash management coupled with a rich set of features found in only the most advanced software-defined storage solutions, including IBM Real-time Compression™, virtualization, dynamic tiering, thin provisioning, snapshots, cloning, replication, data copy services, and high-availability configurations.

- FlashSystem provides industry-leading **performance, reliability, and ultra-low IBM MicroLatency™** and is designed to accelerate the applications that drive meaningful business insight.



For years, IBM has been committed to developing and offering flash-based storage solutions to enterprises of all sizes, from all industry sectors. IBM's relationship with Micron is an extension of this ongoing commitment to flash storage. In 2012, IBM acquired Texas Memory Systems (TMS), a leader in solid state storage array technology. Then in April 2013, IBM moved our commitment to a higher level by announcing a \$1 billion investment in flash storage research, partnerships, product development, and enhancements to flash sales and support infrastructures. As part of that commitment, we opened 12 Flash Centers of Competency in countries such as China, France, Germany, India, Japan, Singapore, South America, the UK, and the US. These Centers of Competency serve as proving grounds where customers can run proof-of-concept scenarios with real-world data to measure the projected performance gains achievable with IBM flash solutions. IBM also significantly increased our flash research and development capabilities at facilities around the globe, from Houston, Texas, to Zurich, Switzerland. It was at these dedicated IBM engineering and R&D facilities, in particular, that the collaboration with Micron occurred.

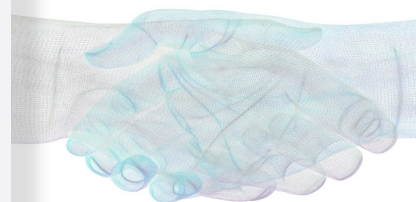




IBM AND MICRON COLLABORATION

From the lowest level storage cell up through the complete die, NAND flash technology exhibits many difficult challenges associated with programming, erasing, and storing data on floating gate transistors. The way in which different manufacturers address these challenges imparts different characteristics to each manufacturer's flash devices. As with any complex engineering effort, many trade-offs are made, based on factors such as cost and the projected use cases for the particular flash product. Some flash products are designed to maximize endurance, while other flash products optimize the length of time a charge can be held before too many electrons leak away from the floating gate and the stored information becomes unreadable.

IBM purchases flash storage media from manufacturers like Micron and then solves the many engineering challenges associated with transforming large arrays of flash chips into products with the speed, endurance, and features required by organizations and applications throughout the world. Creating such products requires managing the particular characteristics of the basic flash storage medium to achieve greater throughput, or higher endurance, or faster data retrieval (lower latency), or lower overall cost. Flash controllers – special-purpose hardware-based processing engines – are incorporated into the product to provide a wide range of flash management functionality. These controllers work together with higher-level general-purpose processors to perform functions such as “garbage collection,” wear leveling, error correction, and many other flash-related management tasks. How – and how well – these controllers manage the basic flash medium determines to a large extent the operational qualities of the storage product. These operational qualities – latency, performance profiles under various loads, reliability, and



certainly cost – are the qualities that differentiate flash array vendors from one another and become the qualities that customers care about.

The interplay between the flash controller, higher-level engineering features, and the basic flash medium thus becomes a major determinant in how the storage array operates, including what features and value it can provide to end users, and what it cannot. This is where the collaboration between IBM and Micron comes into focus.

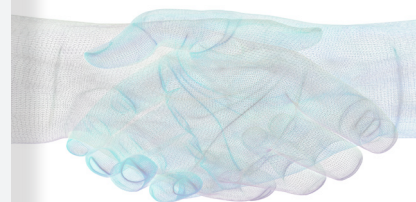
At dedicated labs around the globe, IBM is constantly engaged in testing and evaluating a wide range of components and technologies that may be used in our products, such as FlashSystem storage. Micron's MLC technology provided higher endurance for a given level of errors than other current flash alternatives. This made the chip very intriguing to IBM, not only because of its impressive endurance and performance characteristics, but also because of its overall value.

It is important to note that, contrary to popular belief, the difference between eMLC and MLC flash is not one of quality. The intended use case is also an important consideration. Enterprise use cases demand the highest possible endurance, because enterprise applications are often characterized by the repeated writing and rewriting of data, which translates into a large number of program and erase (P/E) cycles to the individual flash chips, causing flash cells to degrade until they eventually become unusable. Over the past decade or so, a tremendous amount of very innovative engineering has focused on flash controller technologies to optimize the useful life span or endurance of flash chips.

On the other hand, consider a classic MLC use case, such as a flash memory card for a camera. The card may not be exposed to a very large number of P/E cycles throughout its life; it may be thrown into a desk drawer for months or even years with no power applied to the flash or to its associated controller. This latter case is a good candidate for MLC flash, which is optimized for data retention instead of endurance. As it turns out, MLC offers attractive cost advantages over eMLC.

The IBM enhanced Micron MLC technology offered the best of both worlds – the value of MLC with the endurance of eMLC flash, while also meeting the high performance requirements of the next generation of IBM FlashSystem products. IBM and Micron recognized the benefits of a closer collaboration and moved forward, sharing engineering resources and specific technology expertise.

The key to making Micron FortisFlash MLC technology work in IBM FlashSystem products was to very tightly integrate or "tune" the FlashSystem controllers and other flash management functions embodied in IBM FlashCore technology with the particular operational characteristics of Micron's product, then optimize



performance to enterprise use cases while also realizing the cost advantage of increasing the density. IBM was able to achieve exactly this objective, with stunning results. Our engineering collaboration with Micron was certainly one of the main factors enabling this achievement, but another factor also played a very important role – the inherent and advanced capabilities and resiliency of IBM FlashCore technology.

IBM FLASHCORE TECHNOLOGY

IBM FlashCore technology refers to the IBM innovations that enable FlashSystem storage to deliver extreme performance, IBM MicroLatency, enterprise-grade reliability, and a wide range of operational and cost efficiencies. These technologies and innovations are represented in FlashSystem hardware-accelerated architecture, IBM MicroLatency modules, and many other advanced flash management features and capabilities. IBM FlashCore technology truly defines FlashSystem and contrasts it against competing all-flash appliances and hybrid storage architectures. Most importantly for this particular story, FlashCore technology enabled IBM to leverage the powerful characteristics of Micron MLC technology to create an industry-leading enterprise storage solution.

IBM FlashCore technology lies at the heart of IBM FlashSystem storage. Fundamental to this technology is the concept of hardware-accelerated input/output (I/O) management – redundant backplanes, non-blocking crossbars, advanced switch fabrics, hardware-based encryption/decryption, and largely hardware-based RAID controllers – to deliver very high performance with the data protection features essential to a modern enterprise-class storage device. Advanced flash management features include Variable Stripe RAID technology, unique IBM-engineered error correction codes, overprovisioning capabilities, ultra-fast write buffers, and hardware-based data offloads. Advanced flash media wear leveling and garbage collection techniques ensure that FlashSystem data integrity is preserved, write endurance meets enterprise requirements, and performance is maintained even while using IBM enhanced Micron MLC technology as the storage medium. Additionally, all FlashSystem products support concurrent maintenance and concurrent code updates with minimal performance impact.

Because the engineering embodied in FlashCore technology is so strong and yet so flexible, it enables IBM to incorporate a new basic component – Micron FortisFlash storage – into FlashSystem with absolutely no compromise in system performance or reliability, all the while taking full advantage of the chip's extremely attractive density and cost benefits.

Key Features of IBM FlashCore Technology

Hardware Accelerated Architecture

- Engineered for Flash
- Hardware RAID
- Non-blocking Crossbar Switch
- Hardware-only Data Path
- Single Box Highly-available Architecture

IBM MicroLatency Module

- IBM Engineered
- Massively Parallel Design
- FPGAs in the Data Path
- Distributed RAM
- High-speed Interface
- Line Speed Data at Rest Encryption

Advanced Flash Management

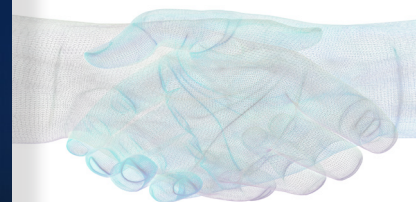
- IBM Variable Stripe RAID
- IBM Engineered ECC
- IBM Optimized Overprovisioning
- Advanced Wear Leveling
- Write Buffer & Hardware Offload
- Adaptive Garbage Collection

CUSTOMER VALUE

The collaboration between IBM and Micron brings value to enterprise storage customers in many ways. Obviously, a chief benefit involves IBM FlashSystem deployment costs. Traditionally, storage costs were only evaluated on the single basis of dollars per capacity. As the marketplace becomes more informed, and as flash storage captures a larger market share, storage cost evaluations are growing more nuanced. Nonetheless, traditions persist and the initial capital investment in IT infrastructure still plays a crucial role in customers' purchase decisions. IBM and Micron certainly understand this. By working together, the two industry leaders have increased FlashSystem storage density and thus value over prior generations. Recent research by independent analysts suggests that IBM FlashSystem already costs significantly less in terms of initial dollars per terabyte than our chief competitors. Thanks to the IBM/Micron relationship, this trend will continue.

The IBM enhanced Micron FortisFlash MLC storage with IBM FlashCore technology brings other benefits. Although it may seem counterintuitive, incorporating Micron flash technology has actually enabled IBM to increase the reliability and endurance of FlashSystem storage. In order to facilitate flash management functions such as wear leveling (spreading data evenly among flash cells to increase flash life) and garbage collection (reclaiming flash capacity by aggregating valid data in the flash chips), every flash storage product designates some amount of its otherwise usable flash capacity to support these management functions. This "overprovisioning" adds cost to the overall product, because customers pay for storage capacity that cannot be used to store their data. This drives one of the classic flash storage engineering trade-offs between controlling costs and enabling vital management functions that deliver higher performance and reliability. Every enterprise flash storage vendor settles on the ratio of "raw" to usable

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capacity that best meets their objectives. One outcome from the collaboration with Micron is that the IBM FlashSystem ratio of overprovisioning has gained added flexibility, because flash media cost constraints are not quite as severe as they once were. IBM engineers have used this added flexibility to increase the endurance and reliability of FlashSystem storage.

Finally, credit should be given where credit is due. IBM's dedicated R&D teams deliver the real value that enables the use of Micron's revolutionary flash. Our unique Error Correction Code (ECC) provides an excellent example. As part of our FlashCore technology, we use our own ECC "hard-decision" algorithm to deliver very high correction strength with lower processing overhead compared to "soft-decision" algorithms. Soft-decision ECC logic is very complex and thus adds significant latency and significant controller cost to systems that employ it. Hard-decision ECC schemes have traditionally been viewed as less robust for a given level of capacity overhead, but IBM R&D efforts have resulted in a very resilient hard-decision ECC scheme that allows for much better performance with less processing overhead/latency. The overall result is that IBM can incorporate Micron technology and still utilize our own unique error correction solutions to drive up performance, reliability, and throughput while driving down complexity and cost.

CONCLUSION

Because two industry giants are working together to get the most out of flash storage, enterprises and consumers around the globe will reap tangible benefits. Deeper data analytics. More secure and convenient online shopping. Quicker cyber fraud detection and reaction. Better distribution, management, and protection of medical records. Mike Kuhn, IBM FlashSystem Business Line Executive, sums it up best:

"Micron is an innovator in flash technology and is collaborating with IBM on next-generation IBM FlashSystem products. Through this relationship, IBM has been able to enhance the capacity, performance, and reliability of our FlashSystem arrays. This collaboration between industry leaders will enable enterprises of all sizes around the world to benefit from the power and cost savings of fully integrated and highly optimized all-flash enterprise storage solutions."



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