SiliconMotion

WHITE PAPER

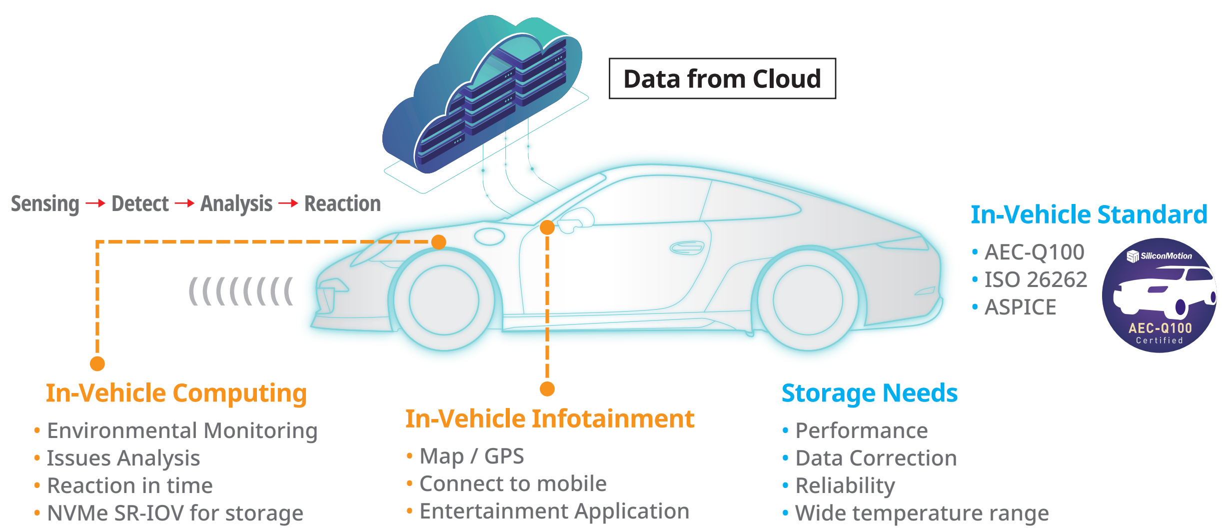
Silicon Motion's Ferri Family

AEC-Q100 Qualified Embedded Storage

How the latest NAND Flash-based storage devices achieve high reliability in high-temperature automotive applications

With the introduction of every new generation of passenger vehicle, the automation, safety and navigation systems become more sophisticated. Supported by an array of cameras, radar (RF) and LiDAR (optical) ranging systems, sensors, and other detection systems, Advanced Driver Assistance Systems (ADAS) generate and process huge quantities of digital data. Infotainment systems, too, are growing in code size as drivers demand superior navigation and information systems, and passengers look for more entertainment options in the front and rear of the cabin.

In functional terms, the car is becoming a data center on wheels – and like a data center, it needs high-speed access to a large data storage capacity. Reliability concerns have led automotive manufacturers to end the use of traditional Hard Disk Drive (HDD) storage devices, which offer a limited lifetime and are prone to mechanical failure.



Instead, automotive system designers today prefer to use a mass storage device which is based on NAND Flash memory technology, such as a Solid State Disk (SSD), eMMC drive or UFS (Universal Flash Storage) device. NAND Flash has become the preferred technology for mass storage in mobile phones, laptop computers and other consumer devices as well as in SSDs because it offers a valuable combination of high memory density and high performance. This means that huge data storage capacity can be provided in a small packaged device, and the user benefits from rapid access to stored data and quick data storage operations.

These characteristics are important as well to automotive manufacturers. But automotive applications impose special requirements which raise important additional questions about manufacturers' choice of NAND storage device:

- **Performance** – in use cases such as driver assistance and navigation, latency is a key figure of merit. Automotive manufacturers require fast Read and Write speeds and high data throughput.

- **Data integrity** – every Read and Write operation carries a risk of generating bit errors, which can lead to data loss or corruption. Reliability is a critical factor in the automotive market, and in a storage device, data integrity is an important marker of reliability.

- **Data retention** – unlike a consumer device such as a mobile phone, a vehicle is expected to have an operating lifetime of at least ten years. Automotive manufacturers want to be confident that their chosen NAND storage device will retain data for the life of the vehicle.

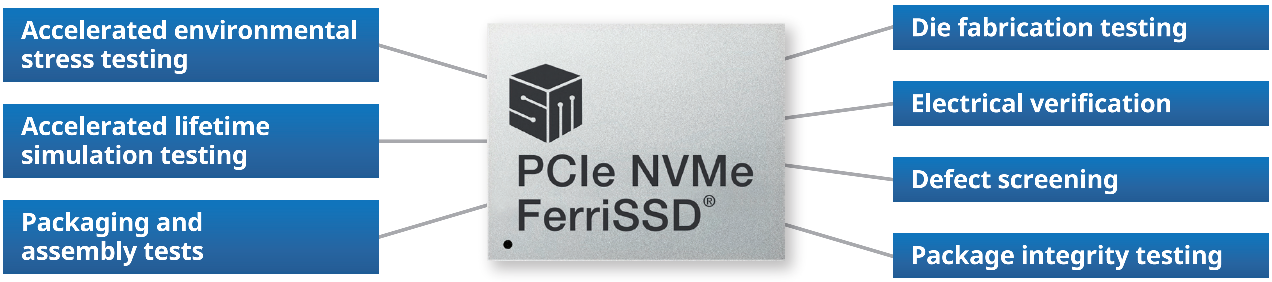
In vehicles, the long-term reliability and lifetime of an electronics component such as a mass storage device are crucial criteria. The automotive industry applies strict qualification tests, according to the AEC-Q100 standard, to the integrated circuits used in automotive Electronic Control Units (ECUs), with the aim of achieving zero defects over a long lifetime at temperatures of 85°C or higher.

The goal of reducing the component defect rate to zero is important because of the long lifetime of a vehicle, the high number of components in a vehicle, and the huge cost of rectifying a known fault in a fleet of vehicles which are in service – not to mention the reputational damage to a car maker's brand.

To illustrate the point simply, imagine a single Electronic Control Unit (ECU) consisting of 1,000 parts. If the ECU manufacturer tolerated a defect rate as low as 1ppm, this single ECU alone would be responsible for 1,000 faults in a fleet of 1 million vehicles. And according to a 2019 report form analyst firm IHS Markit, a new luxury vehicle can contain as many as 150 ECUs1.

This is why the automotive industry imposes the goal of a zero defect rate. And its strategy for reaching this goal is to apply a component qualification process, codified in the various AEC-Q10x standards. The criteria for AEC-Q100 qualification, for example, are extremely strict, and verify a component's reliability across a number of test parameters. The main reliability tests are:

- **Accelerated environmental stress testing**
- **Accelerated lifetime simulation testing**
- **Packaging and assembly tests**
- **Die fabrication testing**
- **Electrical verification**
- **Defect screening**
- **Package integrity testing**



This qualification process is exhaustive, and has been proved to effectively screen out potentially defective parts. Components which pass the tests and achieve AEC-Q100 qualification have demonstrated a remarkably high level of reliability and integrity in a demanding set of environmental and application conditions.

One of the most difficult elements of AEC-Q100 qualification for NAND Flash-based storage products to achieve is to pass the high- temperature and accelerated lifetime simulation tests. Storage systems must maintain reliable operation at continuous temperatures of up to 85°C for AEC-Q100 qualification to Grade 3, and up to 105°C for Grade 2. And the compact, chip-style packages in which the latest products, such as Silicon Motion's Ferri family, are housed, have more constrained thermal pathways than in the larger enclosure of a typical free-standing SSD used as a computing accessory.

To maintain reliable operation and data integrity in automotive storage devices, Silicon Motion applies various unique technologies which draw on its long experience in NAND Flash memory control. An understanding of these technologies will help the automotive system designer to evaluate NAND Flash-based storage devices with confidence that they are robust and reliable enough for use in vehicles.

NAND Flash cell operation at high temperature

To see how technology can counter the effect of high temperatures on NAND Flash cells, it is important to understand the operation of these cells. In Flash memory, data bits are represented by stored charge (electrons) in cells. When NAND Flash technology first came on to the market, memory arrays were made of Single-Level Cell (SLC) elements. In SLC NAND, the cell stores one bit of data – a 1 or 0.

As technology advanced, NAND Flash chip manufacturers responded to demand for higher memory density by developing Multi-Level Cell (MLC) technology, which stores two bits per cell, and then Triple-Level Cell (TLC) technology, with three bits per cell (see Figure 1). This means that the cell volume-per-bit has declined with each new generation of NAND Flash. NAND cell size also shrinks as semiconductor fabrication processes advance from older process nodes to the latest sub-10nm nodes.

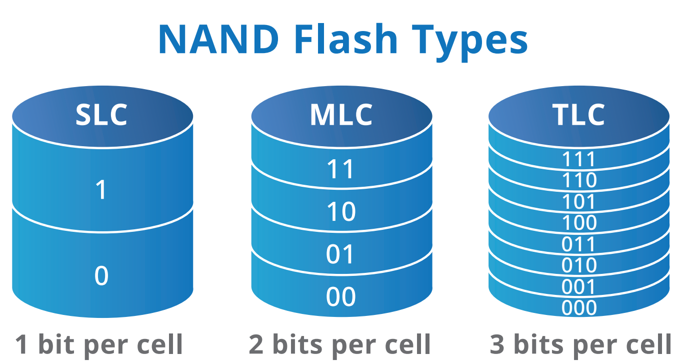


Fig. 1: NAND Flash chip manufacturers developed MLC technology, which stores two bits per cell, and then TLC technology, with three bits per cell.

The high memory density of today's TLC NAND Flash devices means that a storage device such as Silicon Motion's FerriSSD® can provide up to 480GB of data capacity in a surface-mount BGA package with a tiny footprint of just 20mm x 16mm.

But the small size of TLC cells means that they wear out at a faster rate than SLC cells, a factor which the Flash controller embedded in a storage device has to take into account. Every Program/ Erase (P/E) cycle slightly degrades the oxide layer in the cells on which a P/E operation is performed. Smaller TLC cells have a thinner oxide layer than the larger SLC cells, so they degrade faster, and can on average withstand fewer P/E cycles. As this paper describes below, proprietary NANDXtend technology solve this problem in Ferri series storage devices.

NAND Flash cells also experience electron leakage over time. If too much charge leaks from a cell, its data can no longer be read out. 'Data retention' – the length of time for which data can be stored in a cell – declines as more P/E cycles are performed. And heat accelerates electron leakage, so data retention also declines faster as temperature rises, as Figure 2 shows.

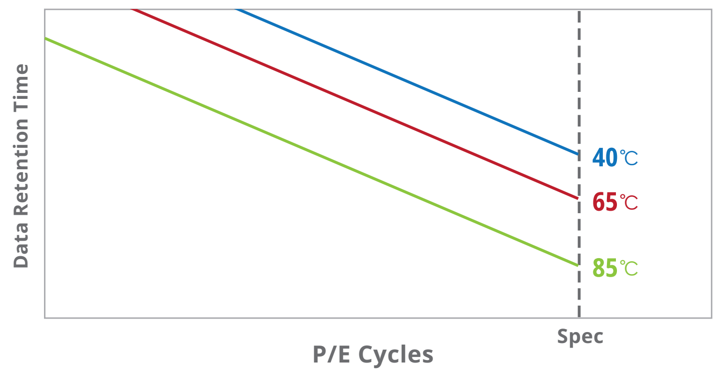


Fig. 2: data retention in NAND Flash cells dramatically declines as temperature rises. (Image credit: Silicon Motion)

So this is the problem for NAND Flash-based storage devices for automotive applications such as the infotainment system: in a car's center console, an infotainment ECU might be required to operate at temperatures as high as 85°C. But data loss is not acceptable in infotainment applications such as mapping and navigation. And the AEC-Q100 standard mandates a defect rate of zero when tested at temperatures up to 85°C (for Grade 3 qualification).

It is a problem that a Silicon Motion storage controller, and the firmware which it runs, can solve.

Central role of storage controller

A NAND Flash-based storage system consists of two basic elements:

- **A NAND Flash array**
- **A NAND Flash controller IC**

The basic role of the controller is the bridge between the NAND Flash cells and the host processor which writes to and reads from the memory. The controller manages the mapping of bits to cell addresses.

Silicon Motion has more than 20 years' experience of developing the specialized controller ICs which manage NAND components. Its deep understanding of NAND characteristics enables it to design both highly optimized ICs and related firmware controller platforms. In fact, more NAND Flash components, including 3D Flash products from Intel, Kioxia, Micron, Samsung, SK Hynix, Western Digital and YMTC, are supported by Silicon Motion controllers than by those of any other company.

Silicon Motion's understanding of the behavior of NAND Flash at high temperatures underlies the operation of its Ferri storage products, all of which are available in versions qualified to AEC-Q100 Grades 3 and 2.

Controller technology extends data retention

As Figure 2 shows, the acceleration of electron leakage from NAND Flash memory cells at high temperatures dramatically shortens data retention, down to as little as 2 days at 85°C for an MLC cell which has undergone its rated maximum number of P/E cycles.

The Silicon Motion solution is to monitor the voltage at every cell in an array to detect those in which leakage has progressed to a critical state, and then to reprogram at-risk cells. The Ferri product feature which implements this technology, IntelligentScan + DataRefresh, is capable of extending NAND Flash array lifetimes far beyond the nominal P/E cycle lifetime specified by the Flash manufacturer (see Figure 3). The intelligence in the IntelligentScan feature also includes responding automatically to temperature, and scanning more frequently when operating at high temperature.

When a cell's oxide layer has degraded so much that it can no longer be sufficiently recharged, the IntelligentScan function will repair it if possible, or retire it, thus avoiding any risk to data integrity.

The controller in Ferri products also implements advanced global wear leveling, so that P/E operations, and thus wear, are evenly allocated across an entire array.

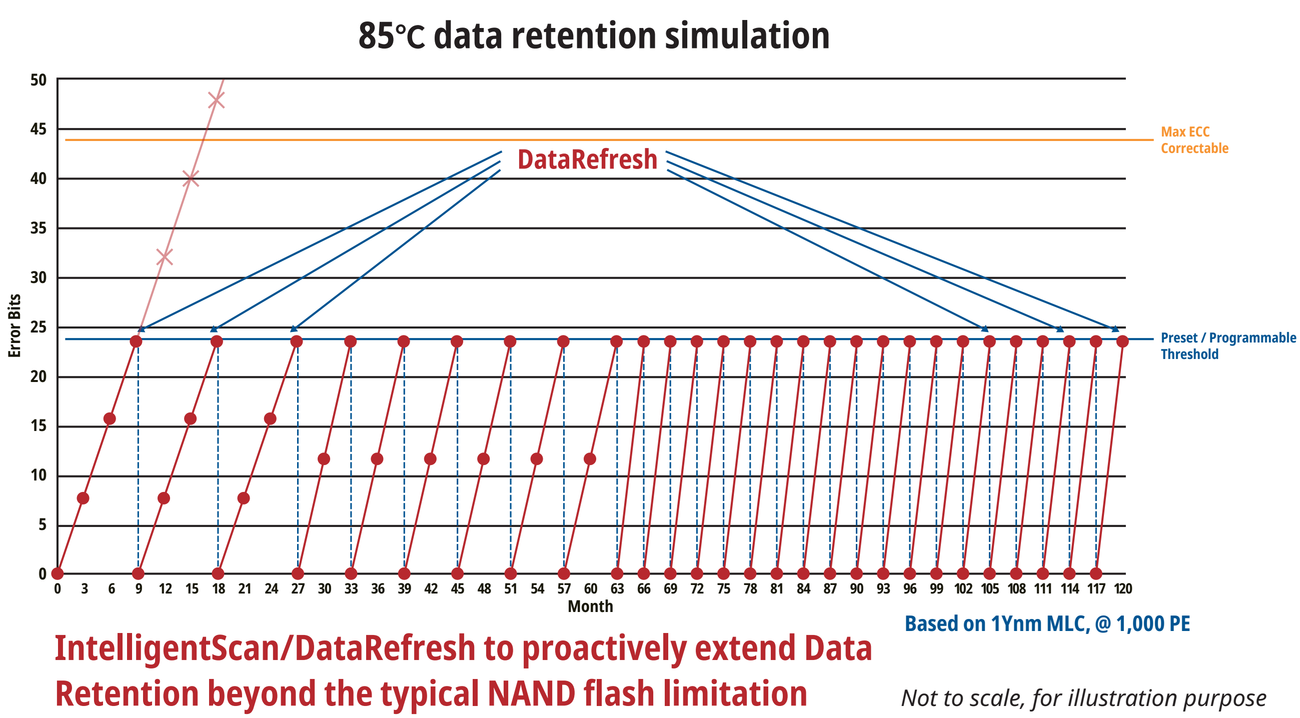


Fig. 3: the DataRefresh function increases the frequency of recharge operations as NAND Flash cells age. (Image credit: Silicon Motion)

Configuring NAND Flash cells for optimized operation

The controller embedded in Silicon Motion AEC-Q100 qualified storage devices also provides the capability for the user to configure operation of TLC NAND Flash to extend data integrity. The SLCMode™ function available in Ferri products virtually groups together TLC or MLC cells into a one-bit SLC-like configuration. This is ideal for use cases in which the nominal storage capacity (in TLC mode) is over-specified. Operation with the SLCMode feature turned on reduces the nominal capacity, but gives SLC-like data retention and data integrity performance.

Ferri products offer MLCmode operation as well as SLCmode, giving users the ability to choose the ideal balance between data integrity and capacity for their application. In addition, they provide an SSDLifeGuard™ feature which automatically monitors the health status of the SSD, and triggers the controller to implement data protection and error correction operations when blocks or pages are at risk.

Extending NAND cell operation beyond ten years

AEC-Q100 qualification for automotive storage devices calls for zero-defect performance at high temperature – a very challenging requirement for NAND Flash-based devices, because of the acceleration in data leakage from NAND cells at high temperatures of 85°C and above. The fact that Silicon Motion's Ferri products are qualified for automotive use at temperatures up to 105°C is testament to the effectiveness of the unique technologies, such as IntelligentScan + DataRefresh, which Silicon Motion has developed for managing NAND Flash arrays.

The optimization of storage products for automotive applications results from Silicon Motion's commitment to the automotive market – a commitment which is also demonstrated by its compliance with the full range of automotive industry standards, including IATF 16949, ASPICE, and VDA 6.3.

Automotive manufacturers can also take confidence from Silicon Motion's leadership position in the market for merchant SSD controllers and embedded storage devices. Silicon Motion is the leading specialist manufacturer of NAND Flash controller technology, and can draw on more than 20 years' experience in developing specialized processor ICs which manage NAND components. In the past ten years, Silicon Motion has shipped more than six billion NAND Flash controllers, more than any other company in the world.

So now automotive manufacturers can embed robust solid-state storage into infotainment and ADAS ECUs with confidence that Silicon Motion's Ferri products' lifetime, data integrity and data retention will meet users' expectations for vehicle lifetimes of ten years and beyond.

1 IHS Markit report cited at:
https://www.eenewsautomotive.com/news/number-automotive-ecus-continues-rise

For more information about Ferri Family, please go to
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