White Paper

Achieving Extensive Data Retention in High-temperature AIoT Applications

Executive Summary

As AIoT applications move into harsher, more remote, and overall more challenging environments, data retention in NAND flash is becoming a key concern. AIoT applications in high-temperature environments are particularly susceptible to data retention issues, making this a vital issue for the industry to address.

Data stored on NAND flash slowly degrades. This degradation is caused by the charge in each NAND flash cell slowly leaking out over time. Data retention refers to the flash cell's ability to hold on to data.

Data retention decreases in higher temperatures and with increasing program/erase (P/E) cycles as both these factors induce a higher rate of charge leakage. Higher temperatures increase the movement/vibration of the charged particles in the cell, whereas P/E cycles damage the cell's structural integrity. The data degradation factor (DF), where DF=1 is data retention at standard temperature, rises to 168 in the 80-85 °C range, meaning that the high-temperature range reduces data retention by a factor of 168.

The issue can be solved by periodically refreshing the data based on temperature and the number of P/E cycles. By swapping data from block to block, similar to wear leveling, the firmware refreshes the data and achieves the desired result. Testing shows that data can theoretically last for decades as long as firmware keeps it refreshed, even in temperatures as high as 85 °C.

Introduction

The solid-state drive (SSD) has become a mainstay in most industries, and particularly so in devices designed for hostile environments, as the SSD is generally sturdier than traditional storage mediums. However, while sturdier overall, SSDs are still susceptible to adverse effects from exposure to extreme-temperature environments.

Data retention describes the NAND flash's ability to retain data it stores over time. In essence, it can be described as a timer that starts counting down after data is written to a NAND flash cell. The data retention countdown continues as long as the data remains unrefreshed, i.e., data is erased, and new data is written). In normal temperature ranges, the retention time is generally long enough that it does not pose a risk to data integrity. However, in higher temperature ranges, this is no longer the case.

There are three main reasons why data retention is an issue in NAND flash. Firstly, due to the flash cell's structure, higher temperatures cause data to degrade at an extremely high rate. Secondly, heavy writing environments further exacerbate the data retention problem. As the number of program/erase (P/E) cycles increases, the cell further weakens, leading to reduced data retention capacity. Lastly, as manufacturers try to fit as many cells as possible in each die, the cell size shrinks, which in turn makes data retention even harder.

These factors necessitate data retention features that can periodically refresh the data to avoid degradation.

Therefore, data retention is considered a challenge in any AIoT device environment that sees high temperatures, such as in-vehicle, automation, as well as in mission-critical applications.

Background

The basic structure of NAND flash cells is the floating gate transistor. The cell works by adding a charge to the floating gate, which is positioned between two isolating layers. This charge represents a binary value. For example, the charge a multi-level cell (MLC) holds can represent four binary numbers, 00, 01, 10, and 11.

All NAND flash types are non-volatile, meaning that the charge is isolated and stays in place after turning off the SSD. Consequently, unlike in volatile DRAM, data remains available even if the SSD is turned off for a while.

When erasing data, the NAND flash cell is hit with a charge that empties the floating gate. This process will also slightly wear the cell, which eventually leads to cell wear-out and storage failure, and is the reason why all NAND flash devices have finite lifespans.

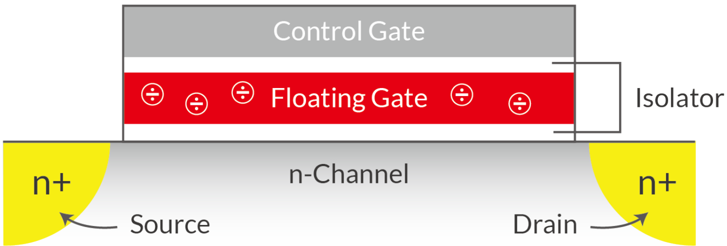


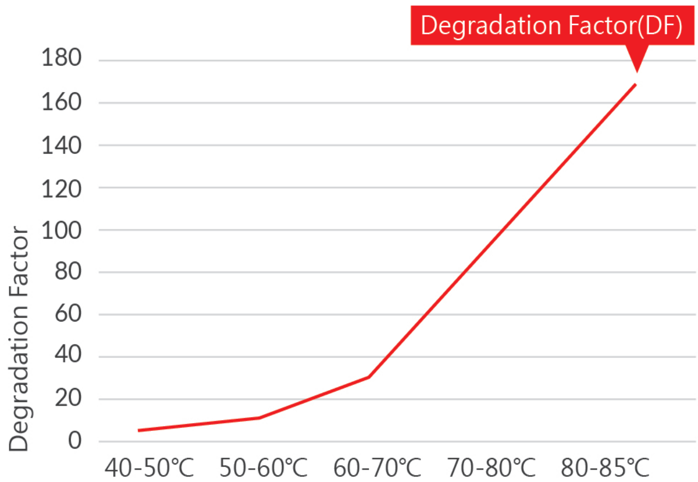
Figure 1: Floating Gate Transistor.

Challenges

Heat

NAND flash mostly remains unaffected at standard temperatures (T<40 °C). But once we reach high temperatures, data retention drastically decreases. The decreased data retention can be explained through simple laws of physics: higher temperatures mean that particles are moving/vibrating faster, and this higher energy translates into a higher chance of a charge leaking.

Testing shows that at the 80-85 °C range, the data degradation factor (DF) reaches 168. In other words, data deteriorates at a dramatic rate, 168 times faster than in the standard temperature range. For example, a device with a hypothetical data retention rate of one year will, if placed in an 80 °C environment, only last around two days before losing its data.



Graph 1: Changes to the degradation factor as temperature increases.

P/E Cycles

A cell is hit with a charge to erase its data. This charge will also, ever so slightly, damage the oxide layers of the cell. As this damage accumulates, the cell gradually loses its data retention capabilities. The reason the deletion process is more detrimental to data retention performance compared to storing data is that the charge used to delete the data is larger by several orders of magnitude. With such a hefty charge, the physical structure of the cell itself deteriorates with every deletion.

The result is that any SSD previously used in heavy-workload environments is particularly unsuited for data retention purposes, as the device's previous operating environment has impeded its data retention capability.

Smaller NAND Flash Cells

Ever since NAND flash entered the market, it has been trending toward decreasing cell sizes and increasing IC density, where die sizes keep shrinking to more easily fit into smaller storage IC packages.

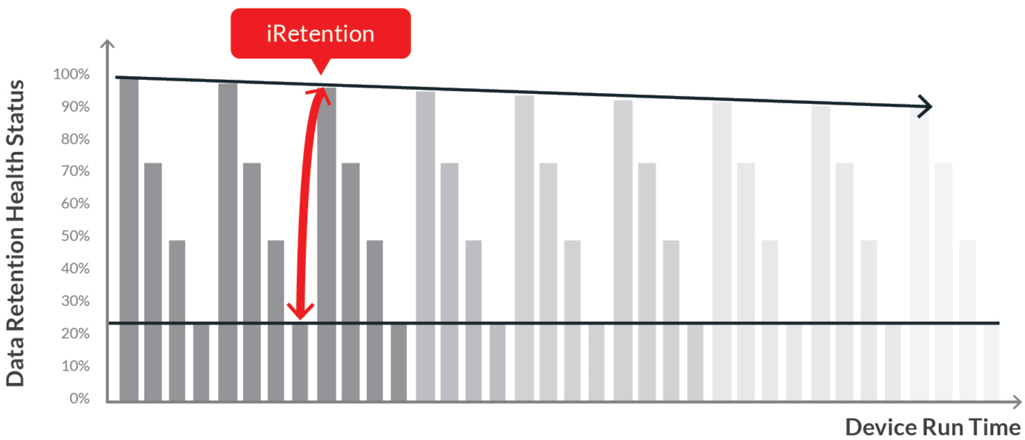
However, one of the physical realities of decreasing cell sizes is that the threshold voltage distribution shrinks, which in turn requires increasingly sophisticated error management from the flash controller and firmware algorithms. The charge in smaller cells leaks at a faster rate compared to legacy NAND flash cells. Although this issue cannot be directly mitigated, it is important to be aware of the fact when evaluating data integrity.

Solutions

Temperature and P/E Cycle Algorithm

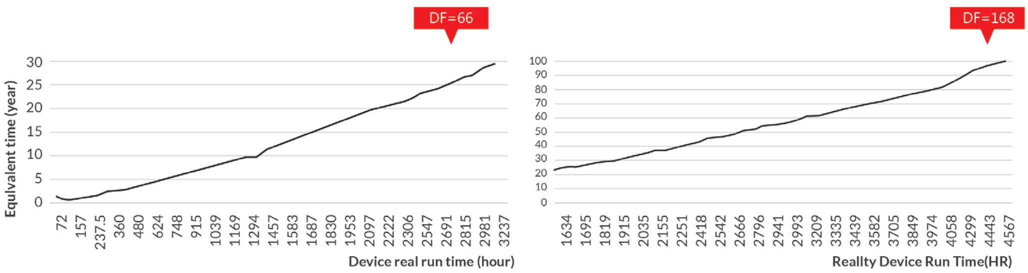
To solve the issue of data retention, the SSD needs to take both temperature and the number of P/E cycles into account.

By adding an onboard sensor, the SSD receives continuous temperature readings. This data and the number of P/E cycles are constantly fed into a firmware algorithm, which in turn lets the SSD self-monitor the data retention situation. The SSD can determine the optimal refresh rate to ensure data integrity while keeping firmware processes to a minimum. In other words, the data is kept safe while having the least amount of impact on SSD performance.



Graph 2: As data retention falls, the SSD initiates a data-refresh operation.

The data refresh operation works on a block-level, where blocks at risk have their data moved to new blocks. This process resets the data retention timer, keeping the data safe until the SSD determines to initiate the next cycle.



Graph 3 and 4: Dual test run with SSDs at a DF of 66 and 168. The horizontal axis shows the test run time; the vertical bar is the theoretical data retention period.

As seen in graphs 3 and 4, testing shows that the temperature and P/E cycle algorithm can theoretically extend data retention by many decades. For example, even in the 80-85 °C range (DF=168), the SSD keeps data refreshed for more than 80 years.

Conclusion

Data retention is not an issue for AIoT applications in standard conditions. However, any operator with AIoT devices in harsh environments should be aware of the risk of data loss and how fast it can happen. The issue can be easily mitigated through temperature monitoring and firmware optimization, saving the operator from costs that would otherwise be incurred from data corruption and data loss.

The Innodisk Solution

iRetention™

iRetention™ is an intelligent technology created by Innodisk. This agile SSD firmware feature is able to maintain data retention in the face of NAND flash aging and high-temperature variations. With this firmware feature, SSD retention time is significantly extended compared to standard NAND flash specifications.

Innodisk Corporation

5F., NO. 237, Sec. 1, Datong Rd., Xizhi Dist., New Tapei City, 221, Taiwan
Tel : +886-2-7703-3000
Fax : +886-2-7703-3555
E-Mail : sales@innodisk.com
Website : www.innodisk.com

innodisk