White Paper

Achieving Extensive Data Retention in High-Temperature Environments

Executive Summary

Data stored on NAND flash will slowly degenerate. This is due to the charge in each NAND flash cell slowly leaking out over time. The cell's ability to hold on to this data is referred to as data retention.

Data retention decreases in higher temperatures and with increasing 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 while 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 data retention is reduced by a factor of 168.

The issue can be solved by periodically refreshing the data based on temperature and the P/E cycle number. This is done by swapping data from block to block, similar to wear leveling. Testing shows that data can theoretically last for decades as long as it is kept refreshed, even in temperatures reaching 85°C.

Introduction

The solid state drive (SSD) has become a mainstay in most industries. This is especially true for devices designed for hostile environments, as the SSD is generally sturdier than traditional storage mediums. Yet, extreme temperatures can still negatively affect the SSD.

Data retention describes the NAND flash's ability to retain data that has been stored over time. It is a clock that starts ticking after data has been written to a NAND flash cell and the countdown continues as long as the data remains unrefreshed (data erased and new data written). In normal temperature ranges, the retention time is generally long enough that it does not pose a risk to data integrity. However, the conditions change as temperature rises.

There are three main reasons why data retention is an issue for NAND flash. Firstly, due to the flash cell's structure, higher temperatures will cause data to degenerate at an extremely high rate. Secondly, heavy writing environments further exacerbate the data retention problem. As the number of program/erase 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 makes data retention even harder.

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

Data retention is a challenge in any environment that sees high temperatures such as in-vehicle, automation, and aerospace and defense.

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 which means that the charge is isolated and will stay in place after the SSD is turned off. This is why data is available even after the SSD has not been turned on for a while, as opposed to volatile DRAM.

To erase 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 will lead to cell wear out and cause a function failure. This is why all NAND flash have a finite lifespan.

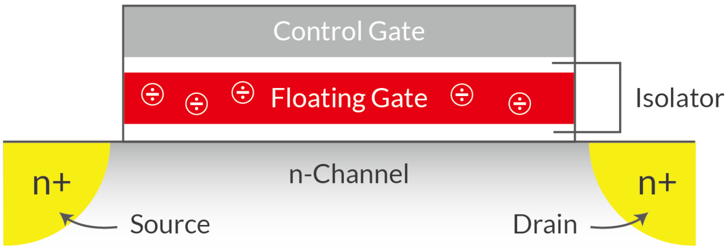


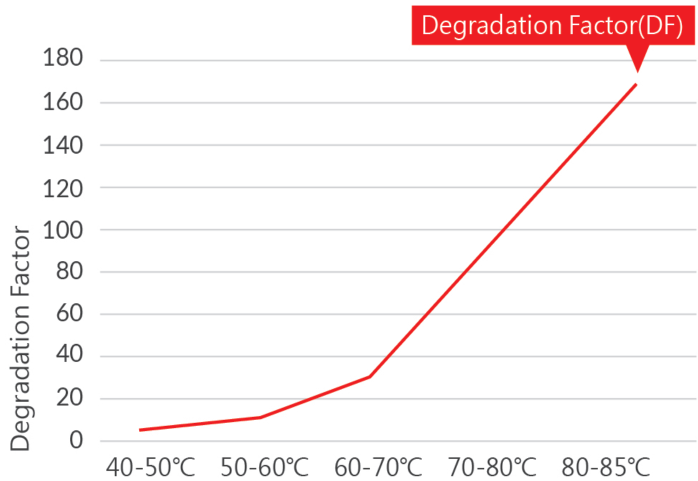
Figure 1: Floating Gate Transistor

Challenges

Heat

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

Testing shows that at the 80°-85°C range the data degradation factor (DF) reaches 168. In other words, data will degenerate at a rate of 168 times faster than at standard temperature. For example, a device with a hypothetical data retention rate of 1 year will, if placed in an 80°C environment, only last around 2 days before data is lost.



Graph 1: Changes to the degradation factor as temperature increases

P/E Cycles

To erase data from a cell, it is hit with a charge. This charge will also ever so slightly damage the oxide layers of the cell. As this damage accumulates, the cell will steadily lose its data retention capabilities. The reason the deletion process is more detrimental compared to storing data is because the charge used to delete the data is larger by several magnitudes. With such a large charge, the physical structure of the cell itself deteriorates with every deletion.

This means that any SSD that previously have been used in heavy-workload environments is particularly unsuited for data retention purposes, as the stated data retention capability will have been significantly reduced.

Smaller NAND Flash Cells

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

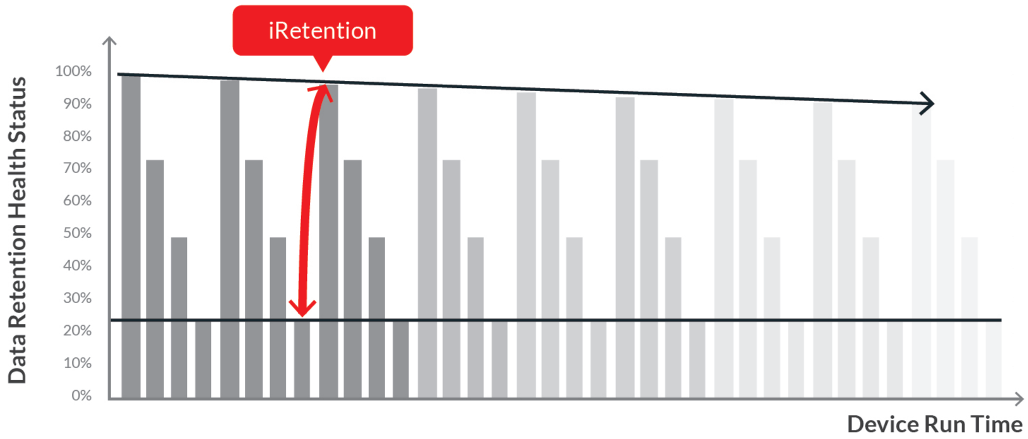
However, one of the physical realities of decreasing cell sizes is that the threshold voltage distribution shrinks, which in turn requires increasingly sophisticated error management from the flash controller and firmware algorithms. The charge in smaller cells will leak at a faster rate compared to 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

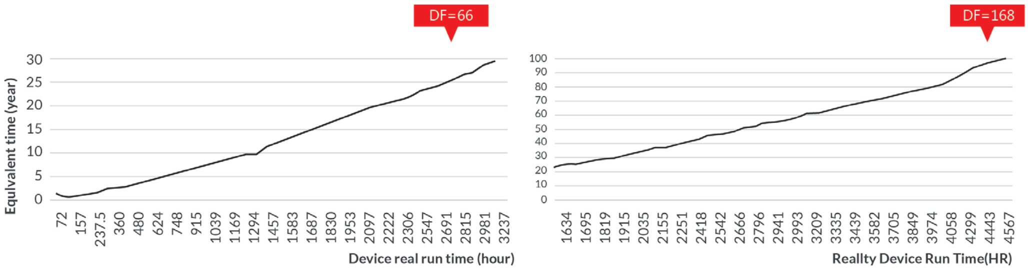
To solve the issue of data retention the SSD needs to take into account both temperature and P/E cycles.

By adding an onboard sensor, the SSD will have a continuous temperature profile. This profile and the number of P/E cycles will constantly be 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 will initiate a data-refresh operation

The data refresh operation works on a block-level, where blocks at risk will have the data moved to a new block. This 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 test run time, the vertical bar is the theoretical data retention period

As seen in the graph 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 will keep data refreshed for more than 80 years.

Conclusion

Data retention is not an issue under standard conditions. However, any operator with 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, and can save the operator from costly losses if data is corrupted and lost.

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.

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