swissbit®

Application Note

AN2102en

Bad Blocks

Contents

1 Abstract

This paper investigates the emergence of "bad blocks" on NAND flash and its consequential impact on storage reliability. Functional tests across the entire temperature range performed by both, manufacturer of the flash and the manufacturer of the storage medium, offer a guarantee to avoiding early failures. During the life of the storage medium, in turn, the capabilities of the firmware are very important for reliability.

2 Framework

NAND flash is very inexpensive compared to other electric storage devices such as NOR flash or DRAM. One reason for this is that with NAND Flash not every single bit needs to be error free. Consequently, yield is high for production. For example, 128 Gbit NAND flash typically yields in excess of 90 %. Correspondingly, an error correction is absolutely necessary for NAND flash in order to be able to correct bit errors. While bit errors seldomly occur in NOR flash and DRAM negating the need for optional error correction for most applications, hard bit errors already exist with NAND flash since production.

3 Factory Bad Blocks

Flash memory components are tested straight after production. The first tests are already performed at wafer level before dividing the wafer into individual dies. Various test patterns and temperatures are applied. Ideally, the entire temperature range is already covered here with a write/read test.

As semiconductor manufacturing processes move in the nanometer range, imperfections are inevitable (lattice defects, tolerances in lithography, positioning errors, dust, ...). When these faults are in active areas of the die and occur, they mainly appear as bit errors of the flash cells. If the bit error rate of a section is above a certain limit during the write/read test, the block is marked as a bad block.

In the unlikely event of the periphery of a flash block being affected by an error (e.g. address decoder or register), the block would also be marked as a bad block because it is not functional.

If too many blocks are rejected, there no longer are enough blocks available to reach the nominal capacity and/or to ensure sufficient reserve blocks. In this case the entire die is marked as bad and discarded after dicing the wafer.

Swissbit's internal tests have shown that for the flash types used by Swissbit the reliability of the flash memory does not correlate with the number of factory bad blocks. An above-average number of bad or defective blocks does not increase the probability of an early failure.

During the lifetime of a storage medium, additional bad blocks may occur (so-called "Grown Bad Blocks" or "Runtime Bad Blocks"). This is completely normal, and flash manufacturers cannot avoid this in advance [1] [2].

The most common cause is a failure of the isolation layer of a NAND transistor when the high voltage needed to erase a cell is applied. Should, during its lifetime, the bit error ratio of a block increase beyond a certain limit after an erase or programming operation, then such a block is hidden by the firmware and replaced by another block. Without this, data loss would occur if the number of bit errors exceeded the number of correctable bit errors. Some precaution is necessary however since soft errors can also occur due to loss of charge (long storage or ionizing radiation).

Safe handling of Grown Bad Blocks is an important function of the storage medium's firm-

Swissbit AG   **Revision: 1.0**
Industriestrasse 4
CH-9552 Bronschhofen   www.swissbit.com   AN2102en_Bad_Blocks.pdf
Switzerland   sales@swissbit.com   Page 2 of 5

ware, since such a block, upon detection, requires both the data already stored in the block to be reliably copied as well as caching the new data intended for it.

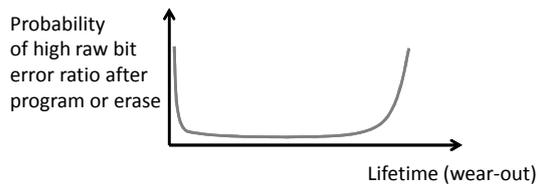The appearance of Grown Bad Blocks follows a bath-tub curve (Figure 1):

Figure 1: Probability of Bad-Block occurrence

At the beginning of the life cycle, early failures can increasingly occur if the insulation layer fails after only a few erase cycles. After that a long period with very low probability follows. After exceeding the specified number of write/erase cycles, the probability of Grown Bad Blocks continues to increase again.

With the continuous improvement of manufacturing processes, established flash technologies will typically have a probability in the single-digit percentage range for at least a single Grown Bad Block during their lifetime. Depending on the technology, about 2–4 % of the total capacity is retained to compensate Grown Bad Blocks, which can be used by the firmware for additional "overprovisioning".

4 3D NAND

In contrast to the typical planar structure of NAND memory, with 3D-NAND, depending on the memory type, further failure modes can occur, which can lead to the failure of one block or multiple pages. Due to the high voltages during erase and programming, short or open circuits to conductor tracks may occur. In such cases, the affected blocks can also be disabled and replaced without affecting the other blocks. However, the failure of a conductor track may affect not only the currently programmed page, but the entire block. Then all written data already in this block is lost. To prevent this data

loss, two different techniques that both significantly increase the complexity of the firmware can be applied:

- With **block parity**, a parity block is calculated over several blocks and stored in flash. If a block fails, it can be restored using the parity information.

- With **read verify**, after each write command to a block, the content of that block is read back and compared to a copy in the controller's RAM. This requires a lot of RAM, because for each open block [2] a complete copy must be kept in RAM.

Combinations from both techniques can also be used.

5 Conclusion

The presence of factory bad blocks in NAND flash is as much based on technology as is the occurrence of further bad blocks during the lifetime. Neither have any (negative) quality implications. However, when bad blocks occur during the lifetime, correct handling by the firmware is critical in order avoid loosing new data as well as the existing stored data of those blocks.

References

[1] https://www.electronicdesign.com/memory/11-myths-about-nand-flash

[2] https://www.micron.com/~/media/documents/products/technical-note/nand-flash/tn2959_bbm_in_nand_flash.pdf

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[2] A block that is no longer erased and not yet completely full

Swissbit AG
Industriestrasse 4
CH-9552 Bronschhofen
Switzerland

www.swissbit.com
sales@swissbit.com

Revision: 1.0

AN2102en_Bad_Blocks.pdf
Page 3 of 5

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CONTACT US

Headquarters	**Swissbit AG** Industriestrasse 4 9552 Bronschhofen Switzerland	Tel. +41 71 913 03 03 sales@swissbit.com
Germany (Berlin)	**Swissbit Germany AG** Bitterfelder Strasse 22 12681 Berlin Germany **Location Berlin, Wolfener Strasse** Swissbit Germany AG Wolfener Strasse 36 12681 Berlin Germany **Human Resources** Tel. +49 30 936 954 89 **hr@swissbit.com**	Tel. +49 30 936 954 0 sales@swissbit.com
Germany (Munich)	**Swissbit Germany AG** Leuchtenbergring 3 81677 Munich Germany	Tel. +49 30 936 954 400 sales@swissbit.com
North and South America	**Swissbit NA Inc.** 238 Littelton Rd #202b Westford, MA 01886 USA	Tel. +1 978-490-3252 sales@swissbitna.com
Japan	**Swissbit Japan Co., Ltd.** 4-20-7 Asagaya-kita, Suginami-ku, Tokyo, 166-0001 Japan	Tel. +81 3 5356 3511 sales@swissbit.co.jp
Taiwan	**Swissbit Taiwan** 4F-1, No 104, Sec. 2, Dunhua S. Rd. Da'an Dist, Taipei City 106 Taiwan (R.O.C.)	Tel. +886 2 27010788 salesasia@swissbit.com
China	**Swissbit China**	Tel. +86 15000 393 870 salesasia@swissbit.com

Swissbit AG
Industriestrasse 4
CH-9552 Bronschhofen
Switzerland

www.swissbit.com
sales@swissbit.com

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AN2102en_Bad_Blocks.pdf
Page 4 of 5

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