TOSHIBA

NAND vs. NOR Flash Memory
## Technology Overview

Introduction

Flash memory has become a powerful and cost-effective solid-state storage technology widely used in mobile electronics devices and other consumer applications. Two major forms of Flash memory, NAND Flash and NOR Flash, have emerged as the dominant varieties of non-volatile semiconductor memories utilized in portable electronics devices. NAND Flash, which was designed with a very small cell size to enable a low cost-per-bit of stored data, has been used primarily as a high-density data storage medium for consumer devices such as digital still cameras and USB solid-state disk drives. NOR Flash has typically been used for code storage and direct execution in portable electronics devices, such as cellular phones and PDAs.

Recently, however, the distinction between the two types of Flash memory has become less clear. New cell phone controllers that support NAND Flash as an alternative to or an addition to NOR Flash have helped make NAND a viable alternative for a broader array of applications. In addition, data storage capacity and performance requirements in cell phones have increased significantly with the growth of feature-rich phones that incorporate camera, music, video, gaming and other functionality. NAND Flash has become an attractive alternative for the data storage aspects of today's cell phones because of its higher speed write and erase performance as well as its low cost-per-bit. As a result, designers of memory subsystems in portable electronics are now using NAND in some traditional NOR-based applications. For today's full-featured cell phones, many designers are utilizing memory architectures that combine NOR with NAND for data storage, or are using NAND as the primary Flash memory in combination with low power DRAM in which the program code can be shadowed and run.   In either case, the different types of memory are frequently stacked in Multi-Chip Packages (MCP) to create a single component.

This overview will briefly discuss the history of Flash memory development, compare and contrast NAND and NOR Flash memory, and discuss the ways in which the two technologies are used today.

Figure 1 below provides a summary of how NAND and NOR Flash vary for a number of important design characteristics: capacity, read speed, write speed, active and standby power consumption, cost-per-bit, and ease of use for file storage and code storage applications.

Fig. 1 Comparison of NOR and NAND Flash
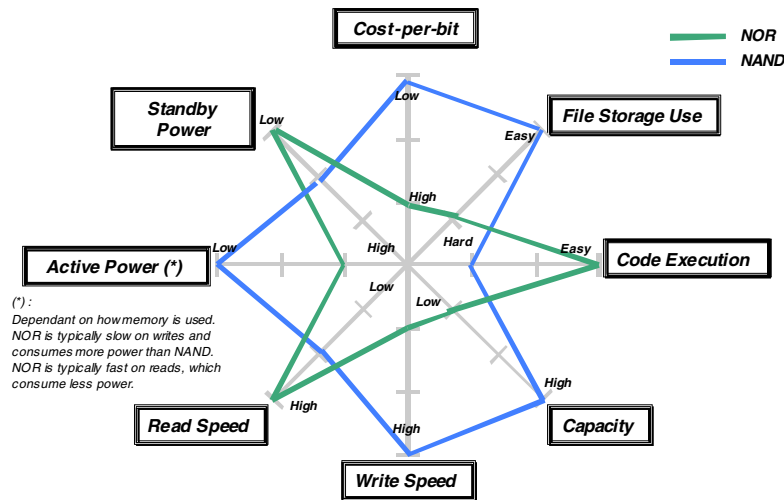
The History of Flash Memory

As a recognized pioneer in flash technology, Toshiba was a principal innovator of both NOR-type and NAND-type Flash technology in the 1980's. These new memories were developed to address the need for a non-volatile memory that is easily reprogrammable within a system. Some kind of non-volatile memory is necessary for computing systems so that the system does not erase all data every time it is powered down, or following a power failure. Both NOR and NAND Flash systems are electrically erasable solutions, and can write and erase data many times, but do not lose stored data when the power is turned off.

NAND and NOR Flash Memory Architecture

In the internal circuit configuration of NOR Flash, the individual memory cells are connected in parallel, which enables the device to achieve random access. This configuration enables the short read times required for the random access of microprocessor instructions. NOR Flash is ideal for lower-density, high-speed read applications, which are mostly read only, often referred to as code-storage applications.

NAND Flash was developed as an alternative optimized for high-density data storage, giving up random access capability in a tradeoff to achieve a smaller cell size, which translates to a smaller chip size and lower cost-per-bit. This was achieved by creating an array of eight memory transistors connected in a series. Utilizing the NAND Flash architecture's high storage density and smaller cell size, NAND Flash systems enable faster write and erase by programming blocks of data. NAND Flash is ideal for low-cost, high-density, high-speed program/erase applications, often referred to as data-storage applications.

NOR vs. NAND Flash Density
For any given lithography process, the density of the NAND Flash memory array will always be higher than NOR Flash. In theory, the highest density NAND will be at least twice the density of NOR, for the same process technology and chip size. In reality, market forces determine the highest density that will be commercially produced. Today, comparing only single chip memory with one bit per cell (also called Single Level Cell, or SLC), the highest density NOR commercially available is 256 megabit[1] (Mb), while NAND is available in densities of 4 gigabit[2] (Gb). Because cost-per-bit, which is closely related to the silicon real estate required, is one of the most important characteristics of memory, the small cell size characteristic of NAND Flash is a significant factor.

Choosing NAND vs. NOR
Toshiba continues to make both types of Flash memory, and recognizes that both forms have their own unique merits.

When should one choose NAND Flash over NOR Flash? The answer depends on the system requirements. Figure 4 below compares NAND Flash with asynchronous NOR Flash in terms of various operating and performance characteristics:

	SLC NAND Flash (x8)	MLC NAND Flash (x8)	MLC NOR Flash (x16)
Density	512 Mbits[1] – 4 Gbits[2]	1Gbit to 16Gbit	16Mbit to 1Gbit
Read Speed	24 MB/s[3]	18.6 MB/s	103MB/s
Write Speed	8.0 MB/s	2.4 MB/s	0.47 MB/s
Erase Time	2.0 mSec	2.0mSec	900mSec
Interface	I/O – indirect access	I/O – indirect access	Random access
Application	Program/Data mass storage	Program/Data mass storage	eXecuteInPlace

Figure 4: NAND and NOR Flash Operating Specifications

The characteristics of NAND Flash are: high density, medium read speed, high write speed, high erase speed, and an indirect or I/O like access. The characteristics of NOR Flash are lower density, high read speed, slow write speed, slow erase speed, and a random access interface.

For a system that needs to boot out of Flash, execute code from the Flash, or if read latency is an issue, NOR Flash may be the answer. However, for storage applications, NAND Flash's higher density, and high programming and erase speeds make it the best choice. While the benefit of high programming speed in high-density Flash devices is obvious, erase performance is equally important, though less obvious. Unlike magnetic memory systems (hard disk drives and tape drives), Flash memory requires a separate erasing step in order to turn all bits back to the "1" state before the device is programmed.

Power is another important concern for many applications. For any write-intensive applications, NAND Flash will consume significantly less power. Although the instantaneous power (voltage current) figures between NOR Flash and NAND Flash appear comparable, total energy will be significantly higher for NOR Flash since energy = power * time.

When a system, such as a camera phone, has a requirement both for code execution and high capacity data storage, designers may need to consider alternatives and tradeoffs, such as using both types of Flash memory, possibly in combination with Pseudo Static RAM (PSRAM), or using NAND as the Flash memory in combination with low power DRAM in which to run the operating code. The best Flash memory to choose will be the one that offers the required performance and density at the lowest cost.

About Multi-Chip Packages (MCP)
Toshiba MCPs (Multi Chip Packages) provides an advanced packaging solution for applications requiring smaller size, higher capacity and faster speed. MCPs can combine NAND Flash, NOR Flash memory, Pseudo SRAM and/or low power DRAM in a single package by using chip-stacking technology. This advanced packaging technology enables a complete memory subsystem with different types of semiconductor memory to be packaged as a single component to reduce size and contribute to cost reduction for cellular phones and other portable devices.

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[1] When used herein, megabit and/or Mb means 1,024x1,024 = 1,048,576 bits. Usable capacity may be less. For details, please refer to specifications.
[2] When used herein, gigabit and/or Gb means 1,024x1,024x1,024 = 1,073,741,824 bits. Usable capacity may be less. For details, please refer to specifications.
[3] For purposes of measuring data transfer rate in this context, megabyte (MB) per second, MB/s and/or MBps = 1,000,000 bytes per second.

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