SLC vs. MLC: An Analysis of Flash Memory
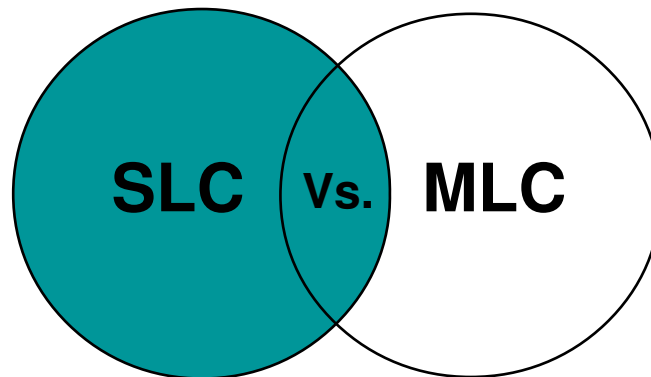
Examining the Quality of Memory:

Understanding the Differences between Flash Grades

SLC Vs. **MLC**

Abstract

Single-level cell (SLC) and multi-level cell (MLC) Flash memory are similar in their design. MLC Flash devices cost less and allow for higher storage density. SLC Flash devices provide faster write performance and greater reliability, even at temperatures above the operating range of MLC Flash devices.

Table 1 provides a summary of the advantages and disadvantages of SLC Flash and MLC Flash.

	SLC	MLC
High Density		✔
Low Cost per Bit		✔
Endurance	✔	
Operating Temperature Range	✔	
Low Power Consumption	✔	
Write/Erase Speeds	✔	
Write/Erase Endurance	✔	

Table 1: Qualities of SLC and MLC

These factors make SLC Flash a good fit in embedded systems, while MLC flash makes it possible to create affordable mobile devices with large amounts of data storage.

Introduction

Given a choice of two like products, consumers will buy the one with the lower price. In figure 1, we see two Flash memory chips that look identical.
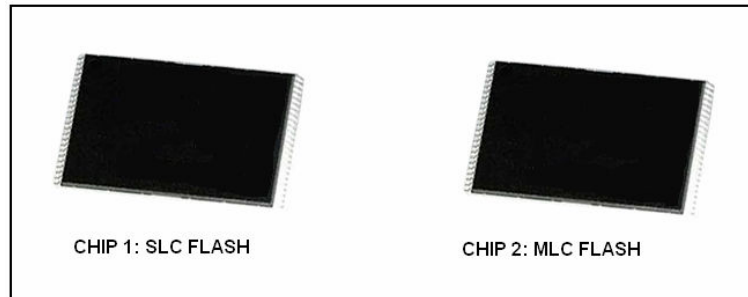

CHIP 1: SLC FLASH   CHIP 2: MLC FLASH

Figure 1: Flash Product Comparison

If Chip 1 costs $30 and Chip 2 costs $10, why would a consumer buy Chip 1? The answer, of course, lies beneath the surface. These chips are not really identical. The chip on the left is a Single-Level Cell (SLC) device, while the other is a Multi-Level Cell (MLC) device.

In order to select the right Flash memory for an application, it is important to analyze the how it will be used. For example, product developers integrating memory into a portable barcode reader will most likely need SLC Flash since performance and durability are important. On the other hand, a company building a portable media player will need the low cost and high density of MLC to price their device competitively. This paper analyzes the differences between SLC and MLC Flash.

Flash Memory Explained

It is important to understand what makes up a Flash cell before explaining the variation between SLC and MLC Flash. Each cell consists of a single transistor, with an additional "floating" gate that can store electrons. Figure 2 shows the architecture of an SLC cell.
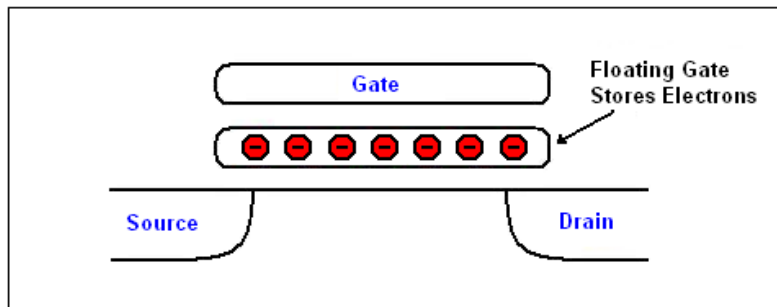

Figure 2: Flash Transistor Cell

A large voltage difference between the drain and the source, $V_d - V_s$, creates a large electric field between the drain and the source. The electric field converts the previously nonconductive poly-Si material to a conductive channel, which allows electrons to flow between the source to the drain.

The electric field caused by a large gate voltage, V_g, is used to bump electrons up from the channel onto the floating gate. As an electron travels closer to the drain, it gains more momentum and thus, more energy. But, this amount of energy is not enough to push an electron onto the floating gate. Electrons with high momentum near the drain can sometimes bump into Si (Silicon) atoms . This bump gives the electron enough energy to be pushed onto the floating gate.

The number of electrons on the floating gate affects the threshold voltage of the cell V_t. This effect is measured to determine the state of the cell.

Single-Level Cell (SLC) Flash

As the name suggests, SLC Flash stores one bit value per cell, which basically is a voltage level. The bit value is interpreted as a "0" or a "1".

Value	State
0	Programmed
1	Erased

Table 2: SLC Levels

Since there are only two states, it represents only one bit value. As seen in Table 2, each bit can have a value of "programmed" or "erased."
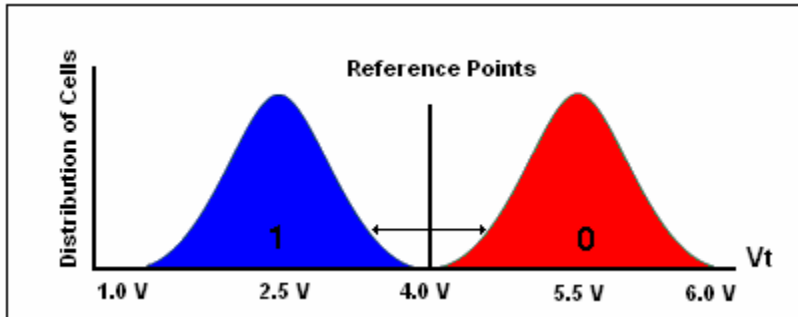

Figure 3: Voltage Reference for SLC

A "0" or "1" is determined by the threshold voltage V_t of the cell. The threshold voltage can be manipulated by the amount of charge put on the floating gate of the Flash cell. Placing charge on the floating gate will increase the threshold voltage of the cell. When the threshold voltage is high enough, around 4.0V, the cell will be read as programmed. No charge, or threshold voltage < 4.0V, will cause the cell to be sensed as erased.

SLC Flash is used in commercial and industrial applications that require high performance and long-term reliability. Some applications include industrial grade Compact Flash cards or Solid State Drives (SSDs).

Multi-Level Cell (MLC) Flash

As the name suggests, there are multiple values that an MLC cell can represent. The values can be interpreted as four distinct states: 00, 01, 10, or 11.

Value	State
00	Fully Programmed
01	Partially Programmed
10	Partially Erased
11	Fully Erased

Table 3: MLC Levels

These four states yield two bits of information. As seen in table 3, the value of the two bits range from fully programmed to fully erased.
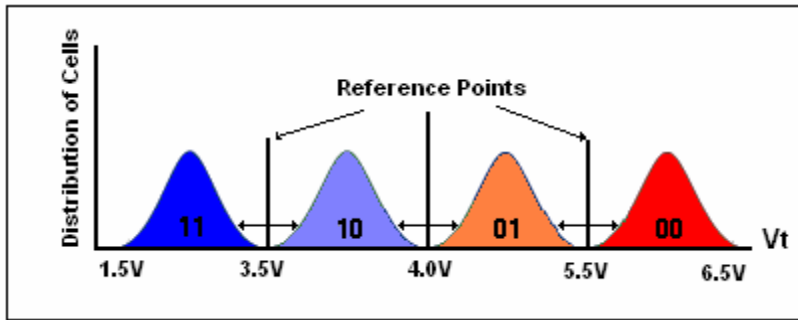
Figure 4: Voltage Reference for MLC

As seen in figure 2, a Flash cell's ability to store charge is why MLC technology works. Since the delta between each level has decreased, the sensitivity between each level increased. Thus, more rigidly controlled programming is needed to manipulate a more precise amount of charge stored on the floating gate. In order for a Flash cell to be considered MLC technology, the cell must exhibit two characteristics:

1. Precise charge placement
2. Precise charge sensing

Thus, MLC Flash works the same way as SLC Flash. The threshold voltage V_t, is used to manipulate the state of the Flash. Once again, the amount of charge on the floating gate is what determines the threshold voltage.

As seen in figure 4, current MLC technology uses two bits, or 4 levels. However, it is possible to hold more bits. Equation 1 is a generic equation to follow to determine how many states are needed for the desired bits.

Equation 1 $$States = 2^N$$

N is equal to the number of desired bits per cell. For example, for a cell to hold three bits, you need eight states equal to: 000, 001, 010, 011, 100, 101, 110, 111.

MLC Flash is used in consumer applications that do not require long term reliability such as consumer grade USB Flash drives, portable media players, and Compact Flash cards.

SLC and MLC Compared

Now that the differences between SLC and MLC have been explained, let's compare their specifications to help further make a distinction between the two grades.

	SLC	MLC	
Density	16Mbit	32Mbit	64Mbit
Read Speed	100ns	120ns	150ns
Block Size	64Kbyte	128Kbyte	
Architecture	x8	x8 / x16	
Endurance	100,000 cycles	10,000 cycles	
Operating Temperature	Industrial	Commercial	

Table 4: Specification Comparison of SLC and MLC

Let's compare each characteristic in table 4. Using the same wafer size, you can double the density of the MLC Flash by using the charge placement technology. Thus, MLC has greater densities.

The read speeds between SLC and MLC are comparable. Reading the level of the Flash cell compares the threshold voltage using a voltage comparator. Thus, the architecture change does not affect sensing. In general, the read speeds of Flash are determined by which controller is used.

The endurance of SLC Flash is 10x more than MLC Flash. The endurance of MLC Flash decreases due to enhanced degradation of Si. This is a main reason why SLC Flash is considered industrial grade Flash and MLC Flash is considered consumer grade Flash.

Higher temperatures cause more leakage in the cells. Combined with the increased sensitivity required to differentiate between the levels, this leakage will cause the sensors to read the wrong level. As a result, the operating temperature of MLC spans only the commercial range. Leakage is not significant in SLC Flash and thus, it can operate in an industrial temperature range.

Conclusion

Table 4 again summarizes the advantages and disadvantages of SLC Flash and MLC Flash.

	SLC	MLC
High Density		✓
Low Cost per Bit		✓
Endurance	✓	
Operating Temperature Range	✓	
Low Power Consumption	✓	
Write/Erase Speeds	✓	
Write/Erase Endurance	✓	

Table 5: Qualities of SLC and MLC

As discussed in the beginning of this whitepaper, it is important to evaluate what type of Flash memory your system needs. If performance and durability are essential for your system, SLC Flash incorporated. If low cost and high density are essential, MLC Flash is the right choice.

For Further Information

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