How Solid-state Drives Work

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**Actually, Seagate makes something called a hybrid drive, which combines solid-state and hard disk drives in one package. This model packs 750 gigabytes.**

**IMAGE COURTESY**[**AMAZON.COM**](http://www.amazon.com/)

In 1956, IBM shipped the world's first **hard disk drive**, or **HDD**, in the RAMAC 305 system. The drive used 50 24-inch (61-centimeter) platters, stored a meager 5 megabytes of data and took up more room than two refrigerators. Oh, and the cost? Just $50,000 ($421,147 in 2012 dollars).

Since then, [hard drives](http://computer.howstuffworks.com/hard-disk.htm) have grown smaller, more capacious and, thankfully, less expensive. For example, the Seagate Momentus laptop hard drive, with a form factor of just 2.5 inches (6.4 centimeters), offers 750 gigabytes of storage for less than $100. But even with advanced protection technologies, the Momentus drive, like all HDDs, can crash and burn, taking precious data with it. That's because hard drives have mechanical parts that can fail. Drop a laptop, and the read-write heads can touch the spinning platters. This almost always results in severe data loss.

Luckily, a new kind of computer drive could make crashes as obsolete as your Apple IIe. Known as a **solid-state drive**, or **SSD**, it uses semiconductor chips, not magnetic media, to store data. Your computer already comes with chips, of course. The motherboard contains some that house your device's system memory, or [RAM](http://computer.howstuffworks.com/ram.htm), which is where information is stored and processed when your computer is running. Computer types refer to such memory as **volatile memory** because it evaporates as soon as your machine loses power. The chips used in a solid-state drive deliver **non-volatile memory**, meaning the data stays put even without power. SSD chips aren't located on the motherboard, either. They have their own home in another part of the computer. In fact, you could remove the hard drive of your laptop and replace it with a solid-state drive, without affecting any other essential components.

But why would you want to? And what exactly would the drive look like -- a green, printed circuit board or a brushed-metal box resembling a traditional hard drive? We'll answer those questions on the following pages, but before we give your machine a makeover, let's review a few computer science basics.

**What Is a Solid-state Drive?**

In computer lingo, there's a difference between memory and storage. Random-access memory, or [RAM](http://computer.howstuffworks.com/ram.htm) (or simply memory), holds the program a computer is executing, as well as any data. Like a person's short-term memory, RAM is fleeting and requires power to do its job. Storage, on the other hand, holds all the stuff of your digital life -- apps, files, photos and music. It retains that stuff even if the power is switched off. Both RAM and storage boast their capacity based on the number of bytes they can hold. For a modern computer, RAM typically comes in 4, 6 or 8 gigabytes. Storage can have almost 100 times more capacity -- the hard drive of a typical laptop, for example, can hold 500 gigabytes.

Here's where it gets a little sticky. Some storage devices have what's referred to as **flash memory**, a confusing term that blurs the line between RAM and storage. Devices with [flash memory](http://computer.howstuffworks.com/flash-memory.htm) still hold lots of info, and they do it whether the power's on or not. But unlike hard drives, which contain spinning platters and turntable-like arms bearing read-write heads, flash-memory devices have no mechanical parts. They're built from transistors and other components you'd find on a computer chip. As a result, they enjoy a label -- **solid state** -- reserved for devices that take advantage of semiconductor properties.

There are two types of flash memory: NOR and NAND. Both contain cells -- transistors -- in a grid, but the wiring between the cells differs. In **NOR flash**, the cells are wired in parallel. In NAND flash, the cells are wired in a series. Because NOR cells contain more wires, they're bigger and more complex. **NAND cells**require fewer wires and can be packed on a chip in greater density. As a result, NAND flash is less expensive, and it can read and write data much more rapidly. This makes NAND flash an ideal storage technology and explains why it's the predominant type of memory in solid-state drives. NOR flash is ideal for lower-density, high-speed, read-only applications, such as those in code-storage applications.

Armed with this background, we can offer a more precise definition of a solid-state drive: It's a device that uses NAND flash to provide non-volatile, rewritable memory. In computers, a solid-state drive can be used as a storage device, replacing the traditional hard disk drive. In fact, manufacturers produce SSDs with shapes and footprints that resemble HDDs so the two technologies can be used interchangeably. But that's where the similarities end. If you cracked open the shell of a solid-state drive, you wouldn't see platters and actuator arms. Let's do that next.

**Memory Sticks and Thumbdrives**

If flash memory sounds vaguely familiar, then you probably have at least one or two thumbdrives -- or memory sticks -- in your computer bag. The little devices, which have surprisingly large capacity and allow you to transfer data quickly between machines, are known officially as USB flash drives. They use the same NAND flash technology and, in many ways, can be thought of as the predecessors of today's solid-state storage devices.

**How Solid-state Drives Save Data**



**In this picture, it's easy to see this hard drive's platters, which look a bit like CDs stacked one on top of another, and an actuator arm.**

**©**[**ISTOCKPHOTO.COM**](http://www.istockphoto.com/)**/JPA1999**

On the outside, solid-state drives look just like HDDs. They're rectangular in shape, covered in a brushed-metal shell and sized to match industry-standard form factors for hard drives -- typically 2.5 and 3.5 inches (6.4 and 8.9 centimeters). But beneath the silver exterior, you'll find an array of chips organized on a board, with no magnetic or optical media in sight. Much of that stuff could fit into a smaller space, but SSD manufacturers dress up their components in extra "housing" to make sure they fit into existing drive slots of laptops and [desktop PCs](http://computer.howstuffworks.com/pc.htm).

Compared to the stark simplicity of a solid-state drive, the innards of a hard drive are a marvel of motion, sound and activity. Round platters, arranged on a spindle, can spin at 7,200 revolutions per minute. An **actuator arm**, branching into multiple read-write heads, races across the platters in too-fast-to-be-seen bursts of speed. The arm connects to the actuator block, which holds the instructions for moving the read-write heads. As those instructions are called up, sometimes up to 50 times a second, the arm pivots at one end and moves the heads in unison over the platters. Once a head arrives at a certain location on a platter, an electromagnet produces a magnetic field, which aligns data-carrying domains in the underlying track. Each domain can be aligned in one of two possible directions -- 1 or 0. As these alignments change, they form patterns that correspond to discrete chunks of digital information.

The NAND flash of a solid-state drive stores data differently. Recall that NAND flash has [transistors](http://electronics.howstuffworks.com/transistor.htm) arranged in a grid with columns and rows. If a chain of transistors conducts current, it has the value of 1. If it doesn't conduct current, it's 0. At first, all transistors are set to 1. But when a save operation begins, current is blocked to some transistors, turning them to 0. This occurs because of how transistors are arranged. At each intersection of column and row, two transistors form a cell. One of the transistors is known as a **control gate**, the other as a **floating gate**. When current reaches the control gate, electrons flow onto the floating gate, creating a net positive charge that interrupts current flow. By applying precise voltages to the transistors, a unique pattern of 1s and 0s emerges.

NAND flash comes in two flavors based on how many 1s and 0s can be stored in each cell. **Single-level cell** (**SLC**) **NAND** stores one bit -- either a 1 or a 0 -- per cell. **Multi-level cell** (**MLC**) **NAND** stores two bits per cell. MLC flash delivers higher capacity, but it wears out more quickly (yes, wears out -- we'll cover that more in a couple of pages). Still, it's less expensive per gigabyte than SLC and, as a result, is the preferred technology in almost all consumer-level SSDs.

Cost has been one of the biggest hurdles of flash memory and, consequently, of solid-state drives. But in recent years, costs have dropped significantly. At the same time, advances in NAND flash development have taken what's good about the technology and made it even better. Up next, we'll look at the advantages of solid-state drives.

**Sold on SSDs: Advantages of Solid-state Drives**



**This 480-gigabyte solid-state drive made by SanDisk was retailing for $372.91 (on sale) when we last checked on Amazon. List price was $699.99.**

**IMAGE COURTESY**[**AMAZON.COM**](http://www.amazon.com/)

You've invested in a top-of-the-line [laptop](http://electronics.howstuffworks.com/gadgets/high-tech-gadgets/10-things-to-look-for-when-buying-laptop.htm) with a 500-gigabyte hard drive, and it's working great. You've got all your photos and videos, your entire music library, five half-finished novels and applications galore packed onto the drive's platters. Why would you consider swapping the HDD for a solid-state drive? Didn't Dad always say, "If it ain't broke, don't fix it"?

Maybe Dad didn't own any hard drives. The harsh reality is that HDDs can and do fail, often more frequently than their technical specs would seem to suggest. For example, hard drive manufacturers rate the reliability of their products using a measurement known as **mean time between failures**, or **MTBF**. A typical consumer hard drive has a MTBF rating of 500,000 hours, meaning that, in a sample of drives tested, there would be one failure every 500,000 hours of testing. That's one failure every 57 years, which sounds pretty good, right? Unfortunately, MTBF scores are misleading. They come from a statistical evaluation based on a small sample size and a short amount of time. In reality, you'd also want to consider a typical HDD's warranty and service life (three to five years or so), along with the MTBF score. Because they have no moving parts, SSDs can deliver improved reliability. They can rate up to 2.5 million hours MTBF, which probably means a few more years added to the lifespan of the device.

An even bigger deal is the performance of solid-state drives compared to HDDs. With no moving heads and spinning platters, SSDs can access one piece of data as quickly as any other piece, even if they aren't in the same proximity. The speediness of the device manifests itself in all key CPU tasks, from booting up system software to opening files to reading and writing data. The following bullets compare SSDs and HDDs on these critical activities:

**Boot-up time** (Windows 7): 22 seconds (SSD), 40 seconds (HDD)

**Data read-write speed**: 510-550 megabytes per second (SSD), 50-150 megabytes per second (HDD)

**Excel file open speed**: 4 seconds (SSD), 14 seconds (HDD)

All of this adds up. Even a casual user will notice a significant increase in the performance of a computer equipped with an SSD. But a power user will really feel the difference. [Game designers](http://electronics.howstuffworks.com/video-game-designer.htm), animators and other folks rendering huge output files were early adopters of SSDs just because of the cumulative time they could save reading and writing large files. Today, gamers, photographers and anyone editing graphics or video files will appreciate the boost in speed a solid-state drive delivers.

Finally, SSDs consume far less power than traditional hard drives, which means they preserve battery life and stay cooler. They're also super quiet, with none of the whirring and clicking you get with HDDs. You'll appreciate this more if you're a frequent traveler and often have your computer perched on your knees, but even if your laptop remains docked most of the time, a cooler, quieter machine can make a noticeable difference in the comfort of your workspace.

Of course, no technology is perfect, and SSDs are far from it. On the next page, we'll examine the negatives of NAND flash and why a combination of technologies may be the best solution.

**Not Sold on SSDs: Disadvantages of Solid-state Drives**

Trading out your [hard drive](http://computer.howstuffworks.com/hard-disk.htm) for a solid-state drive seems like a no-brainer. But before you make the switch, you should understand the limitations of SSDs. Like cost. Even though prices have decreased steadily, NAND [flash memory](http://computer.howstuffworks.com/flash-memory.htm) is still expensive. To get 240 gigabytes of storage on a PNY Prevail SSD, for example, you might shell out $280. That's $1.17 per gigabyte. The Western Digital Scorpio Blue HDD, on the other hand, gives you 250 gigabytes of storage for roughly $65. That works out to be $0.26 per gigabyte.

Then there's the issue of longevity. The NAND flash used in SSDs can only be used for a finite number of writes. Why? Because SSDs can't write a single bit of information without first erasing and then rewriting very large blocks of data at one time. Each time a cell goes through an erase cycle, some charge is left in the floating-gate transistor, which changes its resistance. As the resistance builds, the amount of current required to change the gate increases. Eventually, the gate can't be flipped at all, rendering it useless. This decaying process doesn't affect the read capabilities of SSD, because reading only requires checking, not changing, the voltages of cells. As a result, NAND flash can "rot" into a read-only state.

Some manufacturers use something called **wear-leveling** to counteract the degradation of NAND flash. This technique distributes data writes across all blocks to make sure the flash memory wears evenly, but even with that, SSDs will decay over time. NAND flash memory of the single-level cell variety generally delivers 50,000 program/erase cycles. Flash of the multi-level cell variety -- the kind used in consumer-level products -- wears out after about 5,000 cycles.

For this reason, many data centers and techies use a combination of SSD and HDD. One approach is to use a solid-state drive in a laptop and a traditional hard drive as external storage holding music, photos and other files. This combines the best of both worlds -- the ultrafast, random data access of SSD with the relatively inexpensive, high capacity of HDD. If this sounds good to you, you'll want to start shopping for a suitable solid-state drive. Leading manufacturers include Samsung, Seagate, SanDisk, PNY, Toshiba and OCZ Technology. And don't forget about Intel, which offers a robust line of drives, as well as several tools to help you choose the right technology and calculate how much time and money you can save if you make the switch to SSD.