

Single-Package SSD and Ultra-Small SSD Module Utilizing PCI Express^(†) Interface

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The transition of storage products from hard disk drives (HDDs) to solid-state drives (SSDs) has accelerated with the widespread dissemination of thin and light mobile PCs and tablets. Although HDD-compatible form factors were used at the initial stage of introducing SSDs, new SSD-specific small form factors are also now in use.

In response to the demand for lightweight storage products with a smaller form factor, Toshiba has developed a single-package SSD incorporating NAND flash memory chips and an SSD controller in a package with dimensions of 16 mm × 20 mm × 1.65 mm as the world's first single-package SSD with a PCI Express^(†) interface^(※1). We have also developed an ultra-small card-edge type detachable SSD module containing the single-package SSD and a DC/DC converter with a size of 22 mm × 30 mm as the world's smallest SSD module with a PCI Express^(†) interface^(※1).

1. Introduction

In 2008, Toshiba developed the world's first SSD using multi-level-cell (MLC) NAND flash memories with a capacity of 128 Gbytes. The new SSD was embedded in its slim and lightweight mobile notebook PCs with a long battery life. This SSD met various needs of notebook PC users, including high read/write performance, high shock and vibration resistance, high reliability, low power consumption, light weight, and low cost.

Since then, SSD adoption in PCs has been increasing, driving the needs for even higher performance, smaller form factor, lower power consumption, and lower cost. For example, in 2008, the SSD's sequential-read speed was 100 Mbytes/s at the maximum; now, SSDs have a sequential-read speed exceeding 500 Mbytes/s. Accompanying the increase in performance, SSD manufacturers have replaced Serial Advanced Technology Attachment (SATA) 3 Gbit/s interfaces with SATA 6 Gbit/s interfaces. Designed as drop-in replacements for traditional HDDs, the earliest SSDs had a 1.8-inch form factor (typically measuring 53.6 mm in width × 70.6 mm in length × 3.0 mm in height and 15 g in weight). As 2.5-inch HDDs became the dominant storage device for notebook PCs, SSDs were also made available in the 2.5-inch form factor. In the meantime, compact form factors specific to SSDs have been standardized. For example, SSDs measuring 22 mm in width × 80 mm in length × 2.23 mm in height and 6.4 g in weight, which are considerably smaller than 1.8-inch SSDs, are widely used now. With the evolution of SSDs, slim PC chassis

designed specifically for the housing of an SSD have become commonplace. NAND flash memories have also evolved from 16 Gbit chips fabricated with a 56 nm process to the second-generation 128 Gbit chips fabricated with a 19 nm process. In recent years, manufacturers of SSDs have been working to reduce their standby power consumption, and as a result, most SSDs consume less than 5 mW in standby mode.

Notebook PCs are becoming increasingly slim. Recently, many 2-in-1 detachables, or notebook PCs with a detachable keyboard, have appeared that can be converted into a tablet. Because a thin battery is located behind the liquid crystal display (LCD) in 2-in-1 detachables, there is increasing demand for an even smaller and slimmer storage device to allow for a larger battery.

The ATA commands used in the conventional SATA SSDs were originally designed as an extension of the parallel interface commands of HDDs. Since the ATA commands are not optimized for SSDs, they have failed to draw the best performance out of SSDs.

In order to resolve these issues, the NVM Express^(†) specification was developed and released. NVM Express^(†) is a logical device interface specification for accessing SSDs attached through the PCI Express^(†) bus at the physical layer.

In response to the changing market environment, we have developed the THNSNN128GTY7 and THNSNN256GTY7, the world's first single-package SSDs with a PCI Express^(†) interface (**Figure 1**). Integrating an SSD controller and NAND flash memories in a single semiconductor package measuring only 16 mm in width

(※1) As of January 2015 (as researched by Toshiba)

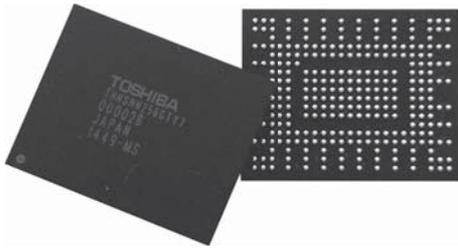


Figure 1. Single-package SSD.

The single-package SSD integrates a controller and NAND flash memories in a package measuring 16 mm in width by 20 mm in length by 1.65 mm in height and has a PCI Express⁽¹⁾ interface.



Figure 2. Ultra-small SSD module.

The world's smallest detachable SSD module has a card-edge PCB measuring 22 mm by 30 mm on which a single-package SSD is soldered and provides a PCI Express⁽¹⁾ interface.

× 20 mm in length and 1.65 mm in height, these single-package SSDs are the ultimate next-generation small and high-performance storage devices for mobile PC applications. We have also developed the world's smallest ultra-small SSD modules, the THNSNN128GSX7 and THNSNN256GSX7, measuring 22 mm × 30 mm that incorporate a single-package SSD and a detachable card edge connector (**Figure 2**).

The single-package SSDs and the ultra-small SSD modules have been commercialized as the BG1 Series.

2. Product overview

Table 1 shows the main specifications of the BG1 Series.

In order to promote widespread use of SSDs, the form factors and electrical specifications of SSDs must be standardized so that different manufacturers can launch compatible SSDs in various designs and shapes. To fulfill this purpose, industry standards must be well planned and designed. Therefore, we are actively engaged in the activities of PCI-SIG⁽²⁾, an industry association, for the standardization of SSD form factor and signal standards.

Our single-package SSDs integrate an SSD controller and NAND flash memories into a ball grid array (BGA) package with 291 solder balls on its bottom.

These single-package SSDs operate from 3.3, 1.8, and 1.2 V power supplies that are commonly used in PCs.

Table 1. Main specifications of single-package SSDs and ultra-small SSD modules

Type		Single-package SSDs		Ultra-small SSD modules	
Model		THNSNN128GTY7	THNSNN256GTY7	THNSNN128GSX7	THNSNN256GSX7
Capacity (Gbytes)		128	256	128	256
Dimensions (mm)	Width	16		22	
	Length	20		30	
	Height	1.40	1.65	2.20	2.45
Weight (g)		0.80	0.95	2.30	2.45
Physical interface		PCI Express ⁽¹⁾ , Revision 3.0 Gen2, 2 lanes			
Logical interface		NVMe Express ⁽¹⁾ , Revision 1.1			

Because of this, our single-package SSDs need only a simple voltage regulator, but not any complex voltage conversion circuit (DC/DC converter). Whereas some of the commercially available single-package NAND flash-based storage devices with multiple power supplies have precise power-on and power-off sequencing, our single-package SSDs need no power sequencing, reducing the designing burden involved in a host computer.

eMMC⁽³⁾ and Universal Flash Storage (UFS) that are widely used for smartphone applications are housed in a BGA package with a ball pitch of 0.5 mm, which needs a build-up multi-layer printed circuit board (PCB) that is manufactured by a costly iterative process of fine-trace etching and laser hole-drilling. Since smartphones and other handheld products have a small PCB, the PCB does not have a significant impact on the overall product cost. For PCs, however, it is desirable to be able to use a less costly through-hole multi-layer PCB in which different layers are interconnected via through-holes. Allowing for the use of a through-hole PCB, Toshiba's single-package SSDs have a ball pitch of 0.8 mm.

Input/output (I/O) pads necessary for SSD-to-host communications, power supplies, and many other functional signals are distributed across the PCB. The purpose of this is to reduce case-to-board thermal resistance in order to enhance the heat transfer to the PCB and to improve soldering reliability.

A controller and NAND flash memories are housed in separate packages in conventional SSDs. Thus, SSDs can be assembled after the NAND flash memory packages have been tested. In contrast, our single-package SSDs provide a function for post-assembly testing since they are assembled prior to the testing of NAND flash memories. Furthermore, our single-package SSDs have several pads reserved for future use to allow easy extension of the specification while maintaining compatibility.

Our single-package SSDs are designed to require as few peripheral components as possible on the PCB.

Whereas some of the conventional single-package SATA SSDs need an external crystal oscillator, our single-package SSDs eliminated the need for it. Our single-package SSDs require only capacitors for differential-signal and power supply decoupling without any special peripheral components. Consequently, components occupy less PCB area, and a reduction in the number of external components also contributes to the reduction in overall size of a system board. The SSD solution footprint can be reduced by roughly 80% by replacing the currently widely used detachable SSD with the M.2 form factor measuring 22 mm × 80 mm by a single-package SSD of the BG1 Series. At present, slim mobile PCs and tablets generally have a sheet battery and a system board on the backside of an LCD. The use of a single-package SSD helps to reduce the system board size and thus increase the battery size.

In addition to the single-package SSDs, we have also developed a detachable ultra-small SSD module compliant with the M.2 specification (measuring 22 mm × 30 mm). Since the M.2 standard specifies a single-supply operation at 3.3 V, a DC/DC converter is necessary in addition to a single-package SSD. However, since few other components are needed, the SSD modules have been successfully implemented on a small PCB.

Their host interface supports the latest technologies including the L1.2 power-saving state of PCI Express^(†) and the autonomous power state transition of NVM Express^(†).

As described above, an increase in the PC battery size and a reduction in the SSD power consumption are expected to contribute to increasing the battery operating time of a PC.

3. Controller

In order to realize low-cost and low-power-consumption SSDs, our SSD controller has a DRAM-less design and incorporates low-power technology.

3.1 DRAM-less design

Typically, SSD controllers use DRAMs. However, with the increasing SSD capacity, the necessary DRAM capacity is also increasing, making its cost no longer negligible. To resolve this issue, a DRAM-less design has been adopted.

The purpose of using DRAMs in an SSD is to increase the data transfer rate by storing the management information of NAND flash memories in faster DRAMs. However, in a DRAM-less design, a small static RAM (SRAM) in the SSD controller handles management information, making it necessary to access NAND flash memories frequently.

So that the read/write performance will not be degraded owing to the disuse of DRAMs, our SSD controller incorporates hardware logic dedicated to the

handling of accesses to user data and the management information of NAND flash memories.

3.2 Low-power technology

In order to reduce leakage current in standby mode, the new SSD controller uses a greater percentage of low-leakage cells than its predecessor. To make up for the lower speed of low-leakage cells, they are driven at a higher voltage than other cells.

In addition, in order to further reduce power consumption, our SSD controller incorporates a retention SRAM and retention flip-flops that retain data while the power supply to their peripheral logic is shut off.

4. Organization and thermal design of single-package SSDs

SSDs come in various form factors, such as HDD-compatible 2.5-inch form factor SSDs and M.2-compliant SSD modules. For example, an M.2 2280 SSD module has a footprint of 22 mm × 80 mm. Our single-package SSDs integrate 16 NAND flash memory chips, a controller and passive components in one BGA package. They occupy only approximately one-fifth the mounting area of an M.2 2280 SSD module (**Figure 3**). Because of the high-density integration, the heat generated by the controller could limit the SSD performance or pose a reliability problem. To avoid these situations, it is necessary to efficiently remove the heat produced inside the package so that the temperatures of NAND flash memory chips will not increase.

Most of the heat generated inside the package is transmitted to the PCB and the casing via balls. Heat removal can be improved by evenly distributing many pads across the PCB, including its periphery. In order to reduce a rise in temperature of the NAND flash memory chips, they are placed beside the controller instead of

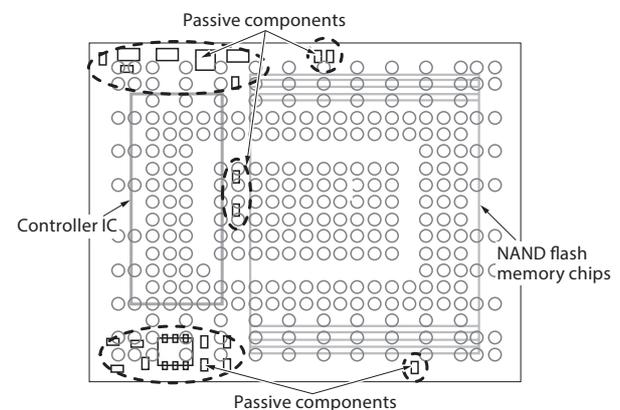


Figure 3. Schematic diagram of internal structure of single-package SSD.

The solder balls are evenly distributed on the bottom of the package. Sixteen NAND flash memory chips are stacked vertically in a staggered manner, and the controller and passive components are placed beside the NAND flash memory chips.

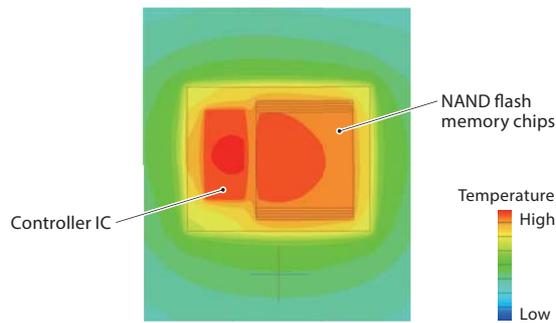


Figure 4. Result of temperature increase simulation.

The heat generated by the controller conducts to the NAND flash memory chips, increasing their temperature. The increase in temperature of the NAND flash memory chips was reduced by placing the controller beside the NAND flash memory chips.

stacking them on the controller since much heat generated by the controller will escape to balls more easily (**Figure 4**). The foregoing has resolved the thermal issue with high-density board assembly.

5. Thermal design of ultra-small SSD modules

Toshiba's SSD modules integrate a single-package SSD, a power supply circuit and other components in an M.2-compliant 2230 card. Since SSD modules in a card form factor are plugged into a system board via

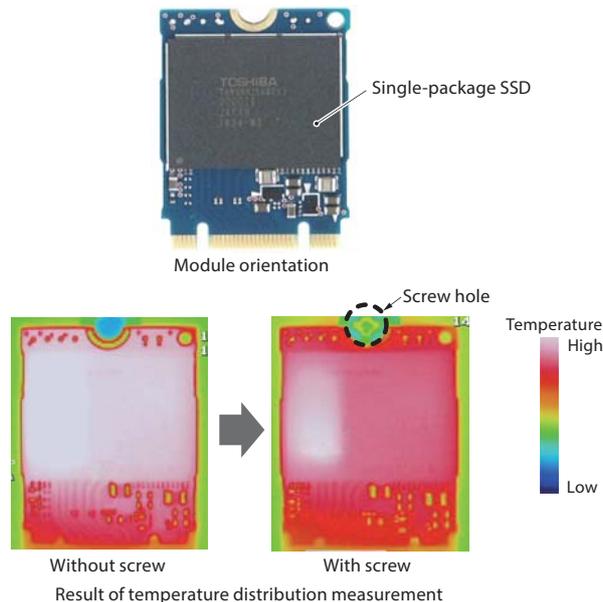


Figure 5. Thermal effect of SSD module affixed to evaluation board with screw.

Since the module measures only 22 mm by 30 mm, affixing it to a motherboard with a screw significantly helps to remove heat. Compared with the case in which the module is plugged into a motherboard without a screw, the temperature of the controller IC dropped by 15°C.

a connector, they do not have a good heat removal capability. Because small modules have less area from which heat can escape, heat tends to persist internally. The M.2 standard stipulates that the opposite side of the connector be affixed to a system board with a screw. We have confirmed that the screw helps to decrease the module temperature. **Figure 5** shows the temperature distribution in an ultra-small SSD module when it is plugged into an evaluation board. Without a screw on the upper side, the entire surface of the single-package SSD became hot. When the SSD module was affixed to the evaluation board with a screw, the temperature of the single-package SSD dropped except near the heat-generating controller. An internal temperature sensor showed that the screw helped to decrease the controller temperature by 15°C.

6. Conclusion

PCs will continue to become slimmer and more lightweight, and the uptake of tablets will continue to climb. Demand is expected to increase not only for high-performance SSDs but also for small and lightweight SSDs. Furthermore, to prolong the battery operating time of notebook PCs and tablets, demand for SSDs with lower power consumption is increasing. To address these market needs, Toshiba will continue to develop not only small and lightweight SSDs but also SSDs with a good performance/power consumption balance.

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Notes:

"-inch" means the form factor of HDDs or SSDs. It does not indicate drive's physical size.

This publication may include Toshiba's original estimation, and/or data based on Toshiba's evaluation.