32-bit Microcontroller Wafer-Level Chip-Scale Package (WLCSP)

AN4383

Introduction

Wafer-Level Chip-Scale Packages (WLCSP) are the smallest possible packages that scale down to the same size as the silicon die. These are manufactured such that bumping, ball drop, and testing are done at the wafer-level. It is after these processes that the wafer is diced and made available, usually in tape and reel media. For conventional lead frame-based packages, such as QFPs and QFNs, the wafer is diced first, and then the die is attached on the lead frame with the wire bonds followed by encapsulation in a mold compound resulting in packaged silicon. Testing is done on the packaged silicon and is made available in tray, tube, or tape and reel media.

Notes:

1. Bumping is an advanced process that provides an electrical connection between the silicon die and the solder ball.
2. The ball drop is a process where the solder balls are attached to the bumped silicon die.

The inherent manufacturing process of WLCSP eliminates the lead frame and mold compound, making it a fragile package compared to the lead-frame based packages. Due to this, WLCSP packages are deemed undesirable for typical automotive and industrial applications, while their small size earns a distinction in space-constrained applications, such as smart phones, wearables, headphones, and tablet accessories like stylus pens. The smallest WLCSP package within the Microchip 32-bit portfolio is a SAMD11 Cortex® M0+ MCU with 20 leads and a 1.9 mm x 2.4 mm size. WLCSPs are also offered for higher performance Cortex M4F families including the SAM D5x/E5x and SAMG5x series. In addition to WLCSP packages, Microchip offers tiny lead-frame based packages for their 32-bit PIC® and SAM MCU portfolios, which are robust and easier to assemble on the PCB. These include a 24-pin VQFN 4 mm x 4 mm, and 32-pin VQFN 5 mm x 5 mm packages. Depending on the type of space-constrained applications, these VQFNs are more popular and can be considered an alternative to WLCSPs where higher temperatures, mechanical stress, handling, and assembling are of concern. To help customers with the assembly and surface mounting of the WLCSP packages, guidelines are provided in the later sections of this document.

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1. Bootloaders

This section provides information about Microchip WLCSP family of devices that come with a preprogrammed bootloader, the protocol used, and pinout details. It also provides details on the non-WLCSP family of devices that have bootloader support.

The bootloader library can be used to upgrade the firmware on a target device without the need for an external programmer or debugger.

A bootloader is a small application that starts the operation of the device. A bootloader does not fully operate the device but can perform the following functions before starting the main application:

- Firmware upgrades
- Application integrity
- Starting the application

The following table provides a list of the WLCSP family of devices that include a factory-programmed bootloader.

Table 1-1. List of WLCSP Family of Devices

Family	Application Note	Protocol	Comments
SAMD1x	—	UART	—
SAMD20	AT09002	I²C/SPI	**AT09002** SAM I²C - SPI bootloader
SAMD21	AT09002	I²C/SPI	**AT09002** SAM I²C - SPI bootloader
SAMC2x	AT09002	UART/I²C	**AT09002** SAM I²C - SPI bootloader
SAML1x	AN2699	UART	**AN2699** SAM UART bootloader
SAML21	AT09002	I²C/SPI	**AT09002** SAM I²C - SPI bootloader
SAML22	AT09002	I²C/SPI	**AT09002** SAM I²C - SPI bootloader
SAMD5x/ E5x	—	UART	—
SAMG5x	AT09002	I²C	**AT09002** SAM I²C - SPI bootloader

Note: Devices in the WLCSP include a factory-programmed bootloader. Contact a local Microchip sales office for more information.

Hardware Pin Configurations

The following table provides the I²C and SPI pin configurations for the WLCSP bootloaders.

Table 1-2. I²C and SPI Pin Configurations

Pin Description	SAML21	SAML22	SAMD1x	SAMD20	SAMD21	SAMC2x	SAMG5x
Reset	RESETN	RESETN	RESETN	PB12	RESETN	RESETN	RESETN
SDA	PA08	PA12	PA06	PA08	PA08	PA22	PA03
SCL	PA11	PA13	PA05	PA09	PA11	PA23	PA04
MISO	PA08	PA12	PA06	PA08	PA08	-	PA12
MOSI	PA11	PA15	PA05	PA18	PA11	-	PA13
SCK	PA09	PA13	PA07	PA09	PA09	-	PA14

.....continued							
Pin Description	SAML21	SAML22	SAMD1x	SAMD20	SAMD21	SAMC2x	SAMG5x
Handshake pin	PA27	PA16	PA14	PB13	PA14	-	PA01
CS	PA10	PA14	PA04	PA17	PA10	-	PA11

The following table provides the UART pin configurations for the WLCSP bootloaders.

Table 1-3. UART Pin Configurations

Device	UART TX	UART RX	Entry
SAMC2x	PA22	PA23	PA19
SAML1x	PA16	PA17	PA19
SAMD5x	PB12	PB13	PA27

Notes:

1. The bootloader entry pin has an active-low level, and its value is sampled at the beginning of the bootloader execution. Although an internal pull-up resistor is enabled before sampling the pin, it is recommended that the bootloader entry pin is pulled-up externally for improved noise immunity.
2. The UART settings used by this bootloader are 115200 8N1.
3. This bootloader supports UART baud rate auto-tuning. This feature may be useful for Hosts that cannot set the exact value of the baud rate. Auto tuning can be initiated at any point of the operation. To perform auto-tuning, the Host must send a break signal (at least 11 bits of low level) followed by a character 0x55. No response is expected for this request.

The following table provides a list of non-WLCSP family of devices that include a factory-programmed bootloader.

Table 1-4. Non-WLCSP Family of Devices with Factory Programmed Bootloader

Family	Protocol	Comments
SAM4S/ SAM4E/ SAM4C/ SAM3x	UART/USB	16 kB ROM with embedded bootloader routines (UART, USB) and IAP routine.
SAM E70/ S70/V70/V71	UART/USB	16 kB ROM with embedded bootloader routines (UART, USB) and IAP routine.
PIC32CM LE/LSx	USB/I^2C	The bootloader resides in the Flash memory location (0x0000-0000) and utilizes up to 4KB of Flash memory. It comes with default protection against write/erase through the SULCK and BOOTPROT fuse settings.

Options to program bootloaders are as follows:

- Microchip pre-programmed at the wafer level (QuickTime Programming)
- Microchip off-board programming (microchipDIRECT programming services)
- On-board programming by customer
- Off-board programming by customer

How to use bootloaders:

- To know how the bootloader library works, refer to the https://github.com/Microchip-MPLAB-Harmony/bootloader.
- For additional information on the PIC32CM LE/LS family bootloader, refer to the github.com/Microchip-MPLAB-Harmony/bootloader_apps_pic32cm_le_ls.

2. Programming

Microchip WLCSP can be pre-programmed with customer code at the wafer level or the package level. The Quick Time Programming (QTP) done at the wafer level gets a unique pattern specific to the customer ordering the part. For programming at the package level, customers can make use of microchipDIRECT programming services by uploading their `hex` code.

3. Ordering Guidelines

Microchip WLCSPs offered in 32-bit MCUs are available in temperature versions ranging from -40°C to 85°C, and -40°C to 105°C. They cannot be canceled or returned. Customers cannot push out the Customer Requested Date (CRD), but they can pull in. WLCSPs ordered for production purposes must meet the Minimum Orderable Quantity (MoQ). For pilot or evaluation builds, approval is required to allow orders below the MoQ. Contact a local Microchip sales office for information if an order below the MoQ is needed, or check microchipDIRECT for the MoQ information of the desired device.

4. WLCSP Handling During Packaging, Shipping, and Surface Mount Technology (SMT)

The following information details handling procedures that must be used with a WLCSP product packed in a Moisture Barrier Bag (MBB) and intended for surface mount applications. Following these handling guidelines will ensure that components maintain their as-shipped dry state, alleviating package cracking and other moisture-related stress-induced concerns that may be associated with the surface mount process. Manual handling of parts with tweezers must be avoided due to the risk of chip out (cracks in the silicon).

1. **Incoming Inspection:**
   Upon receipt, shipments should be inspected for bag integrity. There should not be holes, gouges, tears, or punctures of any kind that expose either the contents or the inner layer of the bag.
2. **Storage Conditions/Shelf Life:**
   When MSL-1 devices are stored according to the JEDEC specification J-STD-033, it has unlimited. shelf life.
3. **Opening an MBB:**
   To open an MBB, cut across the top of the bag, care should be taken not to damage enclosed materials. Once the bag has been opened, follow the guidelines for ambient exposure time in the following section to ensure that devices are maintained below the critical moisture level.
4. **Manufacturing Conditions/Floor Life:**
   Microchip classifies surface mount components into levels of moisture sensitivity, the labels on the MBB list the moisture sensitivity level and the allowable floor life. Microchip recommends that once the MBB is opened, components from the bag be surface mounted and reflowed within the time indicated on the MBB label. This time is based on a manufacturing environment, that is not more extreme than 30°C/60% RH and a maximum component body temperature during solder reflow of 260°C. If the component cannot be mounted within this time frame, they should be put into a storage environment immediately, as specified in J-STD-033, or sealed into an MBB as soon as possible.
5. **Resealing an MBB:**
   If users need to reseal the MBB for any reason, Microchip recommends the following guidelines to ensure that the bag seal does not allow moisture into the bag. The seal area must not exhibit any separation when subjected to the load and temperature conditions specified in the JEDEC J-STD-033 specification. The integrity of the seal is vital to the storage life of the devices.

5. Rework

The WLCSP parts removed during PCB rework should not be reused for final assemblies unless the part needs to be used for further Failure Analysis (FA) work.

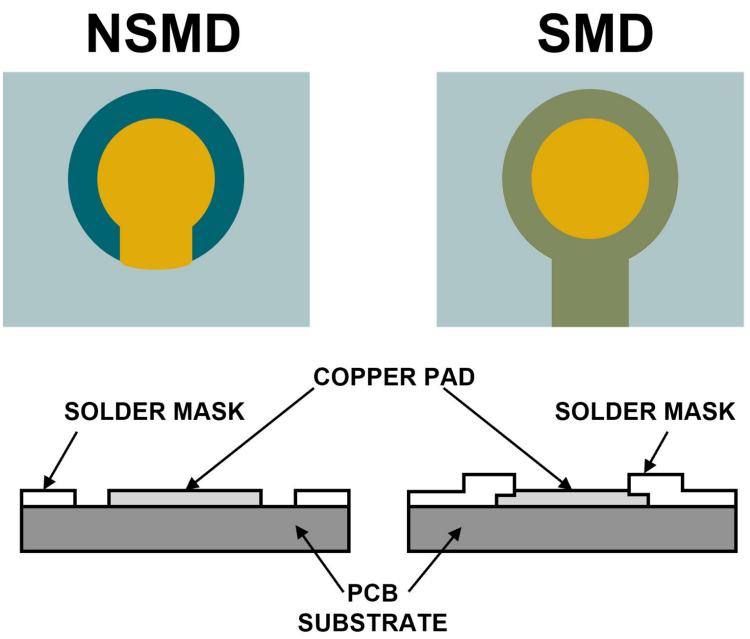
The WLCSP rework process is similar to the BGA-type package rework process. The rework process should use the following steps:

- **Part Removal**: The failed part should be removed from the board by applying hot air on the top of the component and the bottom heating the PCB. Discard the removed failed part if it is not needed for FA work.
- **PCB Cleaning**: The PCB land site must be cleaned and dressed for the attachment of the new component. Either a de-soldering system or iron with solder wick method can be used to effectively remove the residual solder without damaging the solder mask material and the pads. Note that the applied temperature should not be more than 245°C, otherwise, the copper pads on the PCB may peel off.
- **Solder Paste Deposition**: A mini stencil with the same thickness and aperture openings as the production stencil should be used to deposit the solder paste. The printed solder paste must be inspected to ensure uniform and sufficient volume is deposited before the part placement.
- **Part Placement**: A WLCSP reworking station with a vacuum nozzle and vision system should be used to pick the new WLCSP part and accurately align and place it on the corresponding footprint
- **Rework Reflow**: The replaced WLCSP component is then soldered to the PCB using a temperature profile similar to the production reflow profile. The WLCSP reworking station typically has a programmable reflow profile to be selected for a given part.

6. Surface-Mount Technology (SMT) Guidelines and PCB Best Practices

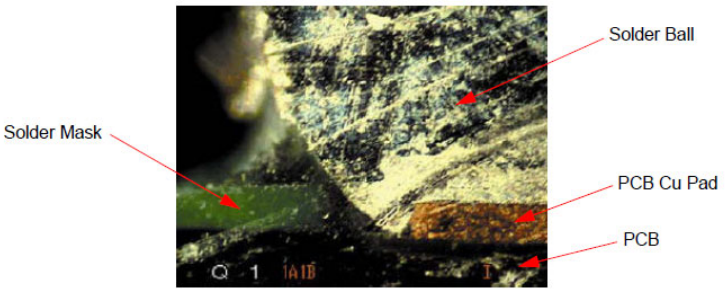
The WLCSP is a surface-mountable package with bottom ball termination of its external connections. The land pattern design for all WLCSP is based on the IPC-7351 and IPC-7095 standards. A Non Solder Mask Defined (NSMD) pad design is recommended for all board pads, as shown in the following figure.

Figure 6-1. NSMD and SMD Board Pad Definition



The NSMD board pad configuration provides a more robust solder joint than the SMD pads because the solder in the NSMD configuration wets the sides of the Cu pads, improving the strength of the solder joint between the WLCSP package and the PCB pads. In the SMD pads, the edge of the solder mask can be a stress initiator at the base of the solder ball, which can result in solder joint cracking. NSMD requires the solder-wetted area of the pad to be determined by the defined Cu area, not by the solder mask. This is an advantage because of the tighter control on the Cu etch process than on the solder mask development operation. Furthermore, the smaller pad size in the NSMD design also provides more room for tight pitch routing on the PCB.

Figure 6-2. Cross Section of an NSMD Solder Joint



The size of the WLCSP part requires care in the PCB design process for optimum reliability, processing, and performance. An example of typical land pattern information is shown in the following figure. Additionally, the user must consider these rules while designing the PCB board:

- The best reliability results are achieved when the PCB laminate glass transition temperature is above the operating range of the intended application.
- Ni/Au surface finishes are not recommended for Pb-free solder devices. The Organic Solderability Preservative (OSP) surface finish will deliver superior reliability performance.
- Cu traces routed away from the PCB land pads should be less than 100 µm wide (preferably = 75 µm) in the exposed area inside the solder mask opening (for NSMD pads). Wider trace widths will reduce the part stand-off and impact the reliability of the solder joints.
- Trace routing away from the WLCSP device should be balanced in 'X' and 'Y' directions to avoid unintentional component movement as a result of unbalanced solder wetting forces.
- No-clean solder paste.

Figure 6-3. Typical WLCSP PCB Land Pattern

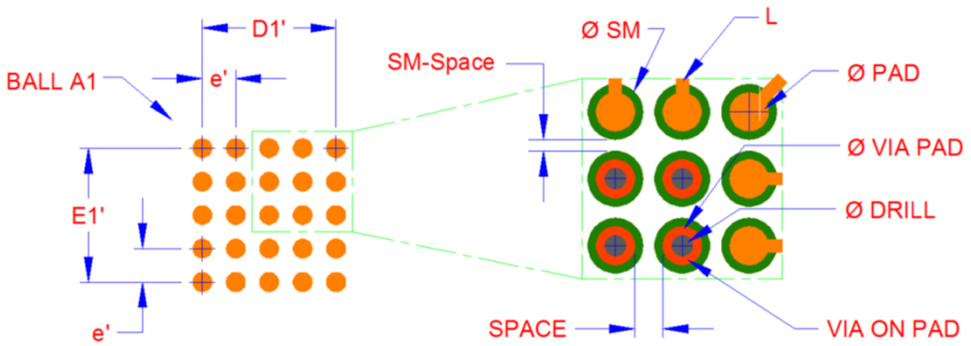


Table 6-1. Land Pattern Symbols and Sizing

Symbol	Min.	Nom	Max.
D1'/E1'		1.600	
e'		0.400	
ØPAD	0.200	0.230	—
ØSM	0.300	0.330	—
Trace Width (L)	—	0.075	—
SPACE (Cu-to-Cu)	—	0.170	—
SM-Space	—	0.070	—
ØVIA PAD	0.200	0.230	—
ØDRILL	0.100	0.125	—

Notes:

1. To obtain the PCB land pattern guidelines and dimensions for each WLCSP, refer to the www.microchip.com/Packaging.
2. The information in this PCB land pattern should only be used as a guideline. Other factors, such as end-user layout and design, product-specific application, and actual experience must be considered to define the final PCB land pattern for the optimum component mounting process.

Reflow Soldering and Profiling

As with all SMT components, it is important that furnace profiles be monitored on all new board designs. In addition, if there are multiple package types on the board, the thermal profile must be measured at multiple locations. The component temperature may vary because of surrounding components, the location of the device on the board, and the package densities. To maximize the self-alignment effect of the WLCSP component, it is recommended that the maximum reflow temperature specified for the solder paste not be exceeded.

Microchip recommends that the user follows the guidelines of industry specifications IPC-7095 and J-STD-020 in developing the optimum reflow profile for the Pb-free WLCSP components on a given board.

7. References

The following documents are to be used for reference purposes. For additional information, visit the Microchip website or contact a local Microchip Sales Representative.

- For more information on Microchip packages:
  www.microchip.com/packaging
- For more information on the QTP process:
  www.microchip.com/QTP
- For more information on microchipDIRECT programming service:
  www.microchipdirect.com/programming
- Package Application Note for WLCSP:
  ww1.microchip.com/downloads/cn/AppNotes/cn584848.pdf
- Atmel AVR211: Wafer Level Chip Scale Packages:
  ww1.microchip.com/downloads/en/Appnotes/doc42007.pdf
- Microchip Unified Bootloaders:
  www.microchip.com/promo/unified-bootloaders
- Package Drawings:
  www.microchip.com/en-us/support/package-drawings
- MPLAB Harmony v3 Bootloader:
  github.com/Microchip-MPLAB-Harmony/bootloader
- Bootloaders Supported on different product families:
  github.com/Microchip-MPLAB-Harmony/bootloader/blob/master/release_notes.md
- PIC32CM LE/LS Family Bootloader:
  github.com/Microchip-MPLAB-Harmony/bootloader_apps_pic32cm_le_ls
- For additional information about 32-bit microcontroller collateral and solutions: ww1.microchip.com/downloads/aemDocuments/documents/MCU32/ProductDocuments/ReferenceManuals/32-bit-Microcontroller-Collateral-and-Solutions-Reference-Guide-DS70005534.pdf

8. Revision History

Revision B - 09/2024

The following updates were performed for this revision:

- Updated the following tables in Bootloaders with new information for the PIC32CM LE/LSx Family of devices:
  - Table 1-1
  - Table 1-2
  - Table 1-3
- Added new verbiage to Ordering Guidelines for finding the MoQ
- Added two entries in References for Bootloaders

Revision A - 01/2022

Initial release of this document.

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