White Paper:

Embedded Energy: Integrating Energy Storage for Power on Chip

Embedded Energy Overview

This paper introduces several new concepts for micro-power chip design. These concepts are based on the fundamental power distribution and energy storage techniques deployed in advanced power grid architectures. With the introduction of small solid state energy storage devices, new Embedded Energy solutions can now be created by placing micro energy storage devices directly at the point of load (POL) where the energy is used. Point of load architectures have previously been deployed in various power architectures down to the circuit board level. But recently introduced breakthroughs in solid state energy device technology enable circuit designers to place energy storage directly at the chip level for true point of load powering.

In order to provide a foundation for understanding Embedded Energy and the advantages of Point of Load energy delivery, the following areas are discussed:

- Defining Embedded Energy
- Introduction of the Chip Grid
- Micropower and nanopower trends with enabling technologies
- Solid state energy storage devices and Embedded Energy
- New point of load and Pervasive Power applications.

What is Embedded Energy?

Embedded Energy is a recently introduced power distribution architecture that utilizes energy storage devices at the actual point of energy usage (point of load) inside a chip. This is accomplished by placing micro-energy storage devices inside a complex device requiring power. Examples include microcontrollers, real-time clocks, SRAM memory, sensors, and multi-chip modules. The introduction of new solid state energy storage devices utilizing a silicon substrate is the enabling technology for a “Power on Chip” configuration. This idea of co-packaged modules using a solid state energy storage device with other ICs exists today and are now commercially available (e.g. Cymbet EnerChip CC CB3150).

Advantages of Embedded Energy

A Pervasive Power architecture is realized when most of the major functional semiconductor chips on a circuit board have Embedded Energy capabilities. There are many advantages that are realized with a Pervasive Power architecture:

- With Power on Chip, it is possible to reduce the amount of energy used
- Power saving techniques for “trickle charging” embedded energy chips
- Damaging in-rush currents are reduced with Power on Chip
- Minimizes induction in the Power train
- Reduces current draw variability
- Potential heat reduction
- Peak energy shaving and energy shifting techniques can be utilized

- “Dirty” power into chips is corrected, with “pure power” delivered
- Reduces bypass capacitors surrounding ICs.
- Lowers I/O switching noise
- Scalable – energy storage on the System increases with each added device

Cross Power Grid Similarities and Point of Load Power Management

If you haven’t had a chance to download Cymbet’s White Paper “*Pervasive Power – Integrating Energy Storage for Point of Load Delivery”*, it is encouraged that you do so. Several concepts in this section are covered in detailin that White Paper. Many of the same techniques and technologies implemented in the Backbone Grid apply even down to the Chip Grid. One of the key methods of effectively managing power is to use Point of Load technologies. Point of Load management involves the following:

- Measuring the power being used at the actual point of use
- Characterizing all the points in the power delivery chain
- Actively managing the power to the point of use through a closed loop control system
- Implementing dynamic power demand algorithms to optimize the efficiency of the power used.
- Providing energy storage at the point of load to enable optimal energy saving profiles independent of the power input.

Point of Load Power-On-Chip Benefits

Placing rechargeable energy storage at the point of load in the Chip Grid has many advantages. These include:

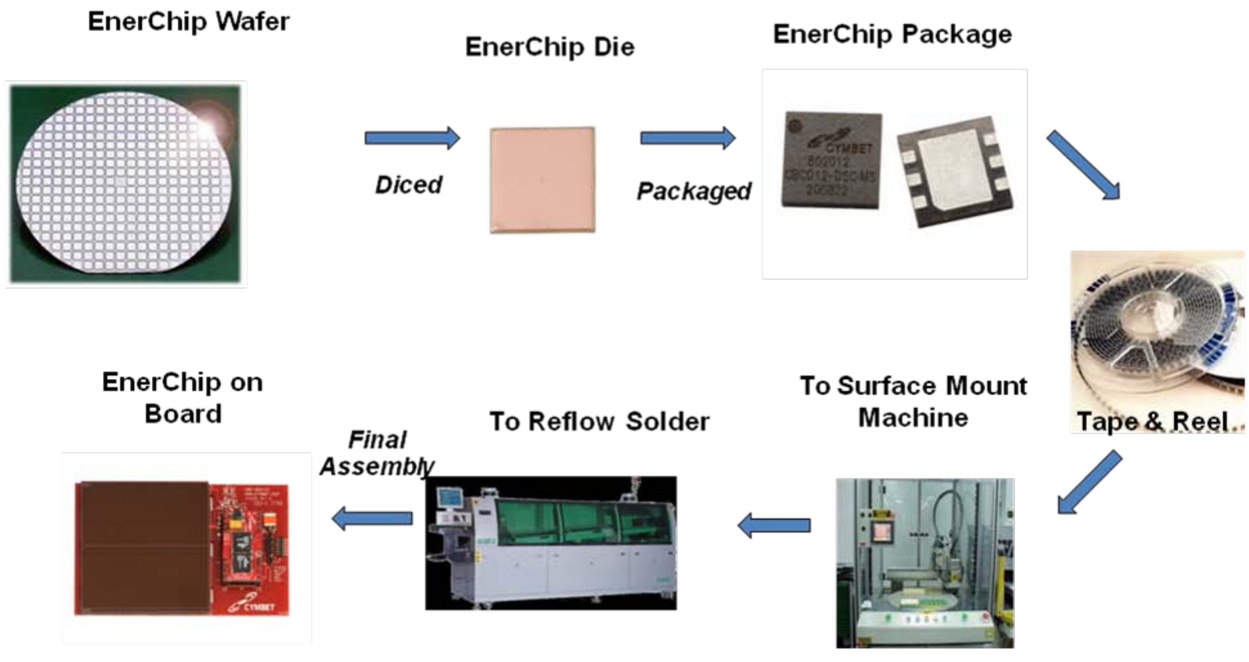
- Minimize I^2R losses – because devices with Power on Chip can be trickled charged, less power needs to be presented to the electrics from the power supply
- Power Sources can be isolated – with Power on Chip devices can be “lifted” off the grid and run on the pure power in the rechargeable energy storage device. When isolation is no longer required, the device can be “placed” back on the grid.
- Reduced I/O switching noise when using on chip power
- Power where ever it is needed – Power on Chip can be placed in any type of device
- Power Bridging – In the event of power brownout/blackout, the on chip energy storage takes over and powers the device.
- Power Boosting – there may be times when a device needs additional power and can draw upon the on chip energy storage vs. placing an additional demand on the main power supply.
- Effective in ultra low power applications which are typically also miniaturized.
- Warm start energy can be used for devices in deep sleep or standby.
- Bridging “error” or early termination conditions – There may be times when a power interruption would create device operation errors or even device failure. Having Power on Chip provides power to complete operations in an orderly fashion.

Chip Grid Trends
The key trends that are occurring at the Chip Grid level include:

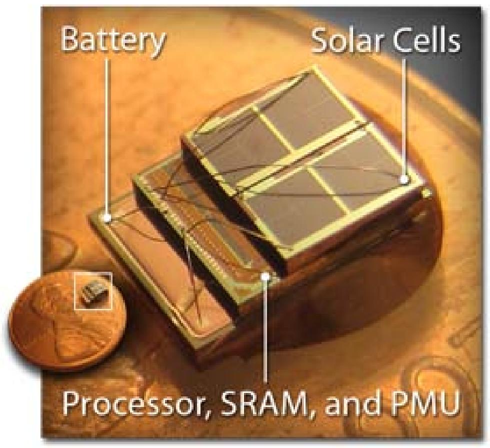
- Lower power devices using lower voltages
- Denser Devices
- Multi-chip modules
- System on Chip
- Lab on Chip
- Advanced power management techniques
- Same digital power control techniques as Board Grids and Rack Grids

All of these trends are pointing toward integration and miniaturization. Many technologies have progressed down this curve, but batteries have not kept pace. So what are the implications to the Chip Grid? One key implication is that we need to integrate intelligent rechargeable energy storage into the Chip Grid. In order to achieve this requirement, a new product technology has been introduced: solid state rechargeable energy storage devices.

Solid State Rechargeable Energy Storage Devices
Cymbet has introduced a solid state rechargeable energy storage device based on a silicon substrate called the EnerChip™. The following photo diagram shows how the EnerChip is created on a silicon wafer. The EnerChips are diced and then can be used as bare die or packaged in standard semiconductor package. Mounted on tape and reel, the EnerChips are placed on circuit boards using Surface Mount Technology and then can be reflow soldered to the board. The EnerChips solid state batteries are treated like the other IC packages on the final board.



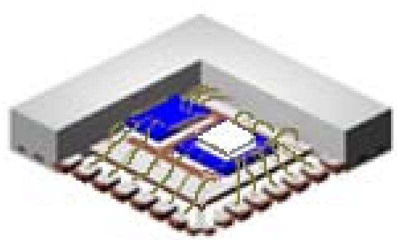
Using the EnerChip bare die has unique advantages for Point of Load energy storage from a packaging perspective as they are small and can be co-packaged in many ways with other ICs or micro devices. The photo below is a millimeter-sized Solar Energy Harvesting sensor. The solar cell sits on an ultra low power microcontroller that sits on a solid state rechargeable energy storage device (EnerChip CBC012). The devices are wire bonded to each other.



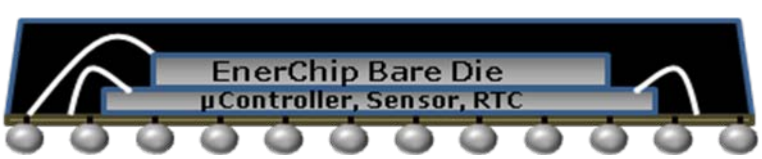
Integrated Energy Storage for Point of Load Power Delivery
With the introduction of solid state rechargeable energy storage devices it is now possible to co-package energy storage directly with other Integrated circuits.

Examples are shown in the following diagrams:

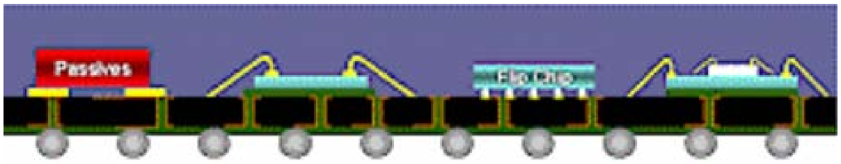
Rechargeable Solid State Energy bare die Co-packaged side-by side with an IC:



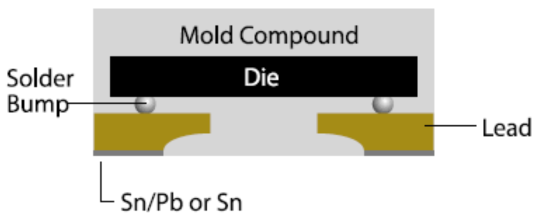
Rechargeable Solid State Energy bare die Co-packaged in “wedding cake” die stack:

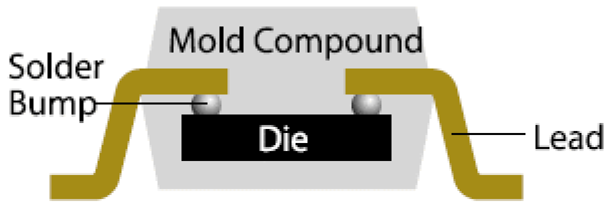


Rechargeable Solid State Energy bare die in System on Chip module:



An important attribute of Solid State Energy Storage built on silicon wafer is that they can be solder attached to the circuit board surface using a “flip chip” technique. The flip chip attachment mechanism opens up many new miniature packaging options.





Conclusions

This paper introduced several key concepts which are summarized as follows:

1 – Pervasive Power is a new power distribution architecture that provides enhanced use of power at the point of load that increases overall system energy efficiency.

2 – There are 5 levels of interconnected Grids terminating in the Chip Grid. Each grid type shares the same principles of power generation, power distribution, energy storage and energy management using dynamic demand algorithms.

3 – The interconnected Grids can utilize digital power control techniques to optimize the end to end use of power and improve energy efficiencies.

4 - In order to enable the Chip Grid, a new energy storage device that can be integrated into the Chip must be used. EnerChip rechargeable solid state energy devices ideally meet this need.

5 – These rechargeable energy storage devices can be co-packaged with other ICs in the Chip Grid to create a miniature highly integrated package.

6 – Once boards are populated with Chips with on-chip energy storage Pervasive Power architecture is created.

For additional information on Pervasive Power for Integrated Energy Storage for Point of Load Delivery, visit the www.cymbet.com website for application notes, datasheets, videos and contact forms.