Millimeter Scale Energy Harvesting Based Sensors

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This article introduces several new concepts for creating millimeter scale intelligent sensors using ambient energy harvesting to power the device autonomously. Using the energy surrounding the sensor can provide life-of-product powering. Energy harvesting techniques are used in large scale applications like solar panel installations and wind farms. But energy harvesting can also be used in extremely small scale devices as is demonstrated in this paper. Light is converted to electricity, stored in rechargeable solid state batteries and delivered to the sensor system. There are no traditional batteries to change out and devices can be placed anywhere.

This white paper is based on the sensor presented in the ISSCC 2011 paper:

A Cubic-Millimeter Energy-Autonomous Wireless Intra-Ocular Pressure Monitor Authors: Gregory Chen, Hassan Ghaed, Razi-ul Haque, Michael Wieckowski, Yejoong Kim, Gyouho Kim, David Fick, Daeyeon Kim, Mingoo Seok,Kensall Wise, David Blaauw, Dennis Sylvester from the University of Michigan, Ann Arbor, MI
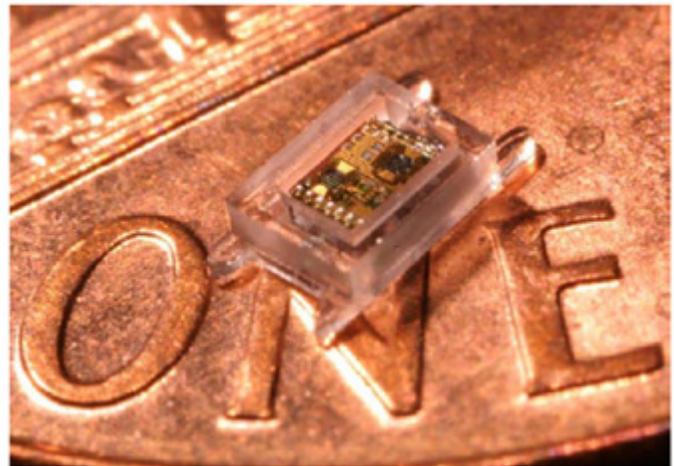
The actual paper can be found here.

Figure 1: Millimeter Scale Computer Wireless Sensor Photo.

This University of Michigan ISSCC paper describes an Intra-Ocular Pressure Monitor (IOPM) device that is implanted in the eye of a glaucoma patient. The most suitable implantation location is the anterior chamber of the eye, which is surgically accessible and out of the field of vision. The IOPM volume is limited to 1.5

cubic millimeters. This aggressive IOPM size constraint creates major challenges for achieving high-resolution capacitance measurements, wireless communication, and multi-year device lifetime. Little energy can be stored on the tiny IOPM system, calling for ultra-low power operation and energy harvesting. The required millimeter antennas or inductors result in lower received power and higher transmission frequency, both increasing micro-system power. The IOPM harvests solar energy that enters the eye through the transparent cornea to achieve energy autonomy. The IOPM contains an integrated solar cell, EnerChip™ thin-film Li battery, MEMS capacitive sensor, and integrated circuits vertically assembled in a biocompatible glass housing as shown in Figure 1. The circuits include a wireless transceiver, capacitance to digital converter (CDC), DC-DC switched capacitor network (SCN), microcontroller (μP), and memory fabricated in 0.18μm CMOS.

Why Millimeter Scale?

As in the case of the Intra-Ocular Pressure Monitor, it is often desirable to place microelectronic systems in very small spaces. New advances in ultra-low power Integrated Circuits, MEMS sensors and Solid State Batteries are making these systems a reality. Miniature wireless sensors, data loggers and computers can now be embedded in hundreds of new applications and millions of locations.

Ultra-Low Power Management is Key

The desired IOPM lifetime is years to converge on a suitable glaucoma treatment. However, the anterior chamber volume limits lifetime by constraining the size and capacity of the micro-system's power sources. The IOPM uses a 1μAh EnerChip™ solid state battery from Cymbet. The lifetime is 28 days with no energy harvesting!

To extend lifetime, the IOPM harvests light energy entering the eye with an integrated 0.07 square millimeter solar cell that recharges the battery. Given the ultra-small solar cell size, energy autonomy requires average power consumption of less than 10nW. For the majority of its lifetime, the IOPM is in a 3.65nW standby mode where mixed-signal circuits are disabled, digital logic is power-gated, and 2.4fW/bitcell SRAM retains IOP instructions and data. The average system power with pressure measurements every 15 minutes and daily wireless

data transmissions is 5.3nW. When sunny, the solar cells supply 80.6nW to the battery. The combination of energy harvesting and low-power operation allows the IOPM to achieve zero-net energy operation in low light. The IOPM requires 10 hours of indoor lighting or 1.5 hours of sunlight per day to achieve energy-autonomy.

EH Wireless Sensor Components

The Intra-Ocular Pressure Monitor is an example of a wireless sensor that uses Energy Harvesting techniques to power the device. With the availability of low cost integrated circuits to perform the sensing, signal processing, communication, and data collection functions, coupled with the versatility that wireless networks afford, we can move away from fixed, hard-wired network installations in both new construction as well as retrofits of existing installations (such as the eye!). The IOPM block diagram is shown in Figure 2.

The IOPM as shown in Figure 2 consists of five basic elements:

1. A pressure sensor to detect and quantify the pressure in that area of the eye.

2. A solar energy harvesting transducer that converts ambient light to electricity.

3. An ultra-low power management device and Solid State Battery to collect, store and deliver electrical energy to the IOPM.

4. A microcontroller to receive the signal from the sensor, convert data into a useful form for analysis, and communicate with the radio link.

5. A specialized radio link at the sensor node to transmit the information from the processor on a periodic basis to a receiver held in front of the patient's eye.

Building Millimeter Scale EH-based Computers

The IOPM millimeter wireless sensor shown in the Figure 1 photo is shown diagrammatically in Figure 3. The device is a 4-layer stack encapsulated in a bio-compatible glass enclosure. The first layer is the MEMS pressure sensor, with a 1uAh rechargeable EnerChip solid state battery sitting on top. The processor with memory, power management and sensor A/D converter
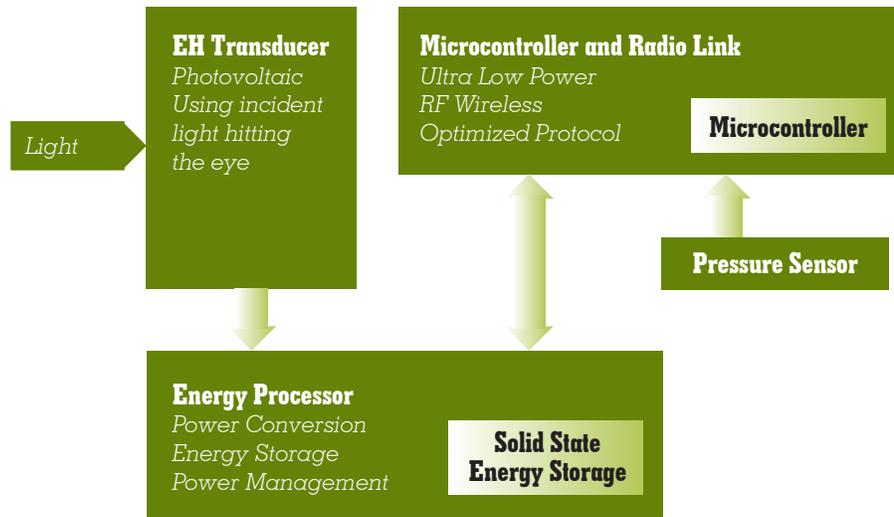
Figure 2: IOPM Wireless Sensor Block Diagram.

sits on the EnerChip. The top layer is the solar cell and wireless transceiver. All the layers in this case were wire bonded together for electrical connectivity.

Permanent Power Using Solid State Rechargeable Batteries

One drawback to moving toward wide-spread wireless sensor installation has been the poor reliability and limited useful life of batteries needed to supply the energy to the sensor, radio, processor, and other electronic elements of the system. This limitation has to some extent curtailed the proliferation of wireless networks especially with small devices. Legacy battery technology can be eliminated through the use of Energy Harvesting techniques which use an energy conversion transducer tied to an integrated rechargeable solid

state battery. This mini "power plant" lasts the life of the wireless sensor.

Cymbet has commercialized a solid state rechargeable battery based on a silicon substrate called the EnerChip. The photo in Figure 4 shows the 1uAH EnerChip used in the IOPM. The EnerChips are used as bare die or packaged in a 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 are treated like the other IC packages on the final board.

Using the EnerChip bare die have unique advantages for internal 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 devices are wire
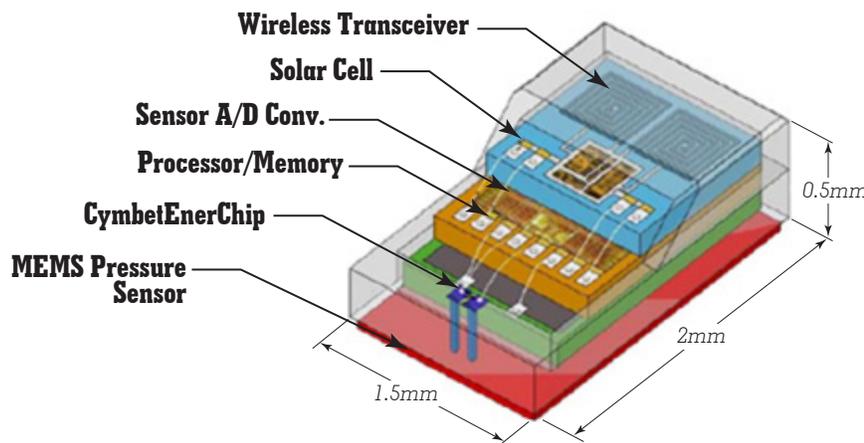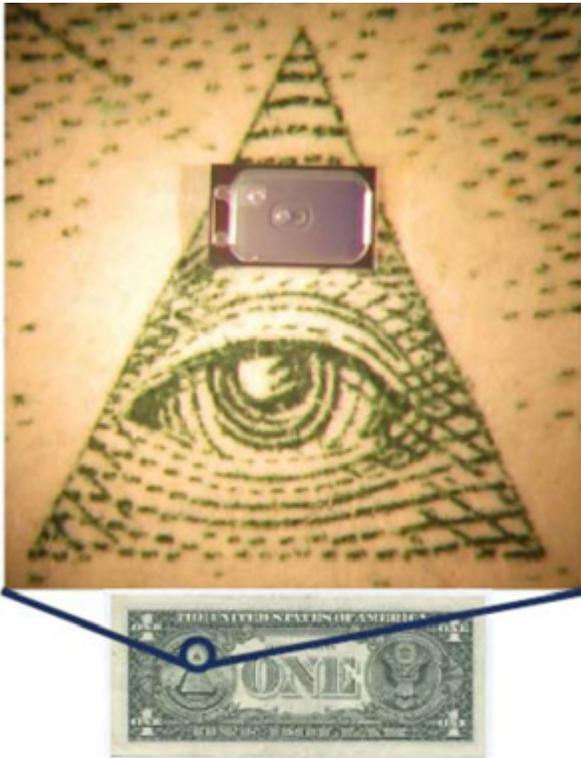

Figure 3: IOPM Layers Block Diagram.

Figure 4: EnerChip 1uAh battery on US Dollar for size reference.

bonded to each other. EnerChip bare die co-packaged in "wedding cake" die stack look like this diagram:

Figure 5

EnerChip bare die can be co-packaged side-by side with an IC, as is the case with the Cymbet CBC3105, CBC3112 and CBC3150:
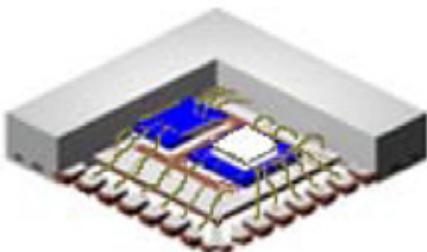

Figure 6

Rechargeable solid state battery bare die can be attached to a substrate with other devices in System on
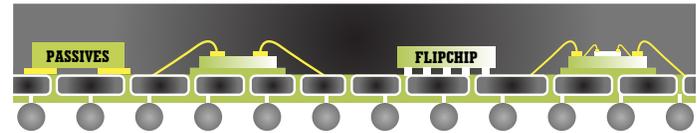
Chip module:

Figure 7

An important attribute of EnerChip batteries built on a silicon wafer is that they can be solder attached to the circuit board surface using a "flip chip" technique. The flip chip attach mechanism opens up many new miniature packaging options.
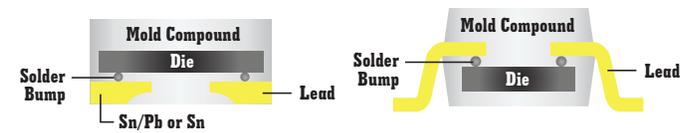

Figure 8

Designing and Deploying Millimeter Scale Sensors

This article demonstrated that existing technologies can be used to build millimeter scale energy harvesting based computing systems and wireless sensors. One of the key enablers for long life operation is rechargeable solid state batteries. There are solid state batteries, ultra low power electronics and Energy Harvesting evaluation kits available today from Cymbet and our Distributors that can be used to design and deploy the concepts discussed in this white paper. Reference schematics, application notes, and ultra low power design techniques can be found at http://www.cymbet.com.

About the Author

Steve Grady is responsible for all strategic messaging, product roadmap, CRM, e-initiatives, collateral and lead generation at Cymbet. He has more than two decades of domestic and international experience in marketing, sales, business development, product management, engineering, and general management in the networking, hardware, and software industries. Steve has been in both startup and large company environments with global scope. Prior to joining Cymbet, Steve held senior management and technical positions at ADC, Marconi, TimeSys, Reltec, and AT&T Bell Labs. He holds BSEE and MSEE degrees from the University of Illinois Champaign-Urbana. ∎