Miniaturization of Electronic Substrates for Medical Device Applications

Frank D. Egitto, Rabindra N. Das, Glen E. Thomas, and Susan Bagen

The medical industry is clearly and urgently in need of the development of advanced packaging that can meet the growing demand for miniaturization, high-speed performance, and flexibility for handheld, portable, in vivo, and implantable devices. To accomplish this, new, smaller packaging structures need to be able to integrate more dies with greater function, higher I/O counts, smaller die pad pitches, and high reliability.

The wide range of applications for medical electronics drives unique requirements that can differ significantly from commercial & military electronics. This is particularly the case for handheld, portable, in vivo, and implantable medical devices that demand increased functionality with decreasing size, weight, and power (SWaP). Form, fit, function, integrated sensors, batteries, leads, biocompatibility, operational life, and reliability specifications define requirements for atypical form factors, unique assemblies, and non-standard material sets.

High Density Substrate Technology
A key enabling technology to achieving SWaP for medical electronics is the substrate. A substrate supplier must offer a range of substrate material sets and solutions to meet different form factor and performance requirements. When a greater degree of miniaturization is required in a rigid substrate, semiconductor packaging laminates fabricated using laminate materials that do not contain glass cloth, unlike typical printed circuit board laminate materials, allow for the formation of higher resolution vias by UV laser drilling as opposed to more conventional mechanical and CO₂ laser drilling. The smaller via size minimizes capture pad area requirements and enables a much greater via density, resulting in substrate size reduction as compared to conventional technology. Because of the omission of glass cloth, the dielectric layer thicknesses are substantially less; therefore, the overall laminate stack-up is much thinner.

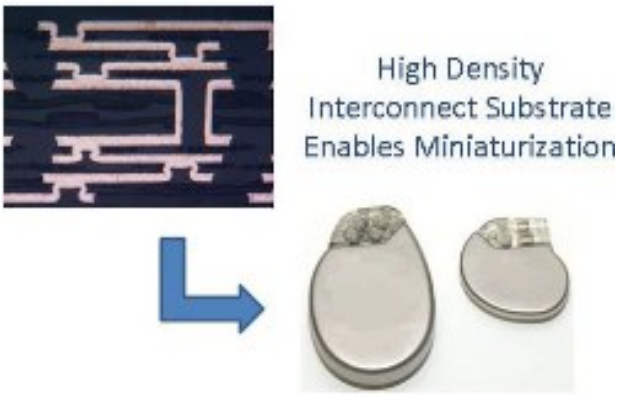

Figure 1: Increased functionality in a decreased form factor for implantable cardiac devices, such as implantable cardioverter defibrillators (ICDs) and pacemakers

Figure 1 depicts a rigid, wirebondable organic substrate that enables increased functionality in decreased form factor for implantable cardiac devices, such as implantable cardioverter defibrillators (ICDs) and pacemakers. The eight-layer substrate cross-section shown incorporates high density build-up layers to accommodate reduced die pad pitch and improve electrical performance.

Embedded Passives
Passives account for a very large part of today's electronic assemblies. This is particularly true for digital products such as cellular phones, camcorders, and computers. Market pressures for new products with more features, smaller size, and lower cost virtually demand smaller, compact, complex circuit boards. An effective strategy is to reduce the number of surface mounted passives by embedding them into the substrate or printed wire boards. In addition, current interconnect technology to accommodate surface mounted passives impose certain limits on board design, which limit the overall circuit speed. Embedding passives is one way to save substrate real estate, reduce parasitic effects, and improve performance .

Among the various passives, embedded thin film capacitors deserve special attention as they provide the greatest potential benefit for high density, high speed, and low voltage IC packaging. Capacitors can be embedded into the substrates to provide decoupling, bypass, termination, and frequency determining functions. In order for embedded capacitors to be useful, the capacitive densities of the films must be high enough to make layout areas reasonable. Available commercial polymer composite technology is not adequate for high capacitance density thin film embedded passives. Polymer nanocomposites have been produced to achieve increased capacitance densities for large area coatings.

Thin film resistors are readily incorporated into the laminate substrate fabrication processing, substantially minimizing the discrete resistor count. Laser trim aids in meeting design requirements for tight resistor tolerances.

New technologies for embedding active die are being developed and implemented into the manufacturing environment. A variety of active silicon die with metal pads have been embedded and electrically connected to develop highly integrated packages.

System-in-Package
System-in-Package (SiP) designs that implement embedded passive and active components further enable SWaP reductions. Thinner, high-density substrate technologies lower

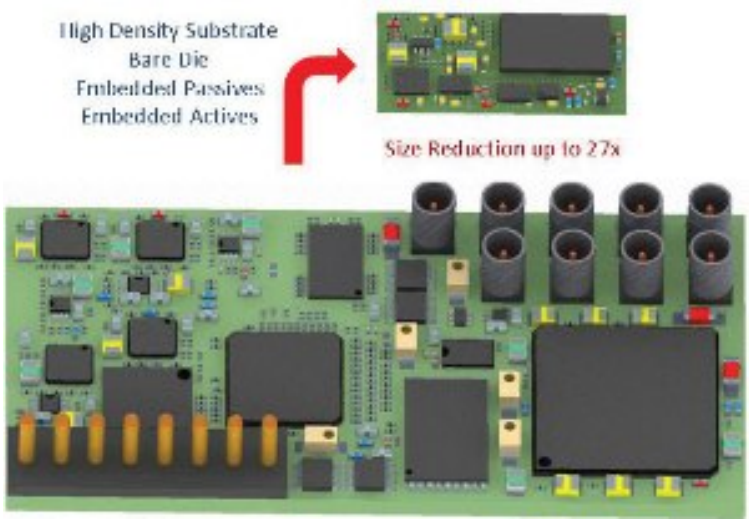

Figure 2: Miniaturization via System-in-Package

inductance, driving down the need for decoupling capacitors in the design. For example, high density interconnect technology combined with embedded passives and small die and component body sizes have been shown to achieve as much as 27 times reduction in physical size for existing printed wiring board assemblies, with significant reductions in weight and power consumption (Figure 2). Primary reductions in power are due to reduced interconnect lengths and corresponding load. Shorter interconnects can also reduce or eliminate the need for termination resistors for some net topologies.

Microflex and Ultra Fine Pitch Flip Chip Assembly

Advanced microflex coupled with ultra fine flip chip assembly is well suited to meeting the challenge of extreme miniaturization and unique form factors requirements. Figure 3 illustrates an example of a highly miniaturized assembly on microflex for use in intravascular ultrasound (IVUS) catheters. IVUS catheters provide physicians with a 360 degree digital view of the inside of a patient’s arteries. A transducer is mounted to a thin flexible substrate, along with a number of ASIC die used to control the functions of the catheter lab (i.e., the digital imaging control unit to which the catheter is attached during use).

An exceptionally thin polyimide flex substrate (12.5 µm) is necessary for the flex assembly to be rolled into a very tight cylinder—in this instance, having a diameter on the order of just over 1.0 mm (about 3.5 F). This rolled assembly is then placed at the end of the catheter after attachment of the electronic leads.

Figure 3: IVUS catheter, containing flex substrate with ASIC die and transducer

The key technical challenges in developing the processes used to fabricate this flex device include use of the ultra-thin polyimide flex material and the fine line circuitization required for miniaturization. Also, to eliminate the need for a soldermask, a means of forming solder dams to prevent solder wicking away from the flip chip bond pads and down the circuit traces had to be devised. To accommodate placement of ASIC die with 22 micron flip chip bumps on a 70 micron pitch, die placement tools with extremely high registration capabilities are required. And finally, maintaining flatness of the flex substrate during die placement and assembly processing at elevated temperatures is key.

The thin polyimide film is held flat and taut during processing. The film is mounted, using an adhesive, to a rigid metal frame by laminating at an elevated temperature. Figure 4 shows a substrate containing multiple images at successively greater magnifications. In the upper right corner, one can see the area of the device having 14 µm lines and spaces, with die bond pads on a 70 µm pitch.

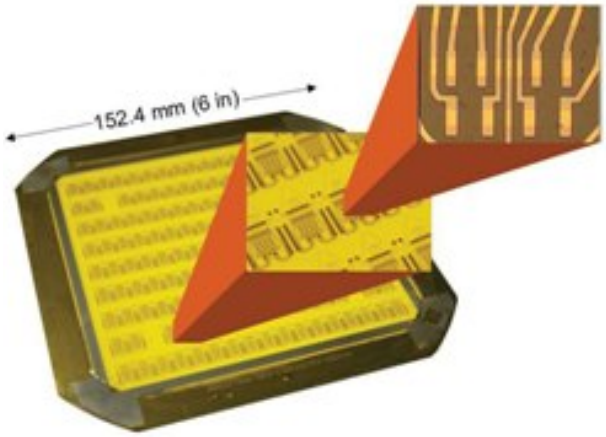

Figure 4: Support of 12.5 µm polyimide film during substrate fabrication using a rigid frame

Figure 5 shows optical views of the flex substrate pre- and post- device attach (Figure 5a and 5b, respectively), with an SEM micrograph showing ASIC die and a piezoelectric transducer (Figure 5c). On the die side, bond pads are plated with Cu studs that are tipped with solder (Figure 5d). The Cu pillars offer greater interconnect density than solder ball bumps as well as enhanced electrical and thermal connection.

To achieve fine line circuitization, a semi-additive, or pattern plating, process was employed (Figure 5e). Since no solder mask is used for this application, a solder dam is formed using a low surface energy metal adjacent to gold bond pads on the flex substrate to prevent solder on the die bumps from wicking down circuit traces (Figure 5f).

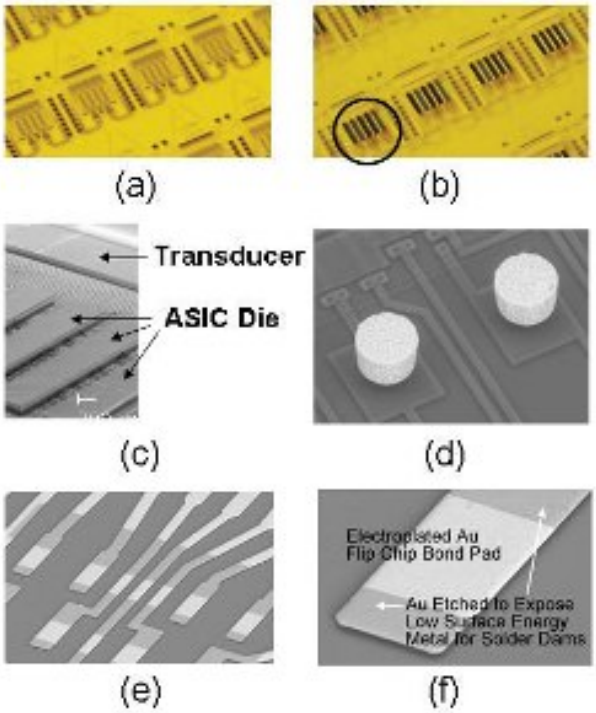

Figure 5: Optical views of the flex substrate pre- (a) and post- (b) device attach, with an SEM micrograph showing the five ASIC die and piezoelectric transducer (c). Bumped die with solder-tipped Cu studs on a 70 µm pitch (d). SEM micrographs showing circuit traces with 14 µm lines and 14 µm spaces (e) and solder dams formed using a low surface energy metal adjacent to gold bond pads (f).

Double-Sided Flex

A separate application (*in vivo* ultrasound diagnostics device) involves a double-sided flex substrate, with finer circuitized features and greater wiring density than the single-sided flex substrate described previously. As with the IVUS example, this device is fabricated by holding the polyimide film flat and taut in a rigid frame. Also similar to the IVUS device, circuit traces are defined using a semi-additive plating process. In this case, minimum line width and spacing between lines are both 11 µm. Metal trace thickness is 6.0 µm. Vias are drilled through the 25 µm thick polyimide film using a frequency-tripled Nd-YAG laser operating at a wavelength of 355 nm. Vias and surface metal are plated simultaneously using the semi-additive plating process (Figure 6). After application of a 6.0 µm thick flexible soldermask to both sides of the substrate, placement of two ASIC die and a number of surface mounted capacitors completes the flex substrate assembly.

Conclusion

Figure 6: Optical photo in cross section of a double-sided flex substrate with 25 µm plated vias and 11 µm plated metal traces

Medical devices, especially handheld, portable, and implantable, are an expanding market driving the need for unique solutions for increased functionality with decreasing size, weight, and power (SWaP). By integrating the building blocks of SiP (e.g., advanced substrate technology, embedded passives, and actives) coupled with concurrent engineering design-for-manufacture (DFM), advanced packaging solutions have been successfully implemented to reduce electronics volume and advance the capabilities of medical device technology. Advanced microflex coupled with ultra fine flip chip assembly helps to meet the challenge of extreme miniaturization and unique form factor requirements and affords the opportunity for cost reduction by migrating from fabrication in a panel format to roll-to-roll processes.

Frank D. Egitto is the director of research and development at Endicott Interconnect Technologies Inc. *[1] Rabindra N. Das is the principal engineer at the company. Glen E. Thomas is the product manager—business development manager semiconductor packaging & assembly. Susan Bagen is a business development manager at Endicott.*

Source URL (retrieved on *05/23/2013 - 5:25pm*):
http://www.mdtmag.com/articles/2012/07/miniaturization-electronic-substrates-medical-device-applications

Links:
[1] http://www.endicottinterconnect.com