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3D integration of ultra-thin functional devices inside standard multilayer flex laminates

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Abstract

Nowadays, more and more wearable electronic systems are being realized on flexible substrates. Main limiting factor for the mechanical flexibility of those wearable systems are typically the rigid components - especially the relatively large active components - mounted on top and bottom of the flex substrates. Integration of these active devices inside the flex multilayers will not only enable for a high degree of miniaturization but can also improve the total flexibility of the system. This paper now presents a technology for the 3D embedding of ultra-thin active components inside standard flex laminates.

Active components are first thinned down to 20-25 μm, and packaged as an Ultra-Thin Chip Package (UTCP). These UTCP packages will serve as flexible interposer: all layers are so thin, that the whole package is even bendable. The limited total package thickness of only 60 μm makes them also suitable for lamination in between commercial flex panels, replacing for example the direct die integration. A fan-out metallization on the package facilitates easy testing before integration, solving the KGD issue, and can also relax the chip contact pitch, excluding the need for very precise placement and the use of expensive, fine-pitch flex substrates.

The technology is successfully demonstrated for the 3D-integration of a Texas Instrument MSP430 low-power microcontroller, inside the conventional double sided flex laminate of a wireless ECG system. The microcontrollers are first thinned down and UTCP packaged. These packages are then laminated in between the large panels of the flex multilayer stack and finally connected to the different layers of the flex board by metallized through-hole interconnects.

The thinning down, the UTCP packaging and the 3D-integration inside the commercial flex panels did not have any affect on the functionality of the TI microcontroller. Smaller SMD´s were finally mounted on top and bottom of the integrated device.

Key words: 3D integration, flex, ultra-thin chip, chip package

Introduction

One of the main challenges in the electronics manufacturing and packaging development is how to integrate more functions inside the same, or even smaller, size. The electrical performance and the number of functions of every new product generation are increasing while the size and the weight of the products are decreasing. To meet this, the semiconductor industry is integrating more and more transistors into the same silicon area. This allows either to reduce the size of the IC or to increase the functionality and performance of the same size IC components. At the same time there is also an interest to increase the packaging density. While silicon chips continue integrating more functionality as per Moore's law, the packaging is challenged to also integrate and shrink.

A high degree of miniaturization can be achieved by removing the assembled active devices from the surface and integrate them inside the inner layers of multilayer FCB or PCB boards.

On flex substrates typically only pure electronic assembly is performed up to flip-chip components. Embedding of passive or active components in conventional flexible printed circuits is at least not state of the art. This limitation to two component layers (front and backside of the flex laminate) limits of course the compactness of the circuit, and the presence of relatively large rigid components also limits the flexibility of the FCB.

This paper now presents the embedding of an ultra-thin, functional microcontroller device inside a double sided flex board, by means of a unique concept for packaging ultra-thin chips: the Ultra-Thin Chip Package (UTCP).

The UTCP serves as flex interposer and can be used for the embedding inside the substrate, replacing for example the direct integration of bare dies. The UTCP allows for easy testing of the chip

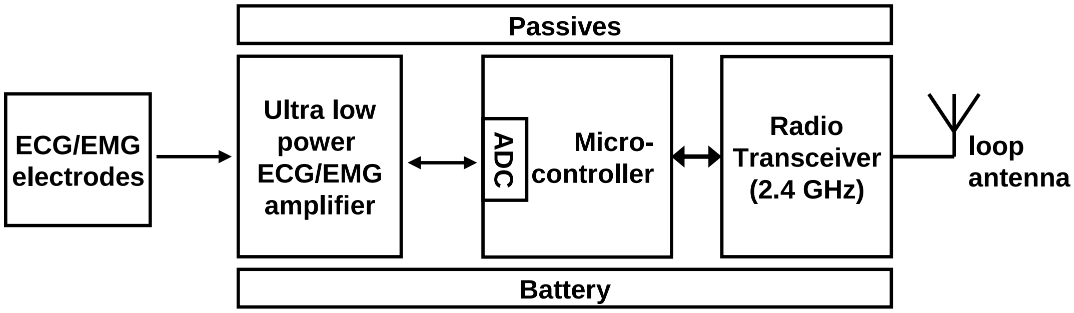

Figure 1 : Block scheme of the ECG circuit

before embedding, solving the KGD issue, and provides a contact fan out with more relaxed pitches, eliminating the need for very fine pitch PCB or FPC compatible with the chip contact pad pitch.

A Texas Instrument MSP430 low-power microcontroller is first UTCP packaged and next laminated inside the conventional double sided flex laminate of a wireless ECG system. This 3D integration of the microcontroller leads to high density integration, since SMD components can be mounted on top and bottom of the integrated devices. In addition, the UTCP packaged thin silicon devices are mechanically flexible itself, leading to an increased total flexibility of the resulting system.

ECG demonstrator

The demonstrator for this 3D integration technology consists of a high-density flexible ExG circuit for personal health or wellness applications. IMEC's ExG system is a bio-potential wireless sensor node, able to monitor the vital body signs provided by portable electrocardiogram (ECG, which monitors the heart activity), electromyogram (EMG, which monitors muscle contraction) and electroencephalogram (EEG, which monitors brain waves). The system collects and processes data from (external) human body sensors and wirelessly transmits the data to a central monitoring system. Small size and low power consumption of the system enables non-invasive and ambulatory monitoring of vital body parameters.

The block scheme of e.g. an ECG/EMG circuit is given in Figure 1. The system uses IMEC's proprietary ultra-low-power bio-potential readout ASIC (application specific integrated circuit) to extract the bio-potential signals produced during the ECG, EMG or EEG measurements. The low power microcontroller MSP430F149 drives the bio-potential chip, also digitalizes the samples with its A/D converter. The signals are finally sent by the 2.4GHz low power radio Nordic NRF2401A using a coplanar antenna. Information can be transmitted to a pc by a 'USB stick' receiver for visualization and recording.

This ECG system was already realized on standard double sided flex laminates. This is shown in Figure 2: the use of flex substrates ensures a certain degree of mechanical flexibility for the wearable systems. However, an important factor limiting miniaturization and flexibility is typically the presence of rigid components, especially the relatively large active devices.

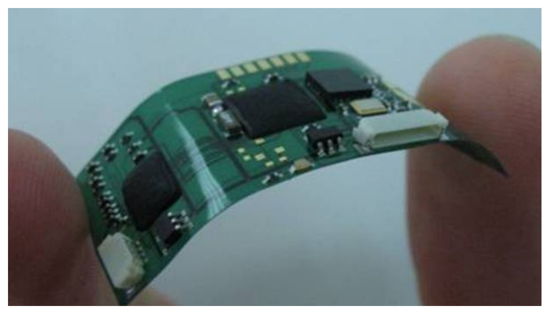

Figure 2 : ExG system realized on standard double sided flex substrate. Flexibility of system is limited by the presence of the large IC's.

In this paper, one of those 3 used actives, the TI microcontroller device, is removed from the surface and embedded as UTCP inside a commercial standard flex substrate. Smaller SMD components can be mounted above and below the embedded chip. This leads to a high density of integration. In addition, the embedded ultra-thin silicon chip becomes mechanically flexible itself. This leads to an increase in total flexibility of the resulting system.

UTCP packaging of ultra-thin microcontroller

Before integration inside the substrate the Texas Instruments microcontroller MSP430F149 is first embedded as Ultra-Thin Chip Package. This UTCP will serve as interposer during the 3D integration, as an alternative for direct die integration.

The UTCP interposers can provide a fan-out of the chip contact pads, enabling for easy testing before integration (compared with naked die integration). Moreover this fan-out metallization can also bridge the gap between the chip contact pitch

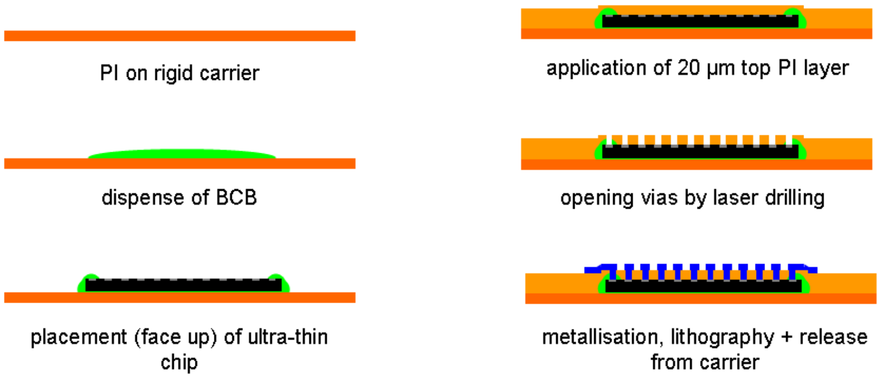

Figure 3 : Overview of UTCP process flow.

and the minimum available substrate pitch, or can exclude the need for expensive fine pitch interconnection substrates.

As the UTCP technology is developed for using ultra-thin chips, the functional TI microcontrollers were also first thinned down to only 20-25 µm.

UTCP technology

After thinning, the active devices are integrated as a UTCP package. An overview of the individual process steps of the Ultra-Thin Chip Package production is depicted in Figure 3. More details on this technology can also be found in [1].

The base substrates for this technology are a 20 µm polyimide layer spincoated on a rigid glass carrier. For the fixation and the placement of the chips a benzocyclobutene (BCB) is used as adhesive. The chip is covered with a next 20 µm thick polyimide layer. For the contacting to the chip, contact openings to the bumps of the chips are laser drilled and a 1 µm TiW/Cu layer is sputtered and photolithographically patterned. This metal layer provides a fan out to the contacts of the chips.

After processing, the whole package can be released easily from the rigid carrier. The result is a very thin, even flexible, chip package, with a total package thickness of only 50–60 µm.

Design

The top metallization on the UTCP package can provide a fan-out of the chip contact pads, with smaller pitch. This is shown in Figure 4: the metallization provides a small fan-out of the 64 die contacts to 400 x 400 µm^2 contacts with pitch of 500 µm, and a larger fan-out to 650 x 1300 µm contacts. The dimensions of this design are: 9 x 9 mm^2 for the small fan-out and 3 x 3cm^2 for the large fan-out. The design also includes solder pads to solder mount an SMD resistor and a LED component on top of the package for visual functionality demonstration after processing.

The outer, larger contact pads on the package can be used to connect the integrated microcontroller for programming and testing. This solves the KGD issue: a UTCP packaged device can easily be tested before integration, compared with a bare die.

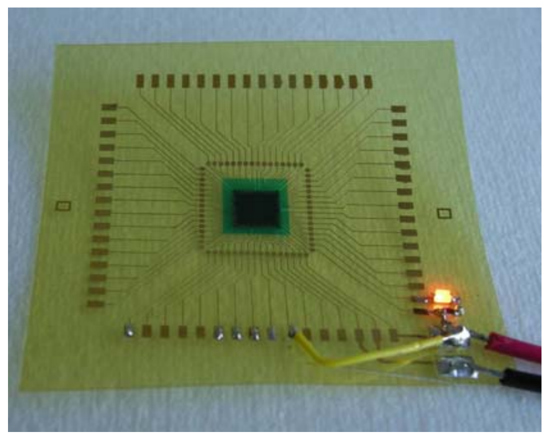

Figure 4 : Fan-out metallization to the UTCP packaged microcontroller device.

The inner contacts match the design rules of conventional flex board manufacturers and will be used for embedding the UTCP package inside multilayer flex boards. This relaxes the chip contact pad pitch to pitches compatible with conventional, low cost flex substrates.

Functionality testing

Functionality of the UTCP integrated microcontroller devices was compared with the bare, unthinned dies.

The fan-out metallization of the UTCP package allows for easy testing of the thinned microcontroller devices, after processing and before the integration inside the flex substrates. First the microcontroller was programmed to generate a blinking sequence on the LED to demonstrate its functionality: see Figure 4. Also more extensive tests of the analog-to-digital converter of the embedded microcontrollers are performed after

UTCP integration. The linearity and also the AC specs (including signal to noise ratio (SNR), effective number of bits (ENOB), total harmonic distortion, spurious free dynamic range) were compared, between a bare, unthinned microcontroller die and UTCP packaged thinned microcontroller. The UTCP performs slightly worse than the naked die (most likely due to parasitics introduced by the package interconnection), but the small deviations are limited and will have only little effect on the usability of the packaged microcontroller.

Flex circuit production

After testing, the UTCP package can be embedded in turn inside a double-layer flex printed circuit board (PCB) using standard flex PCB production techniques. This was done at ACB, a Belgian flex manufacturer.

The principle is as follows: the very thin UTCP packages can be laminated inside the flex multilayer stacks. The packages are first fixed on a flex inner layer sheet, before the multilayer flex is laminated together and the packages are interconnected afterword to the multilayer substrates by conventional through hole interconnections. All these processing steps (lamination, through hole interconnections) are exactly the same as for conventional multilayer board production.

The UTCP packages are first aligned and fixed on a patterned inner layer, having already a prelaminated adhesive sheet. The metal pattern of this first flex inner layer contains a copy of the contact pad layout of the UTCP package, which is used as alignment marks during placement of the UTCP. For the ECG demonstrator only a double sided flex is needed, so the UTCP packaged microcontroller will laminated in between only two flex sheets. For the ECG demonstrator the UTCP packages are aligned manually on the prepatterned alignment marks of a first panel and are fixed by heat tack (using a solder iron) on an adhesive sheet, prelaminated on this panel. Once the package(s) are fixed on this adhesive layer, the second panel of the flex multilayer is laminated on top of these packages. Next, the through holes are drilled, for the interconnection between both sides of the panel, but also for the interconnections to the UTCP contact pads. Finally the through holes are metallized, as for a standard multilayer flex.

After substrate production, the other components are assembled on the flex board. The result after assembly is shown in Figure 5: the microcontroller device is removed from the surface and integrated inside a standard flex substrate. Small SMD components are even mounted on top and/or bottom of the integrated component.

Measurements

The functionality of this wireless biopotential system is tested after assembly. The final ExG demonstrator with integrated microcontroller device is completely functional, and able to monitor ECG signals. Figure 6 shows an example ECG waveform recorded with the wireless system using standard disposable stick-on Ag/AgCl foam electrodes.

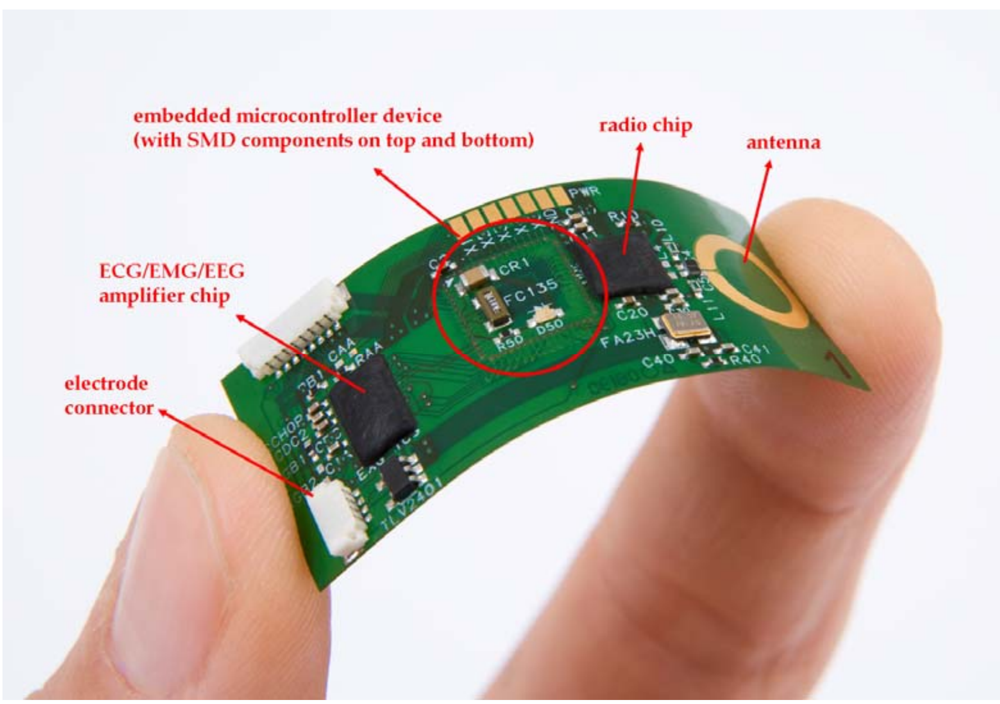

Figure 5 : The flexible wireless biopotential system with integrated microcontroller device (excluding battery).

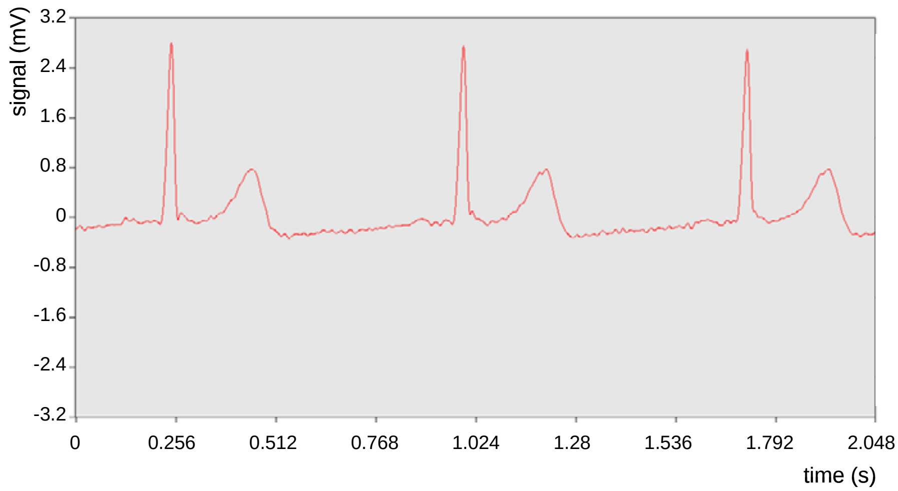

Figure 6 : An example ECG waveform recorded with the wireless system.

Conclusions

The main limiting factor for the total mechanical flexibility of typical electronic assemblies on standard flex substrates are the presence of relatively large rigid components. This paper presents a technology for removing the large IC's from the surface of the flex substrates and integrates them inside the flex multilayer boards.

The components are first embedded as UTCP package. These UTCP's are used as flex interposer during integration inside the multilayer FCB. The packages are only 60 μm thin, and are mechanically flexible. These packages can also provide a fan-out of the chip contacts, enabling easy testing before integration, and relaxing the contact pitch matching the minimum pitch on the flex substrates.

The technology is demonstrated for the integration of a microcontroller device of a wearable, wireless ECG system. The 3D integration of such relatively large components, not only enhances the mechanical flexibility of the wearable system, but can also lead to an increased miniaturization since smaller SMD components are mounted on top and bottom of the integrated device.

The other active components in the system are an ultra-low power biopotential amplifier chip developed by IMEC and a commercial off-the-shelf 2.4GHz low power radio transceiver (Nordic nRF2401A). These components can in principle also be embedded inside the flex PCB just like the microcontroller. This will increase the flexibility and integration density of the device even more.

Acknowledgements

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