

Advances In System Integration And MEMS Packaging

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Interesting times lie ahead in the domain of 3D packaged applications. Continuous scaling and the rise of new technologies, such as MEMS, create a range of opportunities for applications that seemed hardly imaginable only a decade ago. For example the medical industry finds great interest in highly miniaturised sensors. But also the digital imaging industry makes the most of the latest developments in the microsystems technology domain. What follows is an overview of some important research issues and breakthrough technologies that bring these promising applications closer to reality.

The severe pressure on scaling of electronic devices has literally lifted the industry to a higher dimension. Stacking of dies and components in the Z-axis appears on the menu of any research facility involved in this domain. IMEC, the Belgian research centre on nano-electronics and nanotechnology, has also conducted a good amount of work on 3D systems-in-a-package (SiP) in recent years.

Three-dimensional stacks

IMEC's approach consists in dividing the 3D stack into individual subsystems, such as e.g. antenna, RF front-end, radio baseband, main application hardware, MEMS sensors, power management and power generation. The subsystems can be stacked on top of each other, realising a dense 3D-SiP. The advantage is that each subsystem can be fully tested before final assembly, avoiding the known good die problem. Several devices that illustrate this approach have already been reported: a 5GHz wireless LAN transceiver including antenna on the package, a complete Bluetooth radio (baseband and RF) measuring only 7

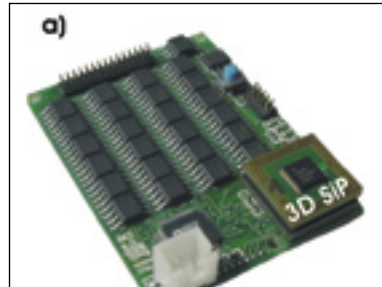


Figure 1a - Integrated 3D SiP sensor platform (bottom right of the board) in an EEG/ECG module

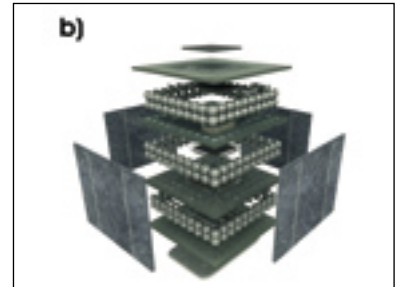


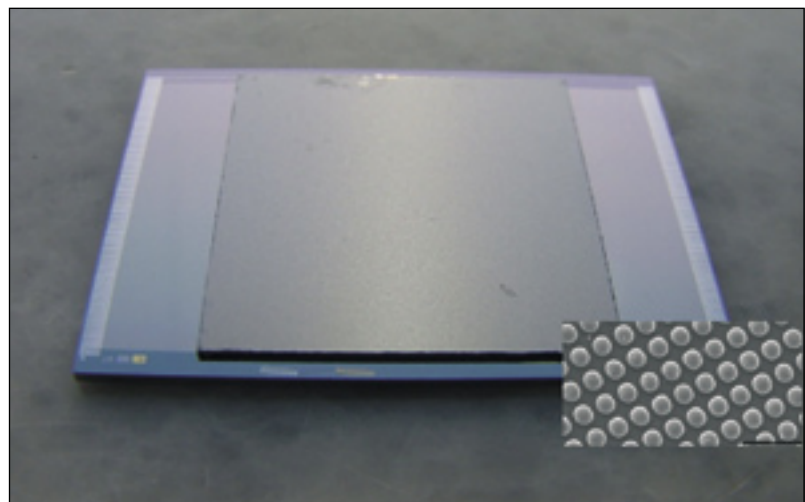
Figure 1b - IMEC's packaging principle towards autonomous smart sensor nodes

by 7mm and an extreme low power autonomous 2.4GHz 1cm³ SiP sensor platform (including antenna).

The last example plays a central part in IMEC's development of a fully autonomous wireless intelligent sensor. Within the Human++ programme, a complete body area network is being developed for patient monitoring. The outcome of the programme, expected around 2010, will give an answer to the demands of the medical and wellness industry for portable and discrete monitoring systems. One of the technology drivers behind Hu-

man++ is an integrated 24 channel EEG and 1 channel ECG unit for use on the human body. The current status is a 1cm³ SiP containing the DSP and communication components, mounted on a board with the necessary analog electronics for signal processing. The latter account for more than 80% of the current surface and make the entire device size more or less like that of a package of cigarettes. (Figure 1). This becomes a whole different story when you consider that the 80% mentioned above is now integrated into a single chip that is smaller than a fingernail.

Figure 2 - Solder bumped 1Mpixel CMOS image sensor with high-density parallel integration scheme and 10µm bump pitches (inset)



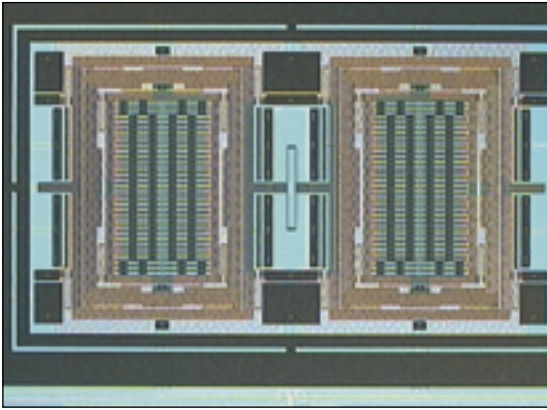


Figure 3 - Poly-SiGe MEMS gyroscope processed at IMEC on standard 5-level CMOS

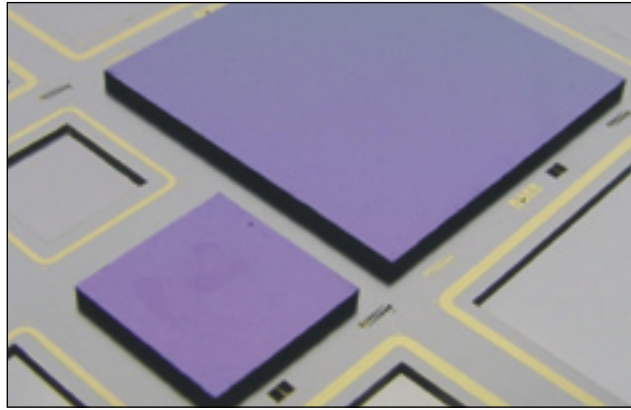


Figure 4 - Illustration of hermetic metal sealing through the indent reflow sealing approach

Die stacking

But there's still a long way to go and some important obstacles must be overcome. Current 3D stacks have typical dimensions around one or a few cm³ and are built with standard components available on the market. For further development of miniaturised devices, interconnection technologies that enable the stacking of layers of chips and integration of MEMS are a key factor.

Massive parallel hybrid integration schemes, using through wafer vias and solder bumps, can allow high-yield assembly. Solder bumps are already used to interconnect megapixel imager sensors to ASIC read-out circuitry (Figure 2). These, as well as image devices for printers or displays, require local interconnect between each imaging pixel and its read-out circuitry, creating the need for high density two-dimensional integration. IMEC demonstrated arrays with a pitch as small as 10 μm. Bumps can easily be realised by electroplating or evaporation on the top and/or bottom substrate. Plan-parallelism is a key issue to achieve connection yields up to 99.5%.

To achieve additional miniaturisation at the system level, innovative methods for thinning, handling and deposition of dies in thin-film platforms have been developed. It's possible to thin dies down to 10μm without causing damage to their functionality. The thin dies can be embedded in a thin-film process and further interconnection can be

performed at the wafer level, avoiding connections via flip-chip or wire bonding.

Even smaller devices can be achieved when the MEMS component is processed directly on top of its ASIC. By using polySiGe as the MEMS structural material, this can be realised perfectly. One example, developed at IMEC within a European research project, is a poly-SiGe gyroscope processed on top of standard 5-level-metal CMOS (Figure 3). Furthermore, the poly-SiGe material is also suited for use as a thin-film cap.

MEMS packaging

MEMS components are indispensable in autonomous 3D sensor nodes. Since MEMS are highly susceptible to post-processing damage and are therefore not compatible with many conventional packaging processes, a typical MEMS packaging sequence starts at level zero. Simple wafer-to-wafer or die-to-wafer assembly techniques using BCB seals prove to be a valuable and reliable option in a variety of situations, requiring only fairly straightforward techniques. Polymer sealing has proven to be topography tolerant, easy to pattern, feasible at low temperatures, while in the meantime compatible with higher ones, and more than sufficiently resistant to thermal and mechanical stress. One limitation is that using polymers results in "semi-hermetic" seals. These guarantee a humidity barrier and effective protection against aggressive assembly operations, and

may even provide a humidity barrier during the device lifetime of MEMS switches.

When full hermeticity (e.g. for vacuum packaging) is required, Sn- or In-based seals (Figure 4) are the best choice, even if demanding a more complex process sequence that will include for example pre-solder metal-lisations on the MEMS. But the result outweighs the complications. Using indent reflow sealing, it is possible to control the ambient in a zero-level package in terms of internal pressure and filling gas. But on long-term and for specific applications, outgassing remains a tricky barrier to overcome and the incorporation of getter material can be required.

With these techniques, caps with a thickness down to 50μm can be mounted. In order to also minimise lateral dimensions, thin-film based capping techniques can be used, but only at the expense of further process complexity and more device-specific process sequences.

Conclusions

Fully autonomous monitoring systems with the size of 1cm³ are very close to reality. Once advanced technologies such as wafer thinning and MEMS processing and packaging are optimised, further miniaturised devices will increasingly be demonstrated. And in a not too distant future, fascinating applications to improve our quality of life will undoubtedly appear on the market.