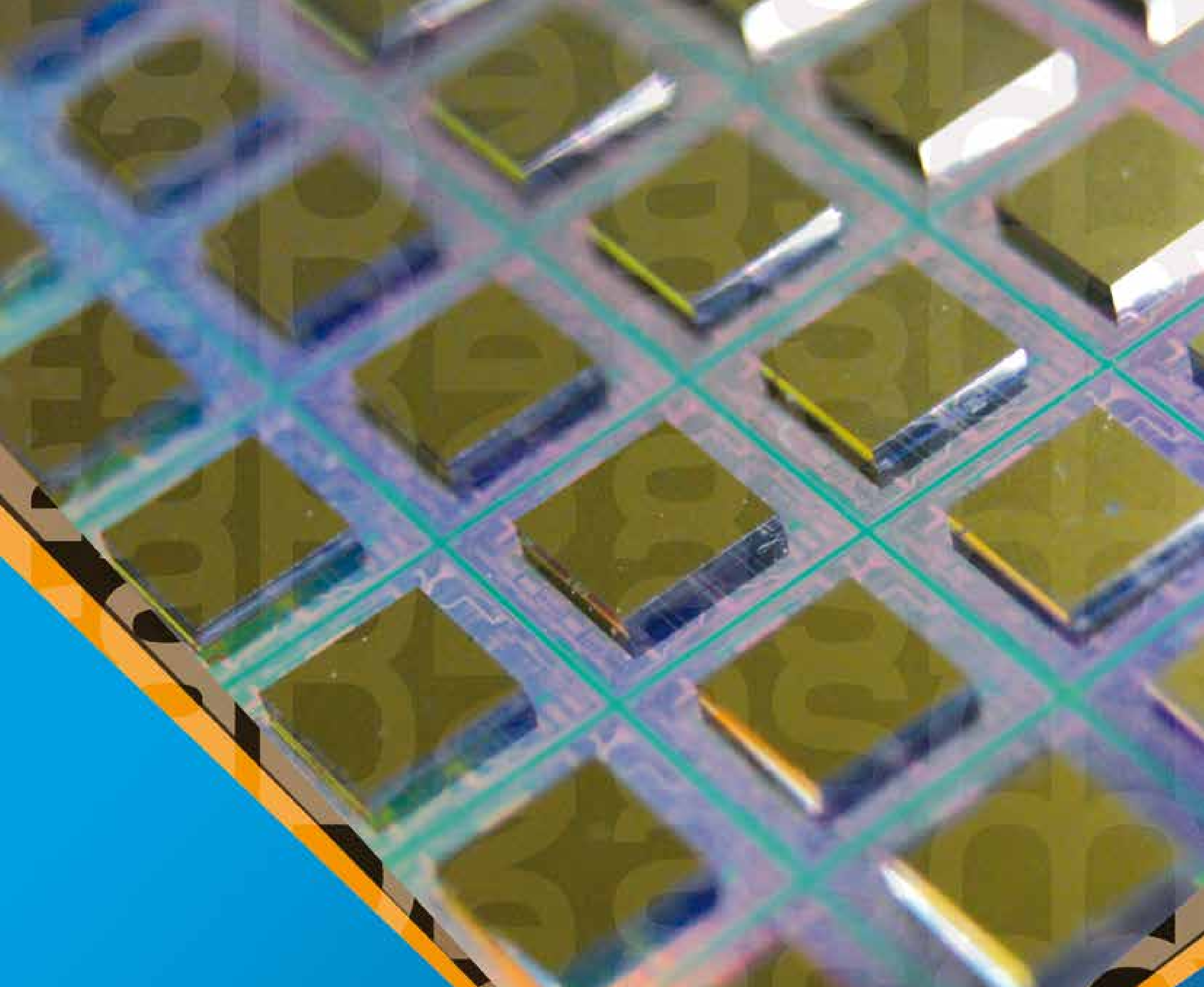

EFFICIENT AND PRECISE 3D INTEGRATION OF HETEROGENEOUS MICROSYSTEMS FROM FABRICATION TO ASSEMBLY

fab2asm
from fabrication to assembly
Results

A European Project supported through the Seventh Framework Programme for Research and Technological Development

THE FAB2ASM CONTEXT

Micro- and nano systems integration is a rapidly developing field where multiple materials, technologies, and functional components form highly integrated micro- and nanosystems for cross-sectorial applications such as intelligent sensors, flash memories, or radio frequency devices in mobile phones. Recently 3D integration by stacking components vertically became a very promising approach. However, so far the cost of high-volume production has been very high because of the low throughput of pick-and-place assembly, especially when high precision is required (e.g. alignment of optical devices), preventing those highly important technologies to be widely implemented.

PROJECT GOALS

FAB2ASM uses a novel hybrid microassembly technology to attack the problem of simultaneous high-throughput and high-precision. It joins traditional robotic pick-and-place and selfassembly of microsystems. Using existing high-speed robotic tools, a throughput of tens of thousands units per hour can be achieved for the fast but coarse feeding of dies to the targets of assembly. Using capillary self-alignment – where surface tension of the liquid aligns small components such as microchips, we can achieve micron accuracy positioning simultaneously with the high speed feeding. Combined with appropriately designed interfaces, permanent fixing and electric connections can be successfully implemented.

FAB2ASM project addresses the full process chain of integration of 3D and heterogeneous microsystems:

- interface design,
- capillary self-alignment,
- bonding techniques,
- integration of industrial robots and hybrid microassembly technology.

3 demonstrators have been developed:

- A high-speed hybrid microassembly machine
- Self-aligned and ultra small VCSEL on silicon bench
- A low-cost small pitch 3D integrated daisy chain chip stack

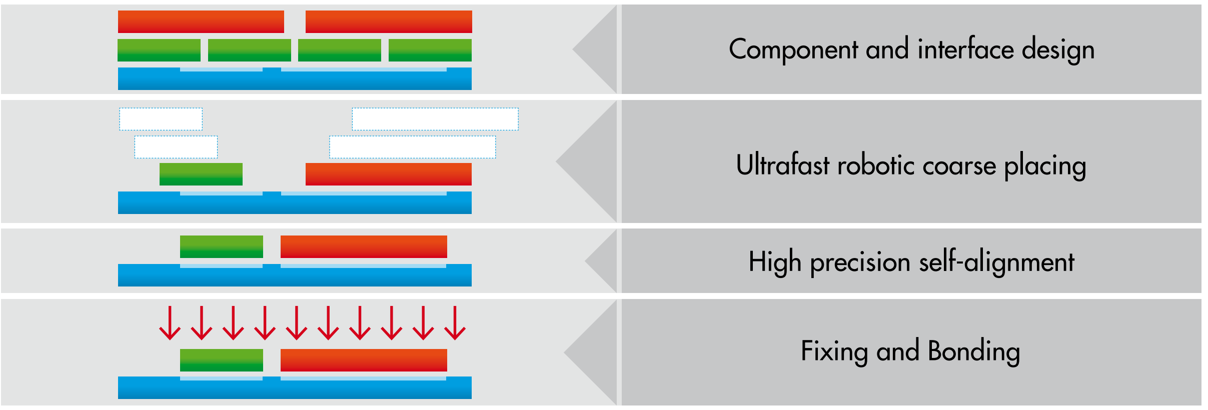

Figure 1: Main process steps of hybrid microassembly

EUROPEAN INDUSTRIAL IMPACT

The results of the FAB2ASM provide the European semiconductor industry a new tool in integration technologies such as chip-to-chip, chip-to-wafer, interposer and fan-out for BGA. It reinforces the competitiveness of European nano- and μ-manufacturing with a technology that pushes beyond the efficiency-precision chart of the state-of-the-art integration technology. For example, the technology developed by FAB2ASM can be adapted into flip-chip/die bonding equipment and upgrade the existing factory to a new level of performance and cost effectiveness. In contrast to many others technologies, the FAB2ASM technologies can preserve the current investment of industry and reuse a great amount of technology know-hows that are the advantages of European industry.

TECHNOLOGIES DEVELOPED IN THE FRAME OF FAB2ASM PROJECT

COMPONENTS AND SURFACE DESIGN FOR SELF-ALIGNMENT

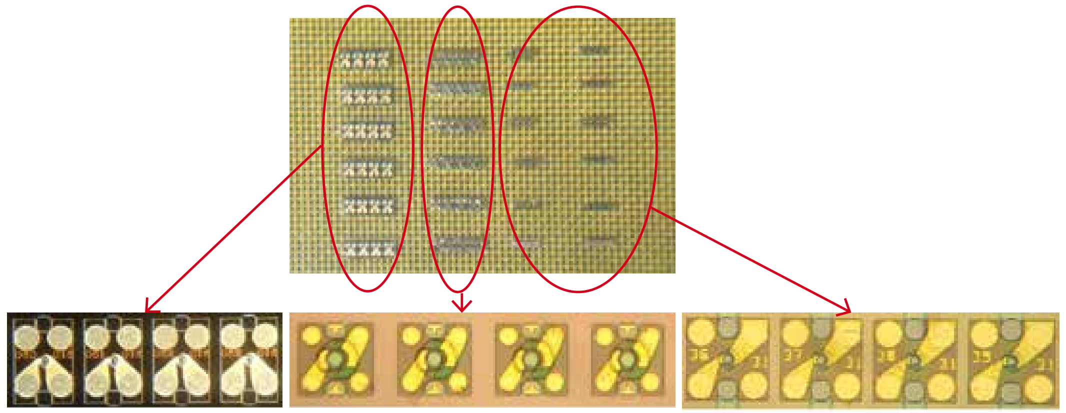

Figure 2: Fabricated 1490 nm VCSELs with different footprints

Components: To integrate self-alignment into a packaging flow, laser chip (VCSEL) and Si chips were developed and fabricated using industry relevant platform . The manufactured Si chips comprise Through Silicon Vias (TSVs), and microbumps at 20μm pitch. In parallel, miniaturized VCSEL and Si bench with integrated photonics wave guide were also developed. The developed miniaturized VCSELs (see figure 2) have reach industry maturity level.

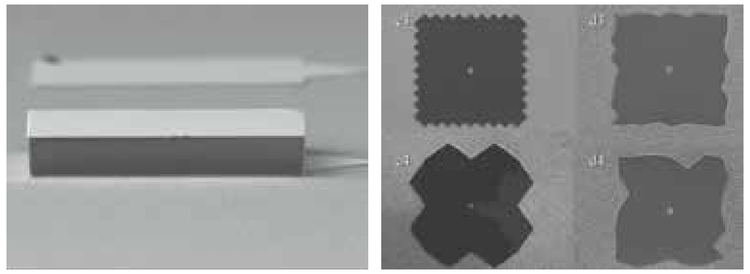

Figure 3: surface design. Left: self-aligned chips; Right: low precision patterns.

Surface design: To achieve hybrid microassembly, the components need to be designed according to the requirement of the self-alignment process. Interfaces based on chemical functionalized hydrophilic/hydrophobic patterns have been developed. Besides chemical functionalization, FAB2ASM has investigated the interfaces based on pure geometrical features, including the novel laser ablated micro trenches for self-alignment [2] .

To understand the requirements of manufacturing precision for self-align patterns, low precision patterns with jagged edges have also been investigated. The results show that the self-alignment process is rather robust despite the significant jaggedness of the edges (see Figure 3) [3]. This results has important implications in reducing the manufacturing requirements and associated costs for industry implementation of hybrid microassembly technology. Electrical functionality of the interface has been considered during the design process.

HYBRID MICROASSEMBLY

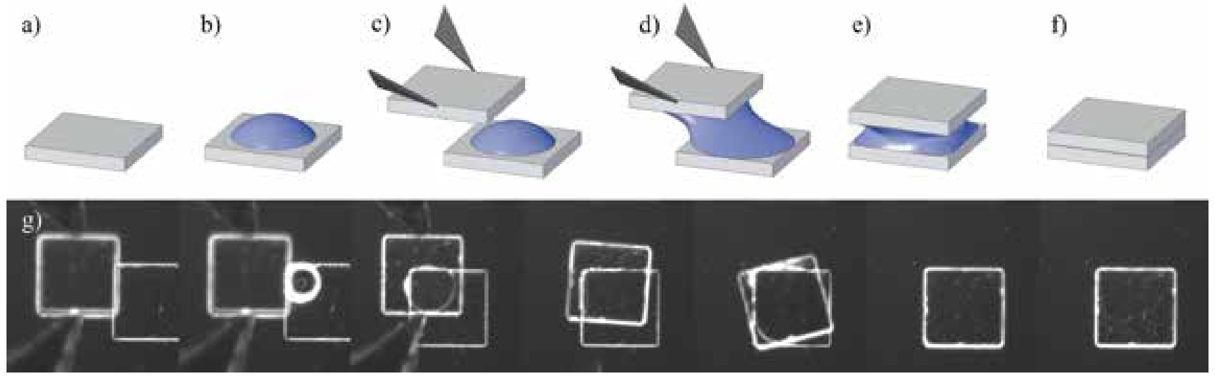

Figure 4: Hybrid microassembly with droplet self-alignment [1]. (a) Assembly site is a protruded structure or a surface pattern. (b) Droplet of liquid (water or adhesive) is dispensed on the assembly site. (c) Microgripper approaches the release site with a part (microchips or other micro components). (d) Droplet contacts with the top part and wets between the part and the assembly site, which forms a meniscus. (e) Microgripper releases the part and the capillary force aligns the parts. (f) Parts are aligned and bonded. (g) Image sequence of the actual experiment, as viewed from the top side.

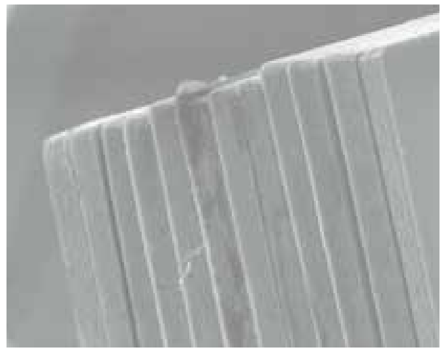

Figure 5: Hybrid microassembly of 12 layers of 1 mm x 1mm die with thickness of 10 µm [4].

The hybrid microassembly technology developed in FAB2ASM focuses on droplet self-alignment assisted technologies [1]. A substrate with patterns that can confine the droplets is the basis of the integration process (see Figure 4).
Reducing the thickness of dies is one way to reduce the price of stacked dies. Indeed, the thinner the dies are, the cheaper the TSVs are. FAB2ASM has demonstrated the handling of 10µm and 5µm-thick dies, well beyond the current state of the art of ultra-thin dies of 40µm. Besides, FAB2ASM has shown a significant advance by demonstrating the ability to stack twelve 10µm-thick dies (see figure 5, [4]).
Moreover, novel hybrid microassembly processes, dielectrophoresis self-alignment [5] and water mist induced parallel hybrid microassembly has been developed (see Figure 6) [6]).

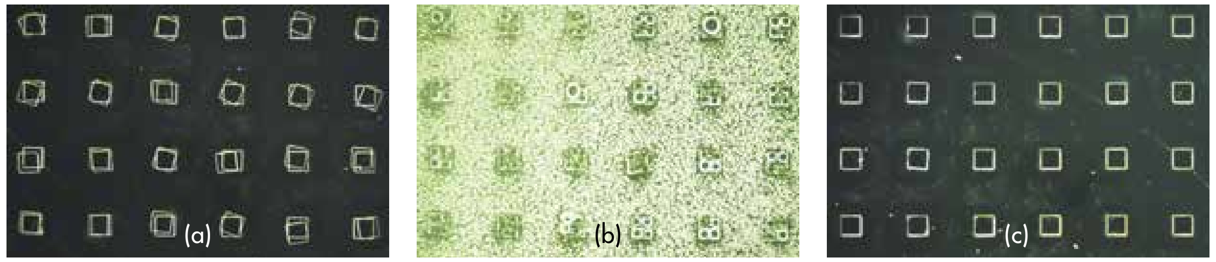

Figure 6: Parallel hybrid microassembly of 30 microchips with water mist: a) 200µm x 200µm x 30µm chips are placed on the top of a matrix of 30 receptors of the same size with random placement error; b) water droplets are delivered in the form of the water mist; c) the placement errors are corrected and all the chips are aligned with the receptors

FIXING AND BONDING

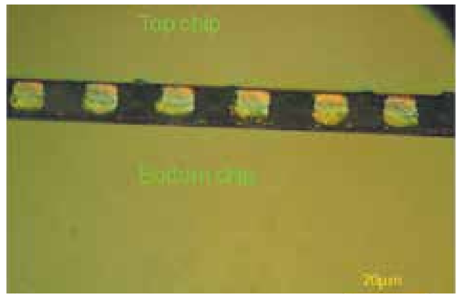

Figure 7: Optical photograph showing cross-section, 7.5µm diameter, 20µm Cu/Sn bumps, assembled using capillary self alignment [7]

Fixing and bonding technologies for hybrid microassembly process have been investigated where Cu/Sn micro-bumped dies with 20 µm pitches have been designed and lead to metallic interconnections with submicron precision after the hybrid microassembly process (see Figure 7, [7]).
Laser drilling of TSVs (see figure 8) and Laser Induced Forward Transferring (LIFT) for TSV filling has also been developed as alternative technology for the TSV manufacturing [8].

Novel multi-layer nanostructured materials for bonding have also been developed. This approach is based on a nanoscale effect that allows for the drastic reduction of melting point for nm thick brazing filler metals. Different multilayer solders, including Ag/Cu, Cu-W, have been developed (see figure 9).

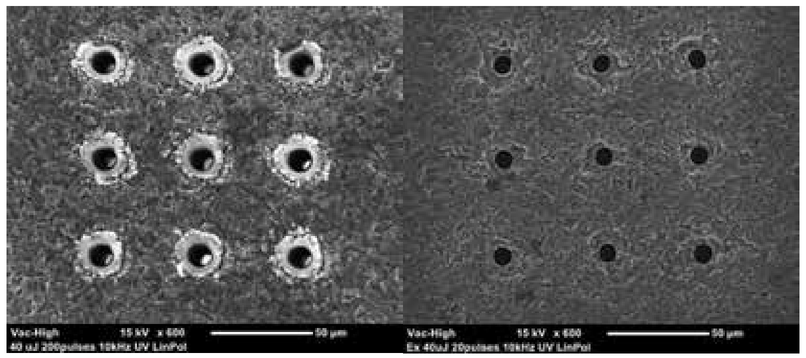

Figure 8. SEM images of the entrance and exit sides of holes drilled using 343nm (ultraviolet) laser light with 40uJ pulse energy and repetition frequency of 10kHz in 200µm thick Si wafer

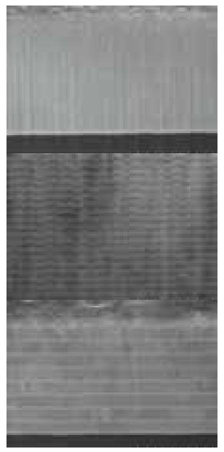

Figure 9. Multi-layer nano solders. Top: 5nm Cu and 2nm W; Middle: 50 nm Cu and 2 nm W; Bottom: 100 nm Cu and 2 nm W

INTEGRATION AND RELIABILITY

The different techniques and technologies developed in FAB2ASM have been integrated with all process steps from fabrication to assembly validated and chained efficiently. Reliability of the processes and the produced products has been ensured by proper mechanical, electrical and optical characterizations.

Hybrid microassembly station

Figure 10: Hybrid micro-assembly test station ultra-thin die handling tool integrated in the front.

A test station for self-assembly and hybrid assembly has been set up for the development of process integration for the demonstrators. The station is capable of handling dies of different form factors: there is a tweezer-type gripper for small dies (down to 50 x 50µm), an ultra-thin die handling tool for thin dies (down to 5µm thick), a vacuum gripper for large dies (> 1 x 1mm), and a novel adhesive gripper for medium and large dies (> 100 x 100µm). Two dispensers have been integrated in the station: a piezoelectric dispenser for water and a pneumatic dispenser for other liquids, such as adhesives.

Small-pitch 3D chip stacks

Assembly of through-silicon-via (TSV) chip stacks using water droplet self-alignment has been demonstrated. 50µm thin chips with small-pitch (down to 20µm) microbumps and TSVs have been fabricated, and stacked using water droplet self-alignment. In the resulting assemblies, TSVs are fully connecting the planar metal on top of the chip to the microbumps of the bottom chip (Fig. 11).

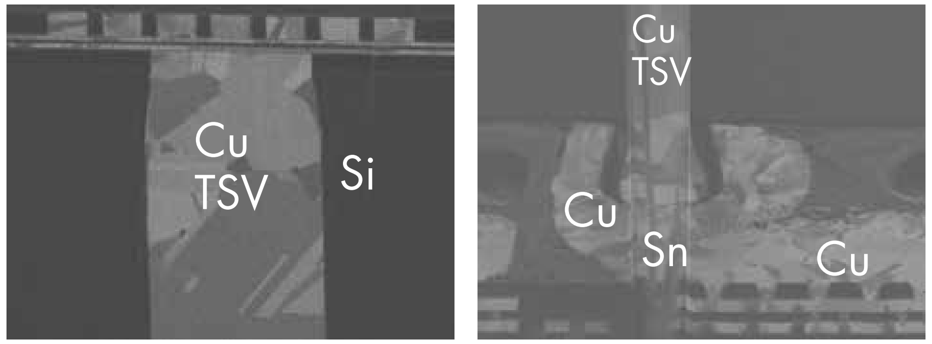

Figure 11: Focused ion beam cross-sectional SEM images of TSV connecting to the metal wiring on the top of the chip (left) and TSV connecting to the microbump of the bottom chip (right)

Reliability and assembly performance

Several testing to assess the performance data of the different assemblies produced in the project have been carried out:

- Electrical and optical testings
- Accuracy, mechanical stability, speed and yield of the assembly process: The performance tests showed that no bottlenecks were present in the assembly processes, and the targeted quality of final assemblies was reached.
- Mechanical testing of bonding: several mechanical strength test methods and set-ups for bonded microparts have been developed:
  - a wedge opening test to determine interface toughness,
  - a shear test to determine the shear strength of interfaces,
  - and an in-situ (inside SEM) micro-compression test for high temperatures.
  - two versatile bonding force measurement platforms capable of measuring forces (nN and mN ranges) between objects from nanospheres to micro-components. They have been used to measure e.g. bonding forces of dies assembled by self-alignment.

DEMONSTRATORS

Three demonstrators have been developed in FAB2ASM, in die integration on lead-frame, integration of VCSELs on benches, and on 3D multi-layer integration of dies on substrate.

A—HYBRID MICROASSEMBLY ON LEAD FRAME

With the further reduction of die size due to the ever evolving demand of reduced foot print and costs, it is a great challenge to achieve high-precision integration of dies on lead frame with the same or even better throughput. To ensure the functionality and reliability of the integrated device and to reduce the package size, the required die placement precision should be much better than the cases with larger dies, despite the even higher throughput. Technologies relying on pure robotic microassembly are reaching their limits in satisfying such demand.
In FAB2ASM, capillary self-alignment assisted hybrid microassembly technology has been integrated in NXP's industry leading high-speed die bonding machine, which can reach a throughput of over 40K units per hour (UPH).

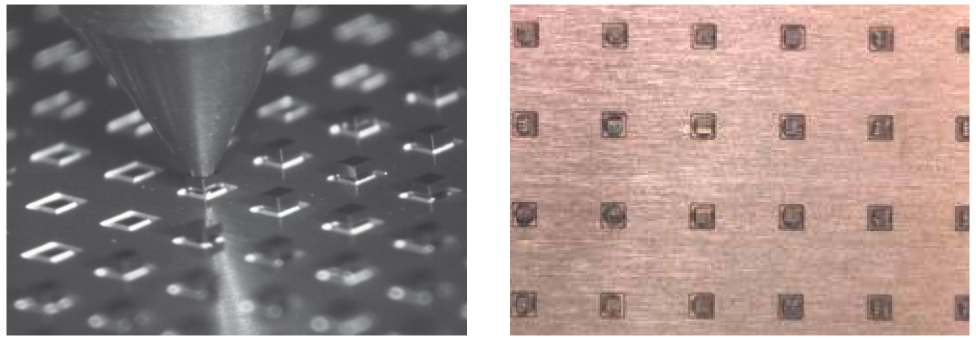

Figure 12: Results of hybrid microassembly of dies on lead frame with NXP high-speed die bonding machine. The assembled dies has a good position accuracy of about 2µm on the substrate. Higher accuracy can be reached with better defined patterns.

B—HYBRID MICROASSEMBLY OF VCSELS

Figure 13: 1490 nm VCSEL arrays assembled on specific design carrier.

Silicon photonics platforms together with appropriate light sources are the key elements for ensuring the functionality of the final products in optical data communication, optical sensing, optical computing etc. Low electrical power consumption, circular optical beam profile and emission wavelength compatible with the transmission spectra of the silicon, make the long wavelength (>1200 nm) Vertical Cavity Surface Emitting Laser (VCSEL) an ideal candidate for laser light source for integration on silicon photonics platforms.
Within the FAB2ASM project, 1490 nm range emitting VCSELs with different footprints have been produced . The devices have been integrated with high precision accuracy onto two types of assemblies: VCSEL on a specific design carrier (Figure 13) and VCSEL on silicon bench (see Figure 14).
Measurements demonstrated that the self-alignment process allows the mounting of VCSEL on Si-platform with required accuracy and keeping the full functionality of the devices.

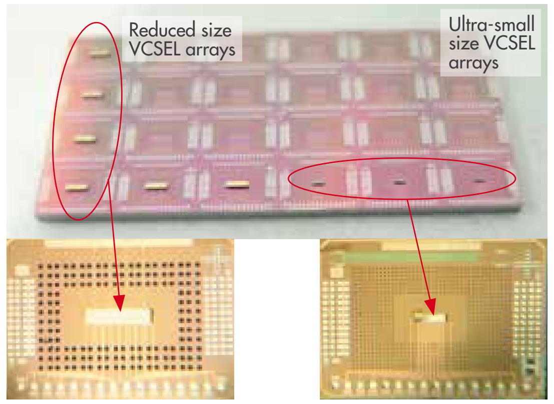

Figure 14: The picture of the Si- bench with reduced and ultra-small size VCSEL arrays assembled using liquid assisted self-alignment (SA) process. Simultaneous SA process of multiple arrays was demonstrated

C —HYBRID MICROASSEMBLY FOR 3D INTEGRATION

Heterogeneous integration is a key enabler for 2.5D and 3D integrated device. It allows to fabricate very advanced solutions with components (IC, memory, sensor, MEMS) coming from different sources. Similarly to the hybrid microassembly of VCSELs, micro bumping is a key enabler to be able to stack components with very high I/O pin count. On top of that, Through Silicon Vias (TSVs) enable true stacking of dies. Today this is the main path for memory applications where the sourcing of the unit memory dices and the TSV processing is made during the IC fabrication.

In FAB2ASM, IMEC have used 50µm thin dies containing TSV (5µm diameter) from a 300mm wafer processed on a 65nm technology platform (see Figure 15). The thin dies are bonded onto a bottom die coming from a 200mm wafer, processed on a 0.13µm platform (see Figure 16). Temporary bonding technique has been used for thin die handling and integration with the microbumps (see Figure 17) using the hybrid microassembly technology based on capillary self-alignment.

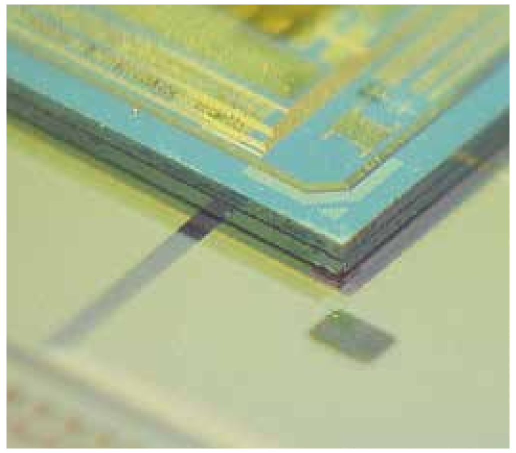

Figure 15: Three layers stacking has been demonstrated in FAB2ASM project: 50µm thin dies bonded on substrate forming a 3 layer-stack.

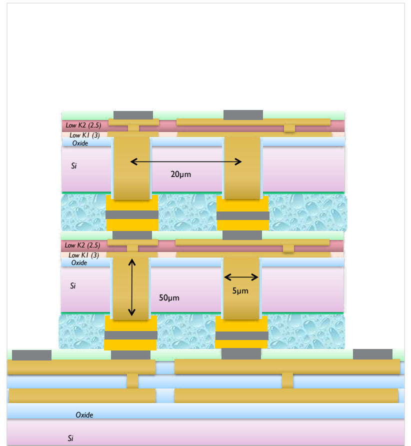

Figure 16: Schematic cross section of die stacking enabled by hybrid microassembly

Figure 17: XSEM view showing 3 layer stacks

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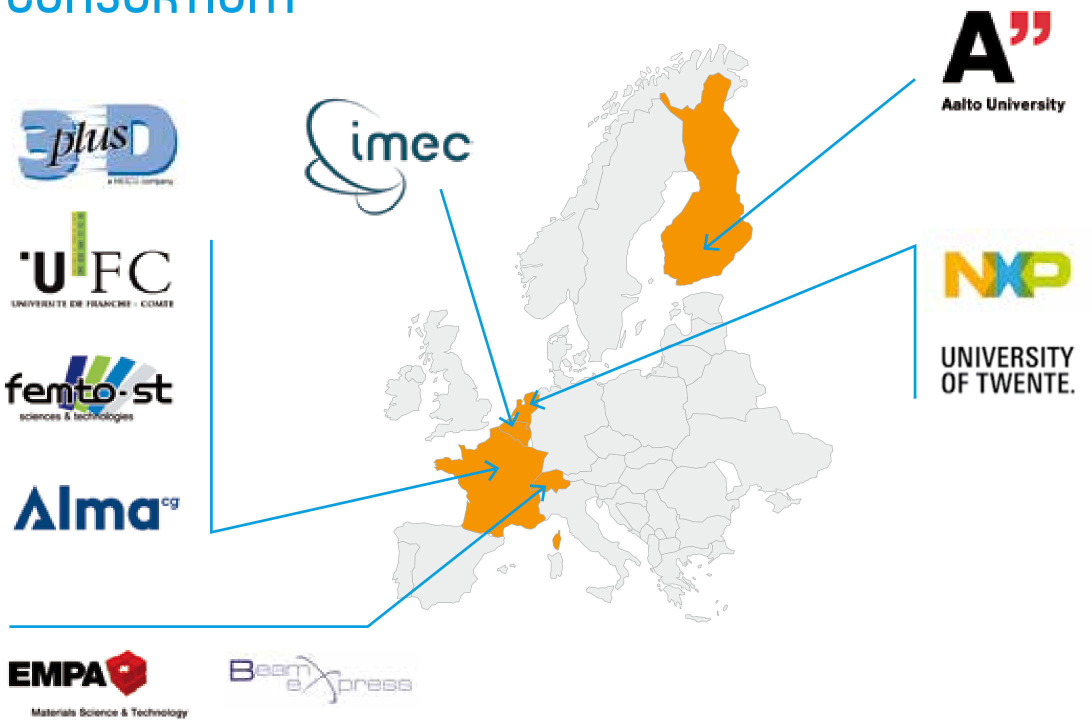
CONSORTIUM



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