Cluster for Application and Technology Research in Europe on NanoElectronics

PROJECT RESULTS

CAT802

European equipment suppliers benefit from smart analysis methods for 3D integration in advanced microsystems and materials

[SAM^3]

The innovative co-labelled EURIPIDES²-CATRENE SAM3 project is gearing up to meet the challenges the next ten years will bring as we witness the next big changes to package materials, highlighting the need for proper characterisation and failure-analysis techniques.

Complex microelectronic devices are at the very core of such innovative projects as the futuristic Smart Cities. This makes More-than-Moore (MtM), System-in-Package (SiP) and 3D high-density integration essential in the design of these projects. To ensure that these devices remain at the technological cutting-edge, we are already witnessing new developments in package materials and processes. This, in turn, will require effective analysis techniques to understand new failure modes and reliability-limiting factors caused by thermo-mechanical mismatch, residual stresses and interaction of new materials and processes.

Now, at the time of this project, there were challenges to be dealt with. For instance, failure-analysis techniques to localise electrical defects in SiP devices with multilevel wiring and efficient and artefact-free sample preparations for physical analysis techniques were limited. This led to a strong interest in '3D-SiP' integration and MtM performance, together with miniaturisation and cost-reduction. Notably, failure analysis was first recognised as a major enabler. This, in turn, called for the development and qualification of new diagnostic tools and advanced methods for material characterisation, defect localisation, sample preparation and physical-failure analysis.

Driving competiveness through quality, price and failure diagnostics

The prime objectives behind the SAM3 project were to strengthen global competitiveness of European Union semiconductor and system suppliers in designing and manufacturing reliable, high-quality and cost-effective MtM and SiP products, and to foster a closer cooperation with suppliers of failure-diagnostics tools in order to shorten product-development cycle times.

This project also aimed at strengthening global competitiveness of innovative diagnostic-tool suppliers by providing them access to the latest available MtM and SiP technology developments. Crucially, implementing innovative failure-localisation and analysis methods and tools in MtM and SiP developments would secure reliability and reduce field returns. Furthermore, by supporting suppliers of semiconductors, systems and diagnostic equipment, research institutes could establish an international, competitive infrastructure and know-how.

The SAM3 project was run by a consortium from France and Germany, comprising four leading European semiconductor and system suppliers, ten tool providers and four research institutes, which provided specialist expertise and experience in such areas as failure localisation, preparation and analysis, and material characterisation.

Project activities – mainly focusing on the impact of analytical methods and the causes of reliability failures – can be summarised as follows:

1. Early technology concept phase:
   - Assess new failure mechanisms, physics of failure;
   - Design for reliability and virtual prototyping (finite element simulation).
2. Technology & assembly-process development:
   - Mature interconnect technology;
   - Robust production processes;
   - Efficient material sets.
3. Product development & qualification:
   - R&D to get first qualified products shipped to the customer.
4. Manufacturing:
   - R&D to improve quality & yield;
   - Inline-check, sampling, monitoring.
5. Customer returns, field failures.

Significant progress was made in failure localisation, preparation and analytical characterisation in 3D packages and SiP. In particular:

- Electrical characterisation and failure narrowing;
- Package-level non-destructive defect localisation;
- Device opening and target preparation;
- Chip-level defect localisation;
- Defect physical analysis;
- Determining root causes of failure;
- Development of failure analysis flows.

Additional significant results with respect to failure analysis equipment were:

- A novel concept for defect localisation by scanning acoustic microscopy (SAM) with GHz-SAM, for example pad cratering;
- Enhanced lock-in thermography (LIT) systems for improved hotspot localisation and thermal mapping;
- A prototype for nanoprober and EBAC (electron beam absorbed current) systems;
- A preparation flow for combined laser/plasma-

PROJECT CONTRIBUTES TO

✓ Communication
✓ Automotive and transport
✓ Safety and security
✓ Energy efficiency
✓ Sensors and actuators
✓ Process development
✓ More than Moore

PARTNERS

Infineon Technologies AG / Robert Bosch GmbH / MUEGGE GmbH / PVA TePla Analytical Systems GmbH / Point Electronic GmbH / SmarAct GmbH / WITec GmbH / 3D-Micromac AG / STMicroelectronics (Grenoble2) SAS / STMicroelectronics (Rousset) SAS / STMicroelectronics (Tours) SAS / Thales Systèmes Aéroportés / Thales Research and Technology / Digit Concept / Orsay Physics / Predictive Image / Sector Technologies SAS / CNRS (represented by LP3-Marseille, LEPMI-Grenoble, and GREMAN-Tours) / GREMAN Tours University / Fraunhofer IMWS / Reutlingen University

COUNTRIES INVOLVED

France
Germany

PROJECT LEADER

Klaus Pressel
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KEY PROJECT DATES

1 October 2015 - 31 December 2018

FIB (focused ion beam) for fast and precise SiP cross-sectioning;

- In-situ delayering by plasma FIB;
- A tool concept for plasma etching of wide bandgap materials;
- New methods for quantitative dopant characterisation;
- A new method for modelling acoustic beam behaviour in microelectronic components tested.

Commercial potential and early market introduction

Importantly, collaborative work by the project's major semiconductor and system suppliers, together with the failure analysis of compact SiP solutions by equipment and method suppliers, produced results with high commercial potential. Here are some notable examples:

- Novel plasma etching tool: achieves an etching rate of better than 1 µm/min for silicon carbide (SiC) by combining a microwave-driven remote plasma source driven by radio-frequency (RF) ion etching;
- Extended optical residual stress measurement: allows maximum efficiency for residual stress measurements on Si devices based on a new spectrometer design extending the frequency range from visible to near ultraviolet (UV);
- Scanning acoustic microscopy µ-crack detection: enables defect analysis on stressed bond-pads, flip-chip contacts and copper-to-copper (Cu-Cu) bonds using SAM in the GHz frequency domain;
- New current imaging system for scanning electron microscopy (SEM): including new electronics and software for resistive defect localisation, which allows parallel probing and highly sensitive EBAC/RCI analysis, as well as in-situ needle-cleaning process to increase throughput;
- Novel 8x SEM in-situ nanoprober system: used for IC-level diagnostics, based on closed-loop piezo technology for large scale positioning with nm precision;
- Improved high-precision, ultra-short-pulse laser system: enables fast cross-sectioning preparation of complex SiP components by combined laser/FIB workflows. In addition, conformal backside thinning of dies (a technique to produce ultrathin dies) is now possible;
- Plasma-laser sample preparation: applies 2.45 GHz cold plasma allows the removal of epoxy moulding compound; and a 512 nm pulse-shaping laser reduces the cross-section effort before FIB significantly – from hours to minutes;
- Faster in-situ plasma FIB: used for delayering and combined laser-/plasma FIB cross-sectioning to enhance preparation throughput;
- Development of reference samples for acoustic microscopy: allows qualification of SAM analysis tools by using test samples with defined artificial defects. Samples are stable over time and easy to use;
- Novel thermography system: multi-point acquisition of thermal transient events and temperature measurements (accuracy to 1°C) on die and complex packages;
- Improved EOTPR system: enables short and open localisation on complex packages with an accuracy of 5 µm.

SiP integration is widespread

Thanks to miniaturisation, SiP has become an enabler for heterogeneous integration. The SiP market is growing and 3D-SiP solutions are appearing in products and components in various sectors: such as automotive electronics (3D image sensor chips); energy generation and energy distribution (like Smart Grid); industrial electronics, where SiP growth of over 20% is predicted; and in such sectors as solid-state lighting, medical and aeronautics.

All this is backed by market statistics. Yole's 2019 report predicts a CAGR of about 11% between 2018 and 2023 for the total assembly market for RF-SiP components in mobile phones. In their market report from May 2019, Zion Market Research forecast a CAGR for SiP of around 8.1% between 2019 and 2025. And market growth is supported by statistics from Allied Market Research, which expect the global SiP packaging technology market to reach US$30 billion by 2022, growing at a CAGR of 9.0% during the forecast period 2016–2022.

Crucially, SAM3 secures European competitive power in key industry sectors already mentioned, allowing Europe to hold a strong position in high-density, complex SiP technologies. All this is occurring just as mass production of some microelectronic devices moves out of Europe. This makes it even more critical for Europe to develop intellectual property in this emerging field to maintain existing employment levels, develop replacement products and reap financial benefits.

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CATRENE focuses on delivering nano-/microelectronic solutions that respond to the needs of society at large, improving the economic prosperity of Europe and reinforcing the ability of its industry to be at the forefront of the global competition.