NANOELEC. ADVANCED CHARACTERISATION PLATFORM GRENOBLE

X-ray nanoprobe aids 3D chip integration

ESRF The European Synchrotron

At a glance

Synchrotron X-ray nanotomography allows manufacturers to visualize voids and phases in copper-pillar interconnects with unprecedented resolution.

Context

For the past 50 years the ability to pack greater numbers of transistors onto silicon chips has brought exponentially increasing computing power and put the microelectronics industry at the center of economic and social development. While transistors have continued to get smaller, faster and more efficient, however, issues such as heat management and current leakage are jeopardizing this famous trend.

In order to build processors that can embrace ever larger data sets and novel IT paradigms such as the Internet of Things, manufacturers are turning to advanced "More than Moore" chip architectures -- including those based on greater 3D integration of chips. 3D fabrication processes are now reaching a high degree of complexity, with copper pillars that pass vertically between silicon planes proving a promising though-silicon-via (TSV) technology.

The challenge

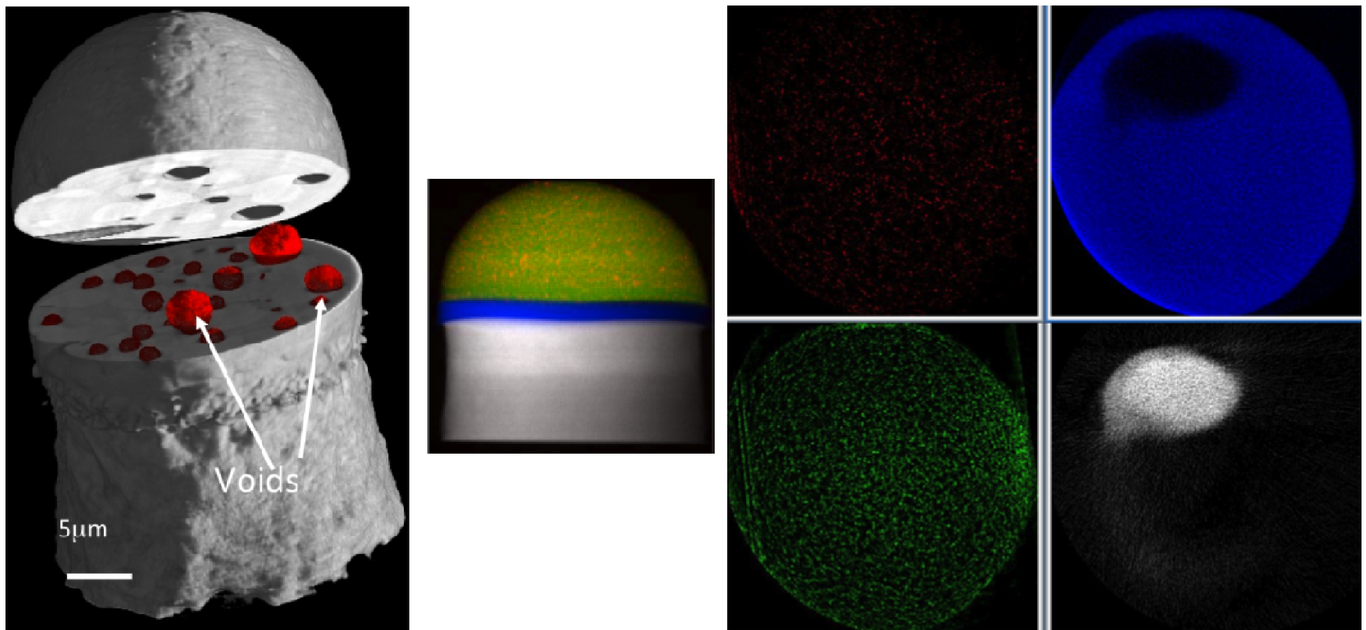
Reliable interconnects are key to ensure that different layers of the 3D stacked structure can communicate at high speeds. Measuring between 1—20 microns in diameter and formed by drilling small holes in silicon, copper pillars present a major manufacturing challenge. Any defects or voids within the material can lead to spikes in the current density that may damage components and affect device performance.

IRT Nanoelec partner ST Microelectronics used X-ray nano-tomography and fluorescence at ESRF nanoimaging beamline ID16A to visualize voids in copper pillars in a prototype 3D-integrated chip. Their aim was to characterize the mechanical stability of the pillar and thus quality of the interconnect by studying the location of voids and elemental phases.

The results

New synchrotron X-ray techniques at the ESRF offer unique capabilities for non-destructive imaging of 3D architectures. The extremely small spot size and high penetration depth of the X-ray beam revealed the existence of voids in the sample with a resolution of just 23nm.

X-ray fluorescence, meanwhile, allowed the team to establish the presence of different elements – including the complex phases that result from alloys formed during soldering (see image).



Nano-computed tomography of a copper pillar reveals the distribution of voids (left), while fluorescence tomography slices at different heights (right) show the elemental phases in the soldered region on top of the pillar: silver (red), nickel (blue), tin (green) and copper (grey). [P Bleuet et al. SPIE Developments in x-ray tomography IX, 2014, San Diego]

Conclusion

ESRF beamline ID16A offers a unique nanoprobe for quantitative 3D characterization of the morphology and the elemental composition of samples in their native state. Applying the technique to copper pillars shows that voids can be resolved at length scales more than ten times shorter than is possible using commercial laboratory equipment.

The success of the experiment led ST Microelectronics to invest in a long-term proposal to characterize even smaller voids in copper pillars and to explore other promising TSV architectures. The ultimate aim is to be able to apply the technique to ensembles of TSVs and perform in-operando analysis on whole working devices.

The technique

- ESRF beamline ID16A is a unique experimental station that uses advanced X-ray optics and a long baseline to produce a high-brilliance beam focused down to nanometer size.
- Nano computed tomography (nanoCT) and X-ray fluorescence (XRF) allow quantitative 3D characterization of the morphology and the elemental composition of specimens in their native state.
- NanoCT requires collecting a large number of magnified phase contrast radiographs while the sample is turned over a 180 degree angle, while in XRF the sample is scanned through the tight focus while collecting the fluorescence signal characteristic of the different elements present in the device.
- Scanning time in 3D was of the order of three hours and produces a data set of several tens of GB per sample, although 2D radiographs can be obtained in a fraction of a second.
- Upgrades to the ESRF source will lead to much improved resolution, allowing smaller device structures to be studied during in operando experiments.

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