ESRF	**Experiment title:** Microstructural characterisation of current flip-chip interconnection technology by synchrotron-radiation computed laminography	**Experiment number:** ME-1038
Beamline: ID15	**Date of experiment:** from: 27/04/05 to: 02/05/05	**Date of report:** 15/09/06
Shifts: 15	**Local contact(s):** M. DiMichiel	*Received at ESRF:*

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Report:
Synchrotron-radiation computed laminography (SRCL) was developed on beamline ID19 (proposal MI-576) for high-resolution three-dimensional (3D) imaging of regions of interests (ROIs) in laterally extended specimens.
The aims of this proposal were

1. the three-dimensional imaging of the microstructure of solder joints and their surroundings for characterisation of the flip-chip bonding technology employed for hybrid detector assembly. This data was supposed as input for analysis of stress in the interconnection by finite-element methods (FEM);
2. establishing SRCL on ID15 for 3D imaging of highly absorbing specimens and devices.

The experiments carried out during ME-1038 were not successful enough to provide 3D data sets of sufficient quality for FEM analysis, but nevertheless provided promising results concerning the inspection of highly absorbing devices which could also be published [1, 2].
In the meanwhile, another experiment with the objective to show the potential of SRCL for imaging of microsystem devices, ME-1209, yielded additional information about the quality obtained by different instrumentation. These results have convinced us that indeed high spatial resolutions can be attained for non-destructive imaging of laterally extended objects with white beam, down to the μm-scale (see below).

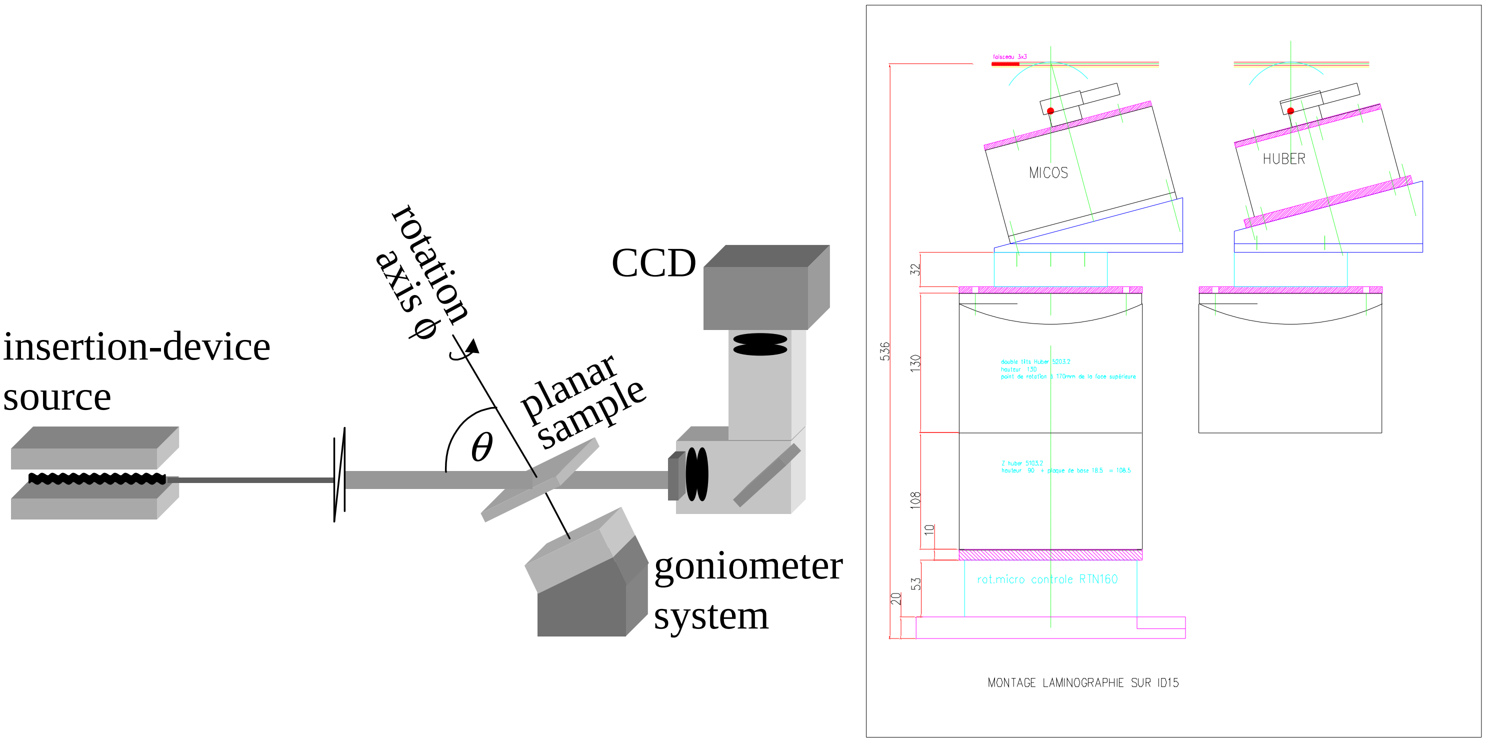

Figure 1: Sletch of the experimental set-up for laminography at ID15 (left). The section drawing of the goniometer system (right) shows two possible implementations, using a MICOS air-bearing rotation table (left section) and a HUBER 410a with conventional ball bearings (right section).

In Fig. 1 the sketch of the experimental set-up is shown (left), together with a drawing concerning the implementation of the goniometer system and sample rotation axis (right). Here, two alternatives were considered: using a HUBER 410a rotation table which has previously been used for MI-576 (laminography on ID19). The other option was using the MICOS rotation table which was recently installed on ID15 for computed tomography experiments and features an air bearing for minimised sample run-out.

Since the behaviour of the air bearing under axis inclination was not investigated at that moment, we opted for the known set-up with the HUBER 410a rotation table with ball bearings. Another constraint was that a large field of view of the detector system was assumed to be beneficial for the method. Therefore we preferred the Frelon2000 detector system which gives a significantly larger field of view than the Dalsa detector. In turn, this limited us to use stepper motor driven rotation tables like the HUBER 410a since a synchronisation between Frelon2000 and the MICOS rotation table was not available.

In the example presented in Fig. 2, a 3D data set reconstructed from 900 projection (acquired at an x-ray energy range between 40 and 60 keV approximately) is shown. The 3D rendition (left) shows that the individual bumps can clearly be resolved. Missing bumps and bridges are not found. Moreover, the bumps are well aligned. The cross-sectional slice (right) at the interface between bump bonds and GaAs sensor crystal shows the sensors metallisation pads which define the individual pixels read out by the underlying CMOS electronics. This is particularly remarkable since these metallisations on the 500 μm thick GaAs crystal only consist of 300 nm Au and a film of WTi of 10 to 20 nm (diffusion barrier).

The closer investigation of reconstructed slices through the centres of the bump bonds show that the internal structures of the bumps are slightly blurred, see Fig. 3. In slice (b) being parallel to the device surface, even the outer boundaries of the bump bonds reveal a correlated, slightly elliptical structure which is due to positioning inaccuracies of the set-up. These inaccuracies were mainly related to

1. a play in the manually driven translation stages mounted on top of the rotation table for sample positioning,
2. a run-out of the rotation table itself (of approximately 3 μm),
3. the implementation of the SPEC scan macros (based on the ESRF “zapscan” macro) where the 360 degrees scan range was not devided into an integer number of intervals.

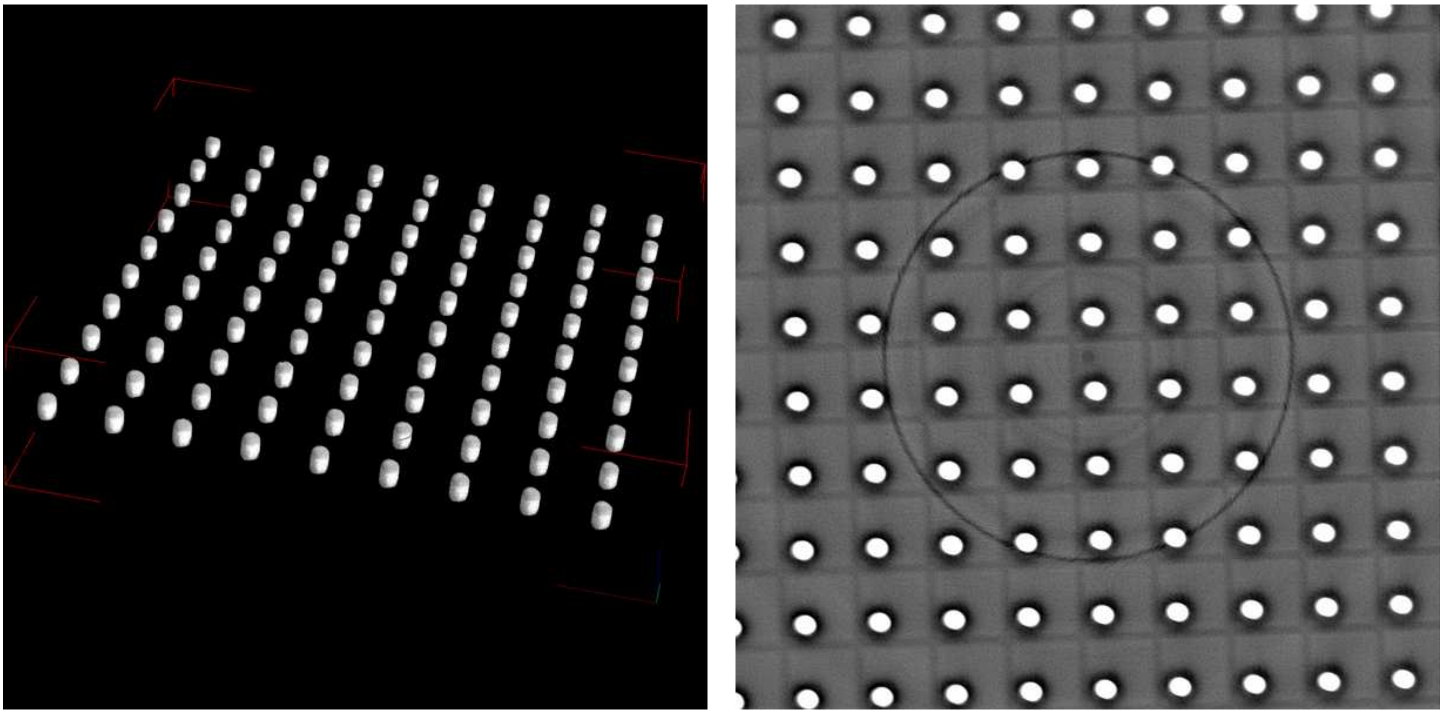

Figure 2: 3D imaging of ROIs of GaAs hybrid detectors during ME-1038 [2]. The individual bumps are arranged in a 2D array with 170 μm pitch (left). A reconstructed cross-sectional slice (right), taken parallel to the device surface, shows the interface between bumps and the GaAs sensor crystal. The dark circular feature is a ring artefact due to static features on the detector (such as non-linear pixels, dust on scintillator *etc.*). Pixel/voxel size is 1.6 μm.

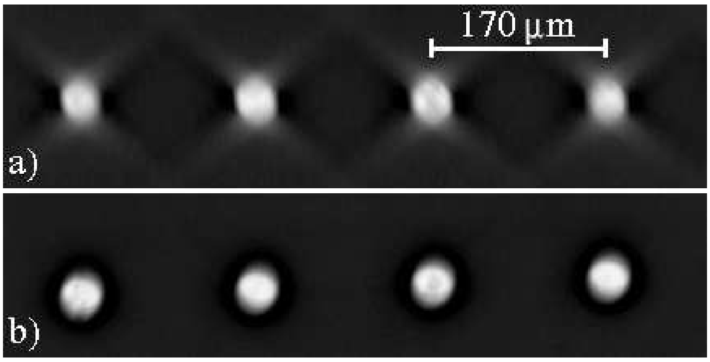

Figure 3: 3D imaging of bump bonds in GaAs hybrid detectors during ME-1038 [2]. The reconstructed cross-sectional slices, perpendicular (a) and and parallel (b) to the device surface, show the interior of four bumps. Pixel/voxel size is 1.6 μm.

The capabilities of SRCL were revealed to a greater extent during the ME-1209 experiments. For these experiments, the MICOS rotation table was used in combination with the Dalsa camera (despite the smaller field of view) which allowed really fast scans to be carried out (about 40 sec for 600 projections or total time of approx 5 minutes for a scan of 1800 projections). The manual sample translations were replaced by a lockable (also manual) goniometer head in order to eliminate play.

Here, the reconstruction of the bump bonds shows much more detail, see Fig. 4. Slice (b) is again taken parallel to the device surface: we clearly see inhomogeneities in the bump bonds, indicating the presence of voids. Such 3D images would be necessary to get a reliable modelling of the solder bump microstructure, *e.g.* by FEM analysis.

We conclude that laminographic imaging with white beam is very promising if the sample manipulation satisfies stringent requirements of the scanning scheme with inclined rotation axis. The 3D data necessary for input to the FEM analysis has not been obtained in this experimental campaign ME-1038, however.

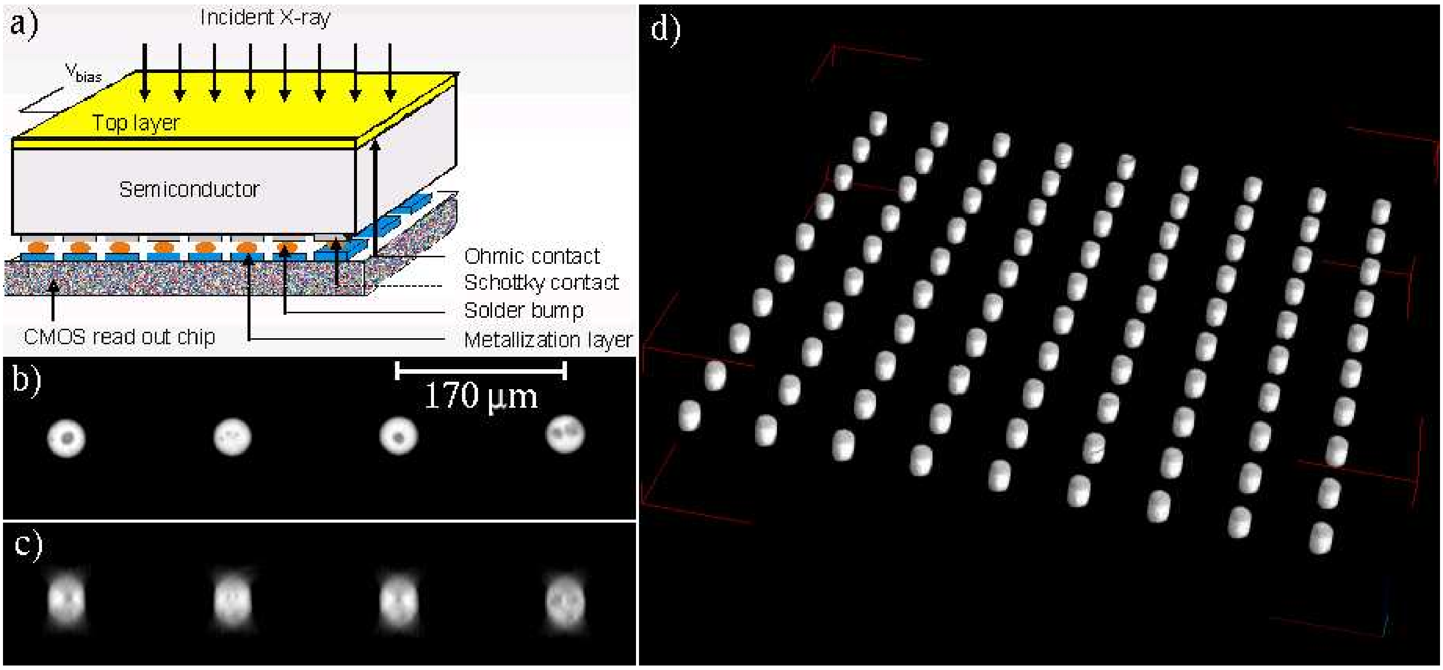

Figure 4: SRCL inspection of a hybrid detector array with a GaAs semiconductor sensor crystal during ME-1209, demonstrating the possiblities with improved mechanics for the goniometer system [3, 4]: sketch of the device (a), two mutually perpendicular slices, parallel (b) and perpendicular (c) to the device surface, and a 3D rendition (d) of imaged ROI at the centre of the 2d array of bump bonds. Pixel/voxel size is 1.6 μm, x-ray energy range approx. 40 to 60 keV.

References

[1] L. Helfen, P. Pernot, M. Mitschke, A. Berthold, and T. Baumbach. Investigation of hybrid pixel detector arrays by synchrotron-radiation computed laminography. In *Proceedings of IWORID7*, page 98, July 4-7 2005, Grenoble, France, 2005.

[2] L. Helfen, A. Myagotin, P. Pernot, M. DiMichiel, P. Mikulík, A. Berthold, and T. Baumbach. Investigation of hybrid pixel detector arrays by synchrotron-radiation imaging. *Nucl. Inst. Meth. A*, 563:163–166, 2006.

[3] L. Helfen, T. Baumbach, P. Pernot, P. Mikulík, M. DiMichiel, and J. Baruchel. High-resolution three-dimensional imaging by synchrotron-radiation computed laminography. *Proc. SPIE*, 6318:63180N, 2006.

[4] L. Helfen, A. Myagotin, M. DiMichiel, M. Kröning, and T. Baumbach. Microsystem and microelectronic devices investigated by synchrotron-radiation imaging techniques. In *Proceedings of the European Conference of Non-Destructive Testing, ECNDT Berlin 2006*, to be published.