EUROPEAN SYNCHROTRON RADIATION FACILITY
ESRF User Office
BP 220, F-38043 GRENOBLE CEDEX, France
Delivery address: 6 rue Jules Horowitz, 38043 GRENOBLE, France
Tel: +33 (0)4 7688 2552; fax: +33 (0)4 7688 2020; email: useroff@esrf.fr; web: http://www.esrf.fr

Application for beam time at ESRF – Experimental Method

Imaging of flip-chip bonds in Medipix detectors based on CdTe and GaAs by using synchrotron radiation computed laminography

Proposal Summary (should state the aims and scientific basis of the proposal):
Photon counting pixel detectors are considered of highest interest for synchrotron experiments [1] and many facilities (ESRF, DESY, ANKA and DIAMOND) participate actively in the Medipix collaboration for developing and adapting the single photon counting pixel detectors to the necessity of the synchrotron community [2]. Currently, the attention of the research is focused on three crucial technological challenges: 1) increasing the speed of the electronic read-out, 2) building up high Z semiconductor based photon counting pixel detectors to extend the energy applicability up to 150 keV, 3) developing the interconnections between sensor and read out. In particular the CdTe and GaAs high Z semiconductor materials are being considered as a valid alternative to the low absorption efficiency of silicon. Here the flip-chip technology is presently one of the crucial bottlenecks for technological breakthrough. During the flip-chip process several defects are formed (such as solder joint displacements, voids, cracks, pores, bridges etc) due to the thermal stress between the read-out chip and the semiconductor sensor. Those defects are later centres of electro and thermal stress migration, bringing the pixel to unavoidable failure. The aim of this proposal is to investigate by non destructive techniques (NDT) the flip-chip interconnections after the pixel sensor (CdTe or GaAs) is bump-bonded to the read-out matrix. Due to the thickness of the used semiconductor (1mm for CdTe and 300 µm for GaAs), its opaque structure, its lateral extension and due to the required imaging resolution (a few µm), the classical optical and ultrasound microscopy techniques are completely inadequate to investigate the origin of those bump-bond defects. The only NDT-3D method presently available is the high resolution Synchrotron Radiation Computed Laminography (SRCL).

Scientific background

Presently, photon-counting pixel detectors are of the main interest for synchrotron experiments. The noiseless detection of X-rays, the high dynamic range, the direct X-ray detection process, make such type of detectors superior to integrating detectors in many applications. In particular, Medipix photon-counting pixel detectors offer a high frame rate, the possibility to adjust the energy threshold in a wide range, and the smallest available pixel pitch of 55 µm in this category of chips [1, 2, 3]. The overall detector array consists of a high resistivity semiconducting sensor material with pixellated electrodes on the front side, which is flip-chip connected to the read-out chip via small metallic spheres (bump bonds) [4, 5]. The most commonly used sensor material is Si. However for energies from 20 keV to 150 keV materials with higher absorption cross sections like GaAs or CdTe [6, 7] must be used in order to obtain an acceptable detection efficiency. The BIRD group, which includes the *Freiburger Materialforschungszentrum* (FMF) and the *Karlsruhe Institute of Technology* (KIT) is one of the leading European developers of High Z direct converting pixel array detectors. At the FMF an innovative flip-chip bonding technology has been developed for guaranteeing a low temperature handling and reducing the pressure on the detector material. The method is based on a flexible process, which permits the use of an eutectic InSn alloy with a photoresist mask and a reflow temperature equal to 150 °C [9]. Despite that, the flip-chip process is still one of the crucial bottlenecks for technological breakthrough. During the flip-chip process an unfortunate formation of defects take place, due to the thermo-mechanical stress between the read-out chip and the semiconductor sensor. Those defects (solder joint displacements, voids, cracks, pores and bridges) are later centres of electro and thermal stress migration, causing the pixel failure. The aim of this proposal is to investigate by NDT the flip-chip interconnections. In particular we need visualising and localising pores and open cracks (either in the centre of the bump or near the metallisation layer of the sensor or near the read-out chip) delaminations and bridges between the bump-bonds. Because of the thickness of the semiconductor (1mm for CdTe and 300 μm for GaAs) opaque structure and lateral extension, and because of the required imaging resolution of a few μm, the classical optical and ultrasound microscopy techniques are completely inadequate to investigate the origin of those bump-bond defects. For visualising the status of the flip-chip interconnections in 3D, it is demanding the use of high resolution X-ray imaging methods. As the sensor is typically flat (1 x 14 x 14 mm^3) the only NDT-3D method presently available is the Synchrotron Radiation Computed Laminography (SRCL) that was peculiarly developed for inspecting Micro System Technology (MST) devices [10, 11]. Due to the high absorption of the sensor materials and their thickness (1mm for CdTe and 300 μm for GaAs) the used X-rays should be high energy and/or filtered white beam radiation.

<u>Experimental technique(s), required set-up(s), measurements strategy, sample details (quantity….etc):</u>

SRCL is the only applicable method for a reliable inspection of the bump-bonds in high Z CdTe and GaAs X-ray detectors. In our experiment we will investigate a group of CdTe and GaAs sensors flip-chipped at the FMF using the innovative technique described in the previous section. The laminography scans will be acquired with filtered white X-ray beam at average energies of 95 keV and 60 keV for the CdTe and the GaAs sensors, respectively. The required spatial resolution is 1-2 μm and the field of view 1-2 mm. The Dalsa Pantera 1M60 CCD camera will be used.

<u>Beamline(s) and beam time requested with justification:</u>

6 CdTe and 4 GaAs sensors will be investigated by SRCL and for each sensor 50 regions of interest (ROI) will be scanned. Since the assemblies are rather thick (scale of 1 mm) and strongly absorbing we request for beam time at ID15. For the installation and the alignment of the set-up we need 1 day. For the 3D laminography 12 shifts (4 days) are necessary. Therefore, we apply for 15 shifts (5 days) of the beamtime at ID15.

<u>Results expected and their significance in the respective field of research:</u>

The non-destructive 3D volume image analysis of the flip-chip bonds will allow visualising and localising the bump-bonds defects which are responsible of the pixel failure. Several ROIs will be investigated, which include working and not-counting black areas of the detector. The comparison will allow: 1) clarifying the correlation between the not-counting areas of the detector and the status of the flip-chips in the same regions, 2) understanding the origin of the flip-chip defects and eventually modifying the technique for the next family of high Z Medipix detectors that will be used afterwards for high energy X-ray imaging.

<u>References</u>

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