FUSION TECHNOLOGY DESCRIPTION

EUROfusion
TECHNOLOGY TRANSFER PROGRAMME

3-D Mesoscale Soft X-ray microtomography for low contrast biological or soft samples, with control of the X-ray range

ENEA Laboratories in Frascati developed this mesoscale soft X-ray microtomography for reconstructing the 3-D structure of small, pretty transparent to X-rays objects, with moderate spatial resolution and very low contrast, like biological samples. Commercial microtomographs are not suitable for this application due to high energy working X-rays and not efficient detection. With this fusion-derived technology, the energy spectrum is tailored to maximize the contrast of the sample and the X-ray detector is optimized accordingly.

Description of the technology

This tomography set-up is composed of a microfocus X-ray source (about 30 μm spot size), a rotator and a two-dimensional C-MOS detector called PIXIRAD, located next to the sample (contact radiography) in a fixed position. The X-ray tube has been used to produce a spectrum from 5 to 35 keV and a beam current of 300 μA, optimised to maximise the imaging contrast of the sample. PIXIRAD detector is an INFN-Pisa Spin-off, it works in photon counting in the range 2-100 keV and it is noise free. It is realized by coupling an X-ray sensor made of a thin layer of crystalline CdTe (650 μm) to a large area VLSI CMOS pixel ASIC. The CMOS VLSI chip has an active area of 30.7×24.8 mm², organized on a matrix of 512×476 pixels each one of 55×55 μm2. The sample is rotated with angular steps of 1° and the radiographies (476 x 512 pixels) are acquired in 3 sec per position (see fig.1).

In order to apply microtomography to small and almost transparent samples it is mandatory to tailor the right X-ray spectrum. Maximum energy can be fixed with the HV of the tube, ranging from 5 to 50 KV, while the lowest value can be chosen with appropriate filters. For biological samples or light (soft) materials , the X-ray band is pretty narrow, because, under the minimum of the band, they absorb too much, while over the maximum, they become transparent. In figures 2 and 3 two radiographies of a snail are shown, produced with X-ray band 12-22 keV and 22-30 keV respectively. Already in 22-30 keV range, the sample becomes almost transparent. With commercial tomographs (20-120 keV), this kind of samples cannot be investigated. In addition, in case of samples such as algae (see fig.4); there are full parts (branches) and voids (interstitial gaps) and the branches are so thin that the sample shows a very low contrast. With the proposed microtomography set, once the spectrum has been optimized for the specific sample, also the detector has to be "tuned".

For this purpose, a new generation of detectors was used, stemming from the research in physics, the so called C-MOS imagers. These are made of pixellated semiconductors (e.g. Si, CdTl, CZT, etc.) coupled with microchip electronics (ASIC). They are proportional detector working in photon counting and they are "noise free". The C-MOS imagers detect each individual photon and discriminate its energy. Electronic Threshold can be adjusted in order to count only the photons in the band where the X-ray tube has been set. Therefore, because of this and due to the lack of intrinsic noise, very clean images can be acquired even for very low contrast samples.

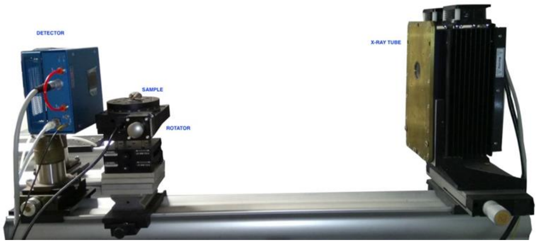

Fig.1 : Experimental set-up for micro-tomographic analyses of a snail

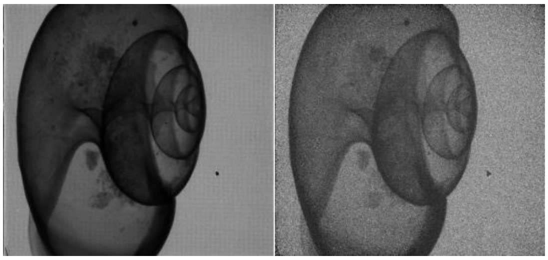

Fig.2 : Snail radiography in range 12-22 keV (left) and in range 22-30 keV (right)

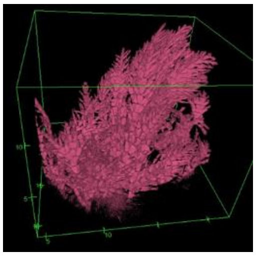

Fig.3: 3-D reconstruction of a sea alga Ellisolandia Elongata (1 cm3)

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Innovation and advantages of the offer

Commercial microtomographs work with X-rays in the range 20-120 keV, with indirect and noisy detection (scintillators and CCDs); they are adequate for heavy or dense materials (metals, stones, bones, etc.) and offer high spatial resolution (sub-micron). The 3-D microtomograph herein described can be used for light and soft materials (soft tissues, polymers, gel, foam, biological samples, micro devices, plastics, vegetables, small animals….). It works at very low energy (5-35 keV), with a fine tailoring of the X-ray spectrum and with innovative C-MOS detectors working in single photon counting with energy discrimination. These detectors, despite of a larger pixel size (55µm), are noise-free and offer an higher quantum detection efficiency and modulation transfer function compared to CCDs. Considering that they are limited in active area, spatial resolution is in the order of a few microns at best. Furthermore, the innovative C-MOS detectors, at the basis of this mesoscale Soft X microtomograph, are now available on the market, so the proposed system can potentially be realised at industrial level.

Non-fusion Applications

Non-commercial X-ray detectors, developed for fusion applications, i.e. the C-MOS imagers, and the experience in the use of the spectral analysis to investigate the interaction of X-rays with the matter, as function of their energy, are the enabling factors of the microtomography system herein proposed.

The technology can be used to perform 3-D tomography analyses on small biological samples (small animals or plants), low Z materials, low-density materials small animals or plants, like polymers, like foam, gel, or carbon fibre based materials. Metals or carbonated structures can be contained into the samples, but with thickness order of hundreds of microns.

EUROfusion Heritage

The technology herein proposed was developed at ENEA X-ray laboratory NIXT in Frascati. This laboratory was carried out under the auspices of EUROfusion programs (2009-2011) for developing new soft X-ray imaging diagnostics for fusion magnetic plasmas. In particular, ENEA Researchers introduced a new SXR technique in photon counting with energy discrimination, based on GEM gas detector and C-MOS silicon imagers.

These detectors have been installed in different tokamaks (FTU, NSTX, KSTAR, and EAST) all over the world. The expertise in tomography at the basis of the system herein described has been built also because tomography is widely used in magnetic fusion devices and the new detectors developed at NIXT can be used both in configuration imaging and in configuration tomography. ENEA X-ray laboratory detectors open also the way to energy discrimination and imaging in different energy bands, particularly useful to study impurity dynamics in tokamak plasmas. All these experiments in fusion plasmas have been done in the framework and with the support of EUROfusion.

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