Application Note

X-ray sCMOS camera with on-chip scintillator enables fast phase-contrast tomography

1. Introduction

For high-resolution 3D imaging of large biological samples such as the cochlea, a compact laboratory microfocus X-ray tomography setup based on a liquid-metal jet source and a very fast and sensitive sCMOS camera can be used [1,2]. This enables the structure determination of soft tissue for example, thin membranes or nerve fibers within surrounding bone. Compared to other imaging techniques such as classical histology [3] or magnetic resonance imaging [4], X-ray imaging offers the potential for a high-spatial resolution without the need for invasive sample preparation [5].

Classical tomography which is based on absorption within the sample gives nearly no contrast for soft tissues. Instead the phase-shift of the sample, of which the underlying optical constants are up to three orders of magnitude larger than for the absorption, can be used. One possibility to make this phase shift visible is free-space propagation behind the object, which enables the interference of the disturbed wave [1,6]. With suitable reconstruction algorithms, the original phase of the object can be retrieved from the recorded intensity images.

In this application note we demonstrate that the sCMOS camera with on-chip scintillator enables very fast and continuous acquisition of phase-contrast tomograms at a very high spatial resolution.

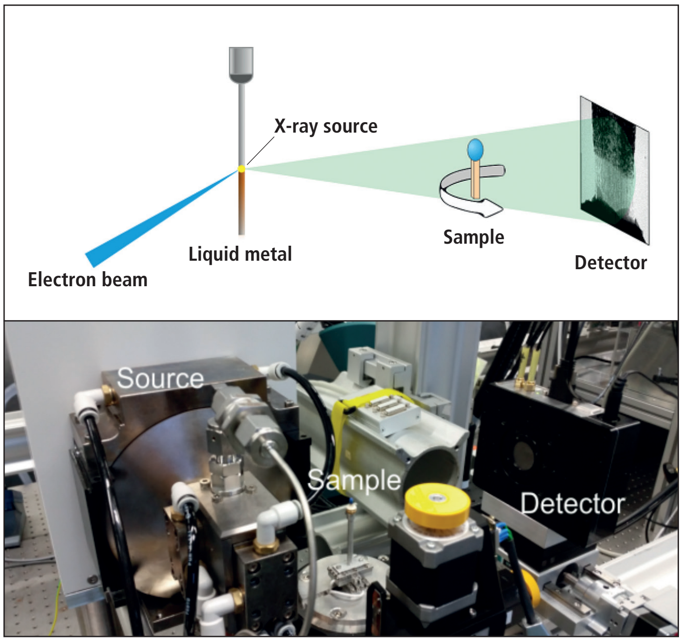

Figure 1 Top: sketch of the setup consisting of the source, sample and the X-ray detector. Bottom: photograph of the setup

2. Phase-Contrast Tomography Setup

A typical propagation-based phase-contrast tomography (PCT) setup consists of a partially coherent source, which enables the interference of the wave behind the object, the object on a flexible sample tower, which includes a rotation perpendicular to the optical axis and the X-ray sCMOS detector (C12849-102U, Hamamatsu Photonics) with a pixel size of 6.5 µm some distance behind the object. The 16bit detector has a total resolution of 2048 x 2048 pxl and is equipped with a gadolinium oxysulfide (GOS) scintillator having a thickness of 20µm. The full well capacity of 30,000 electrons and the dynamic range of 18,000:1 makes the detector highly efficient.

Figure 1 shows a sketch as well as a photograph of such a setup. The liquid-metal-jet source (MetalJet D2, Excillum) enables a small source spot which is necessary for the partial coherence of the X-ray beam as well as a high photon flux of 5.2e10 photons/(s·mm^2·$mrad^2$·line) Ga-K_α peak brightness for a 10 µm source spot and an electron-beam power of 100 W [7]. Due to the cone-beam geometry of the setup, the effective pixel size can be varied via the geometrical magnification.

3. Measurement

An ordinary match is chosen as a test object and imaged with an effective pixel size of 2.24 µm, resulting from a source-to-sample distance of 92 mm and a source-to-detector distance of 269 mm. In total, the field of view is 4588 x 4588 µm.

For the recording of a fast tomogram a continuous recording mode is established. This enables the stepless measurement of projections over the full range of 360° in a specified time (here 70 s, leading to 1994 projections in total) while the exposure time is kept constant at 25 ms. The high speed of 30 fps (full sensor resolution) and the high efficiency of the detector, together with the high flux of the X-ray source, facilitate such small exposure times. The 3D volume is obtained from a phase retrieval, which uses the Bronnikov-aided correction (BAC) algorithm [8], followed by a standard filtered back projection.

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Figure 2 shows the result of the fast tomogram. In the slice through the object perpendicular to the rotation axis (left) the structure of the wooden part of the match is visible. The inset enables the observation of small fibers within the match (top right). The progression of the fibers can be followed in the slice parallel to the rotation axis (bottom right).

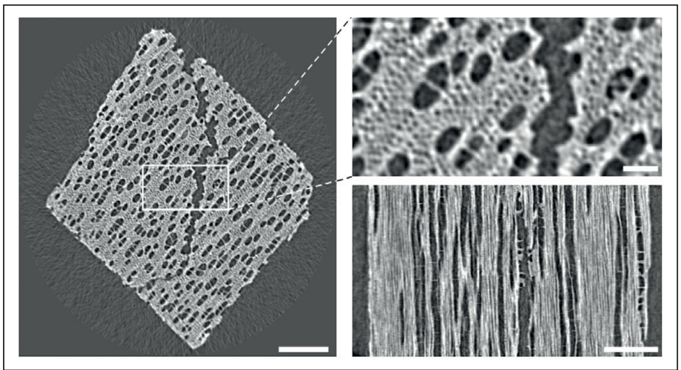

Figure 2: Left: slice perpendicular to the rotation axis with inset resolving the small fibers through the wood (top right), bottom right: slice parallel to rotation axis. Scalebars: 500 μm (left, bottom right) and 100 μm (top right) detector. Bottom: photograph of the setup

For comparison, a conventional step-by-step tomogram with 1995 projections and an exposure time of 100 ms is performed. In this approach all motor positions and detector information are read and stored between the recordings of the single projections. Consequently, the total measurement time increases by a factor of 36 compared to the continuous scan. The 3D volume is reconstructed analogous to the continuous scan.

The comparison between the standard and the continuous tomogram is shown in figure 3. This demonstrates that in spite of the different recording modes the reconstruction of the two scans is of the same quality and resolution.

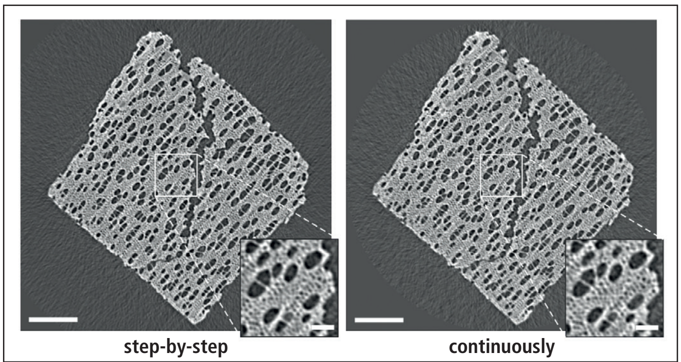

Figure 3: Comparison between analogous slices of the step-by-step recorded tomogram and the continuously recorded tomogram. Scalebars: 500 μm and 100 μm (insets)

4. Conclusion

The X-ray sCMOS camera with on-chip scintillator in combination with a high photon flux X-ray source enables fast and continuous phase-contrast tomographic measurements at a high spatial resolution. By utilizing the induced phase-shift of the sample, imaging of soft biological tissue with a small exposure time, but good contrast and resolution, is therefore possible. This allows for resolving small biological features which might otherwise not be visible due to shrinkage during the measurement [1]. The high speed of the sCMOS camera allows stepless tomography acquisition at the same quality in comparison to classical step-by-step acquisition.

References

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Key Words
X-ray sCMOS, on-chip scintillator, fast Phase-Contrast Tomography

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