A high fringe visibility glancing-angle grating interferometer for high energy X-ray phase contrast CT

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Introduction

Differential X-ray phase contrast CT using Talbot-Lau grating interferometers shows potential to combine high soft tissue contrast comparable to MRI with the high spatial resolution and high penetration power of X-rays. Material science applications and industrial scanning could also benefit from this new technique. But if these applications are in mind, the technique has to be 'moved' to higher X-ray energies (> 40 keV mean) to be able to penetrate thick human body parts and metal components used in industry.

Unfortunately, X-ray grating interferometers have not been able to perform at their best in this energy range because of limitations in the grating fabrication process. Simply put, grating bars of a source and an absorption gratings cannot be made thick enough to absorb all the incoming radiation, which causes radiation to 'leak' and lowers the fringe visibility of the system. This leads to degradation of image quality and increases noise level.

Experimental setup

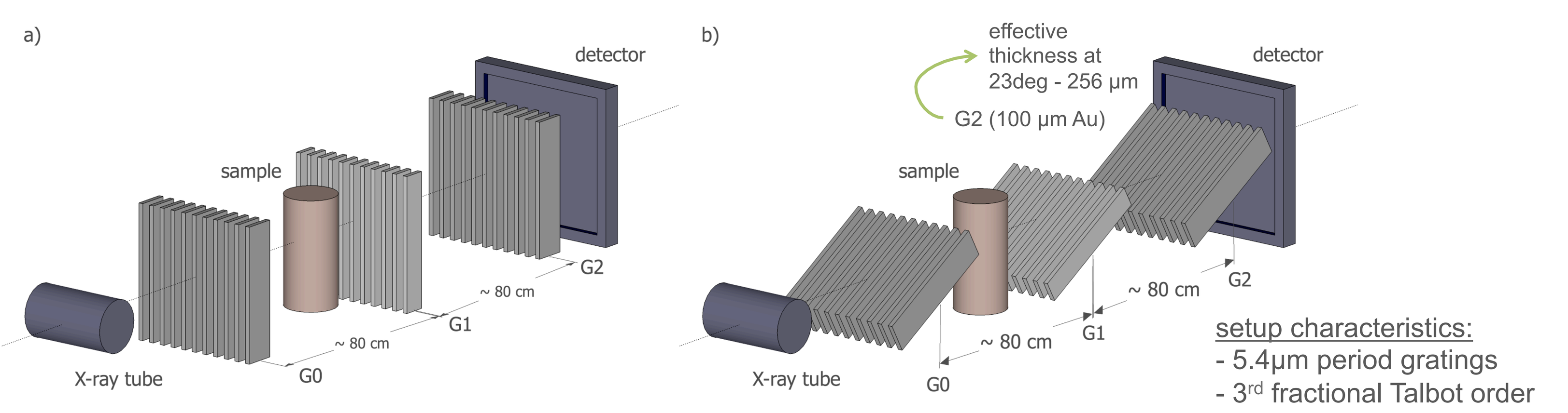

FIG. 1. Schematic representation of the setups at a standard (a) and at a glancing angle configuration (b) . Objects and distances are not in scale.

By tilting the gratings along the direction of the source-detector axis [1] the effective thickness of the grating bars increases by a factor of ~1/sin(α) ➔ 2.56 for tilting angle of 23 deg. This leads to increase of X-ray absorption in the gratings and increase of the fringe visibility.

X-ray tube:

tungsten target X-ray tube with 60μm spot size

45keV mean X-ray energy: 1mA, 65kVp filtered by 40mm H_2O, 1.5mm of Al and 0.125mm of Cu

Detector:

lens coupled CCD detector (90μm pixel size) to a CsI scintillator screen with a f/1 relay lens

Results – Biomedical samples

Using the system with high fringe visibility and high X-ray energy (75kVp/ ~48keV mean) we were able to acquire a phase contrast image through a bone of a human finger fixed in alcohol (see Fig. 4) without streak artifacts typical for lower X-ray energy systems.

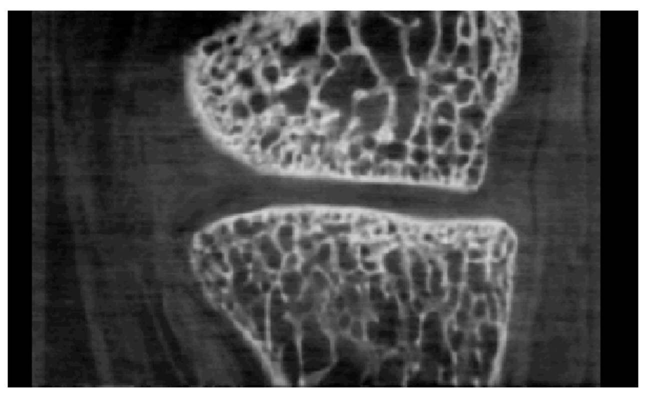

FIG. 4. Phase contrast CT reconstruction in a coronal plane of a human finger. The image nicely shows the internal structure of the bone and surrounding soft tissue, which would not be possible with a lower visibility and lower X-ray energy system

Furthermore, we obtained high soft tissue contrast images at high X-ray energy (~45 keV mean) of various pig soft tissues (see Fig. 5) with a dose level comparable to conventional absorption CT (dose estimate using Monte-Carlo software) and using a sliding window interlaced (SWI) scanning method first introduced by Zanette et al. [3] which is fully compatible with continuous rotation of the CT gantry.

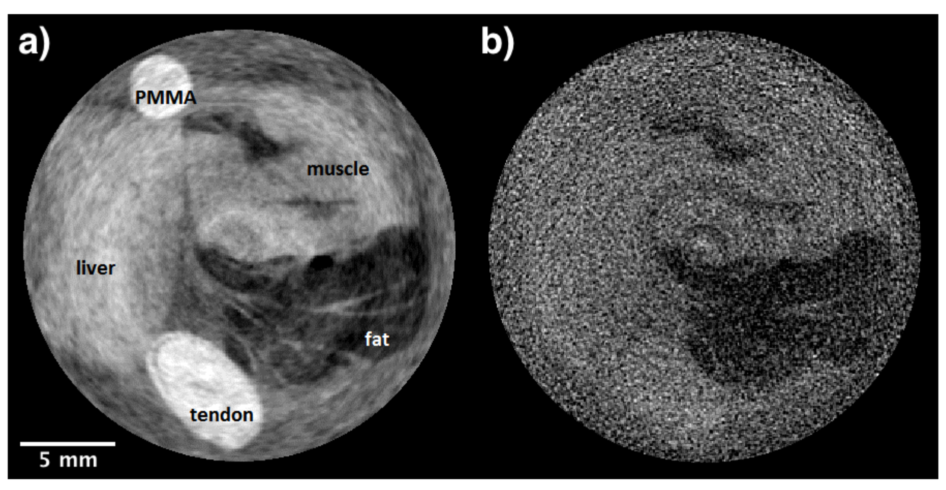

FIG. 5. Axial slices of PC-CT (a) and absorption-CT (b) reconstruction on various pig soft tissues immersed in water obtained at ~45 keV mean X-ray energy using a sliding window interlaced stepping method

Fringe visibility

Fringe visibility (V) is defined as:

$$V = (I_{max} - I_{min}) / (I_{max} + I_{min})$$

where I_{max} and I_{min} are, respectively, the minimum and maximum values of the intensity pattern produced by the phase grating (see Fig. 2). It is a parameter used to compare different interferometers in terms of their optical performance. The higher the visibility, the better the image quality (SNR ~ V * √flux) [2]

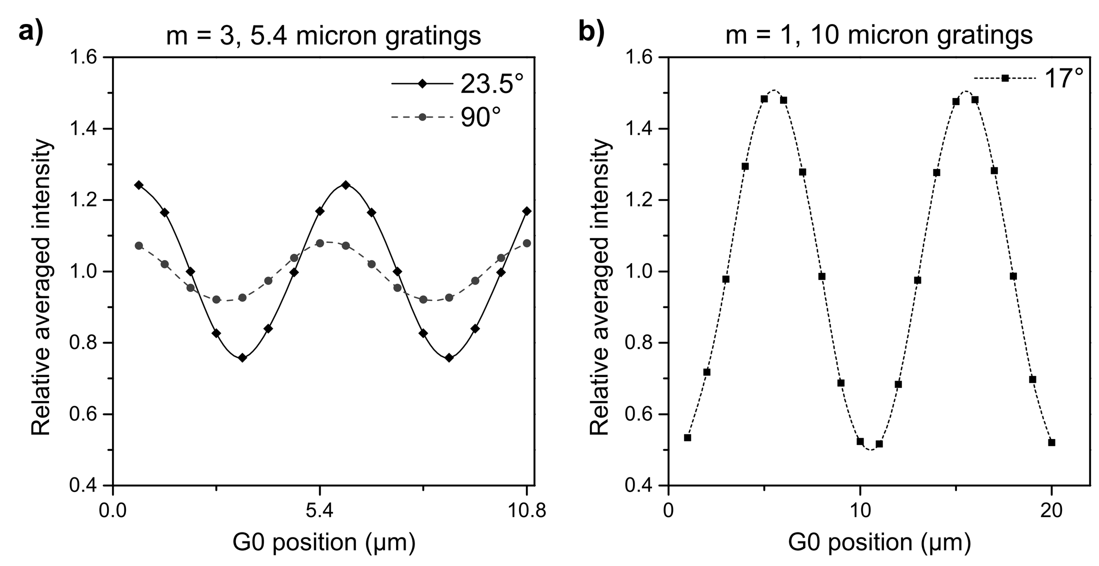

FIG. 2. Intensity profiles obtained through phase stepping scan
a) 7% & 23% mean fringe visibility
b) 50% mean V

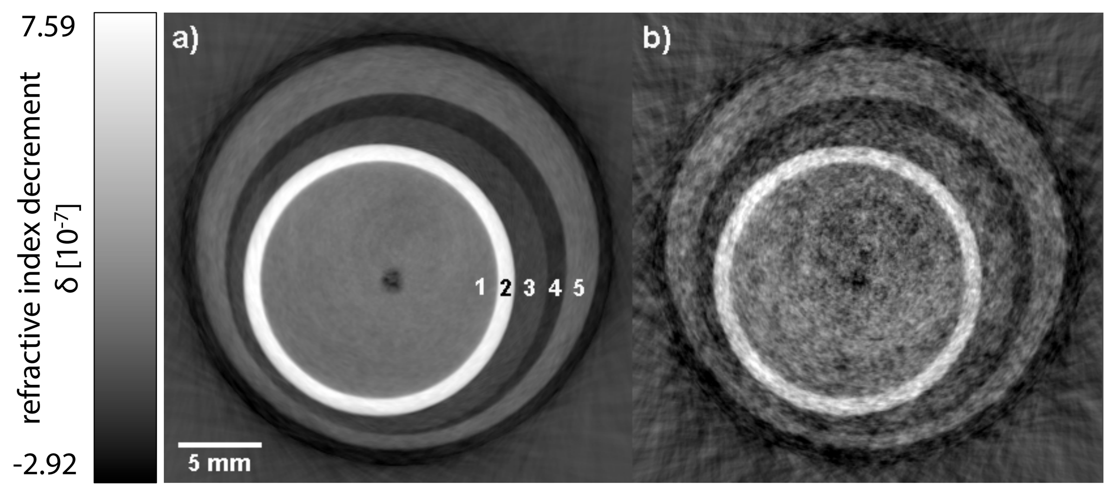

FIG. 3. Phase contrast CT axial reconstruction slices of a joint phantom obtained with a 7% (a) and 23% visibility system (b) keeping the total acquisition time the same

Results – Hydroxyapatite crystal

The phase contrast CT images (Fig. 6a & b) nicely show the internal cracks/ voids. The scatter image (Fig. 6c) show an unusual internal structure, likely an imperfect growth front. The crystal is totally opaque to visible light.

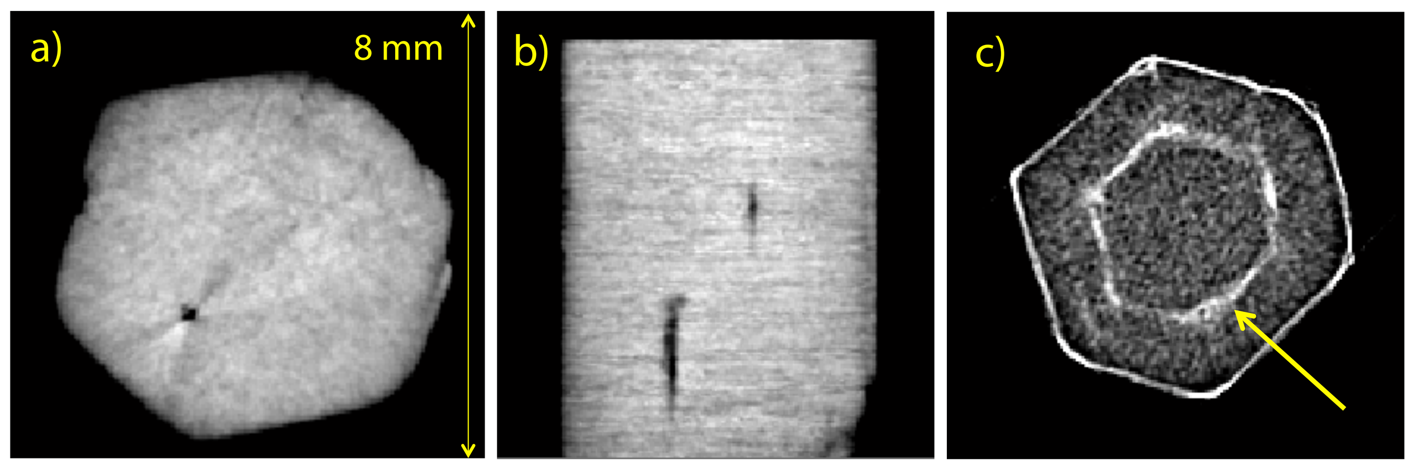

FIG. 6. PC-CT (a & b) and ultra-small scattering CT (c) slices at 65kVp X-ray energy (45 keV mean) [4]

Conclusion

As major technical improvements in the grating fabrication are not expected in the near future, the glancing angle interferometer offers a simple solution for DPC-CT at X-ray energies in the range of approximately 50 - 120kVp, in optimal conditions of high fringe visibility.

References:
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