X-ray Tomography of Tin Whiskers Using Large Area Photon Counting Detectors WidePIX

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Motivation

In the current contribution X-ray micro tomography is presented as an alternative to scanning electron microscopy (SEM) for the investigation of tin whiskers.
Other than SEM, this approach provides 3D morphological information, crucial to the understanding of the growth mechanisms of these features.
Here a Timepix large area detector featuring Si sensors was employed. raphic analysis in this investigation benefits from the extremely high contrast of direct converting pixel

What are tin whiskers?

The formation of metallic whiskers, among tin whiskers, is an only partially understood phenomenon. However, the occurrence of these microscopic conductive structures causes massive problems in electrical devices.
Since 1992, tin whiskers have been blamed for the complete failure of 3 commercial satellites and the partial disabling of 4 others. Whisker-related failures have also been reported in pacemakers, missiles, aircraft radar systems, and electrical relays at a nuclear power plant [1].
Alloys containing lead, which is known to suppress the growth of whiskers, has been broadly banned from consumer electronics in the recent decade, due to the entailed health implications. Therefore the investigation of the growth mechanisms of whiskers is of prevailing interest to the electronics industry.
The diameter of tin whiskers ranges from **0.3** to **10** microns, and they can grow to a **few millimeters** in length. They can be straight, bent, kinked or forked. They are usually solid, but some can be hollow, as they mostly grow up under heat and stress[2]. The topic is of even broader interest since metallic whiskers do not only grow from pure tin, but also from gold, cadmium, lead, zinc, silver, aluminum and indium and even alloys.

Large Area Photon Counting Detector Widepix and X-ray Imaging System

The WidePIX large area detector developed in the Institute of Experimental and Applied Physic [3], which was employed in this investigation, is depicted in fig. 1 on the right. It consists of an edgeless assembly of 5x4 TimePix ASICs, equipped with 500µm Si sensors. The total resolution of the device is 1280x1024 pixels, with a pitch of 55µm. This results in an active area of $1.98cm^2$ per detector element. Dependent on the requirements in the sensor characteristics in the respective application field, this type of detector can be alternatively equipped with high Z semiconductor sensors, like CdTe, CZT or GaAs.
The tomographic setup used here is equipped with a Hamamatsu L12161-07 microfoucs X-ray source, which provides a 5µm focal spot up to 100kVp. The total source-to-detector distance is limited to 680mm by the dimensions of the shielded cabine.

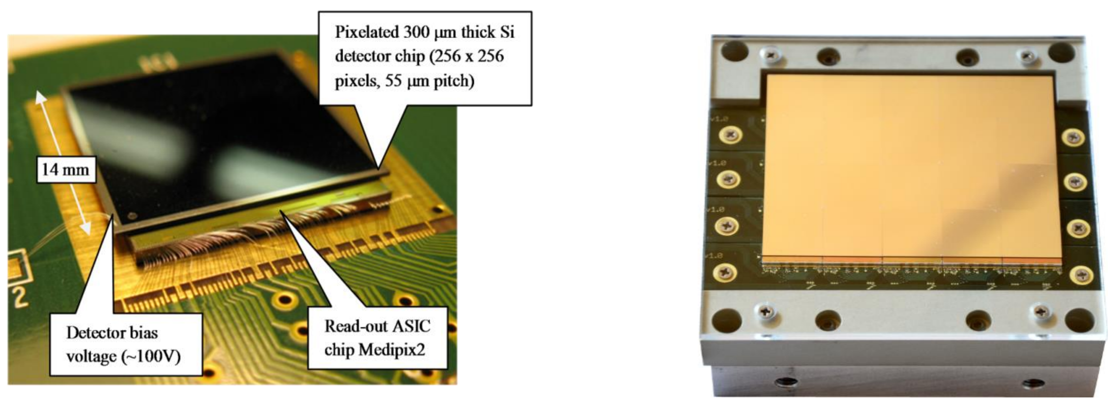

Figure 1. left Timepix chip consists of 256×256 pixels with 55µm pitch, right Widepix detector consists of 20 timepix chip assembled without gaps

Sample Description

The samples investigated here consist of a thin copper plate, covered by a 20-30µm layer of tin solder, produced by the Faculty of Electerical Engineering, Czech Technical University in Prague.
Whisker growth was driven by bending of the plates at 50 ˚C for a duration of 120 to 200 hours [4].
Subsequently the plates were cut into smaller pieces in order to allow high magnification tomography, figure (3) .

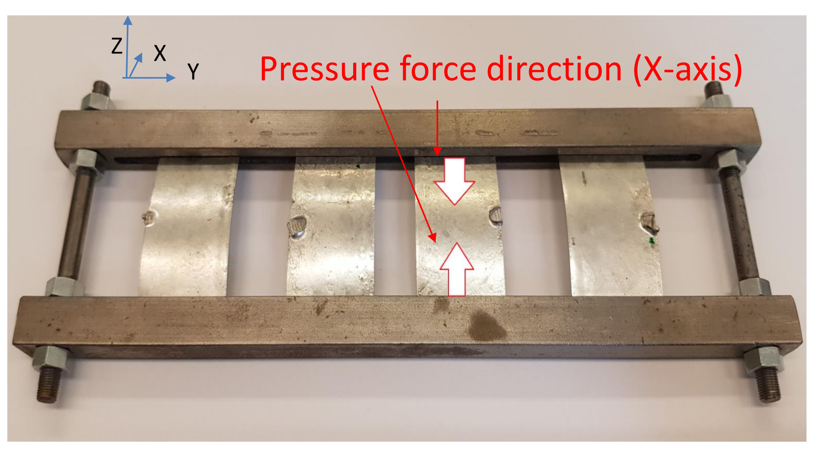

Figure 2. Copper samples covered with tin stressed in clamps

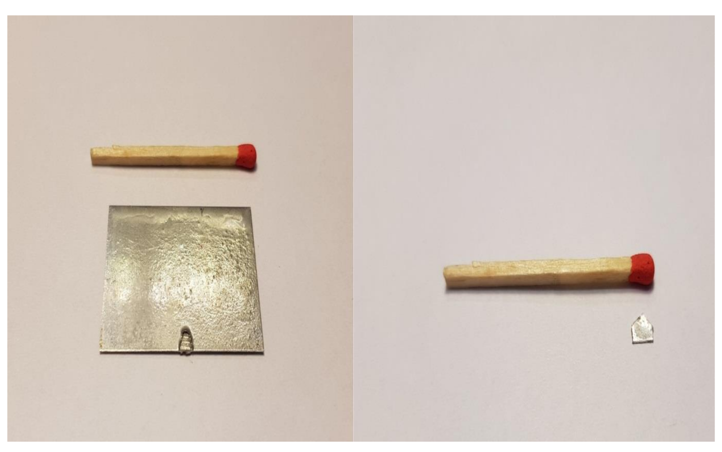

Figure3. right Individual sample(36mm×22mm), left the cut sample for tomography.

Measurements and Results

In order to achieve high resolution in X-ray computed tomography typically large geometrical magnification is employed. Within the limitations of the setup used here, a spot-object distance (SOD) of 66.8mm and the maximum available source-detector distance (SDD) of 668 were set, giving us a magnification of 10x.
The sample was mounted parallel to the neutral plane in order to make the whisker visible on the detector in contrast with air.
The x-ray tube was operated at 40kVp and the sample was rotated 360˚ with a step width of 0.2˚, resulting in 1800 projections of 3.7s exposure time each. In 90% of the projections the whisker was visible without shealding by the copper plate. To correct for the detector response a thickness equivalent beam hardening calibration was performed by use of Al filters.

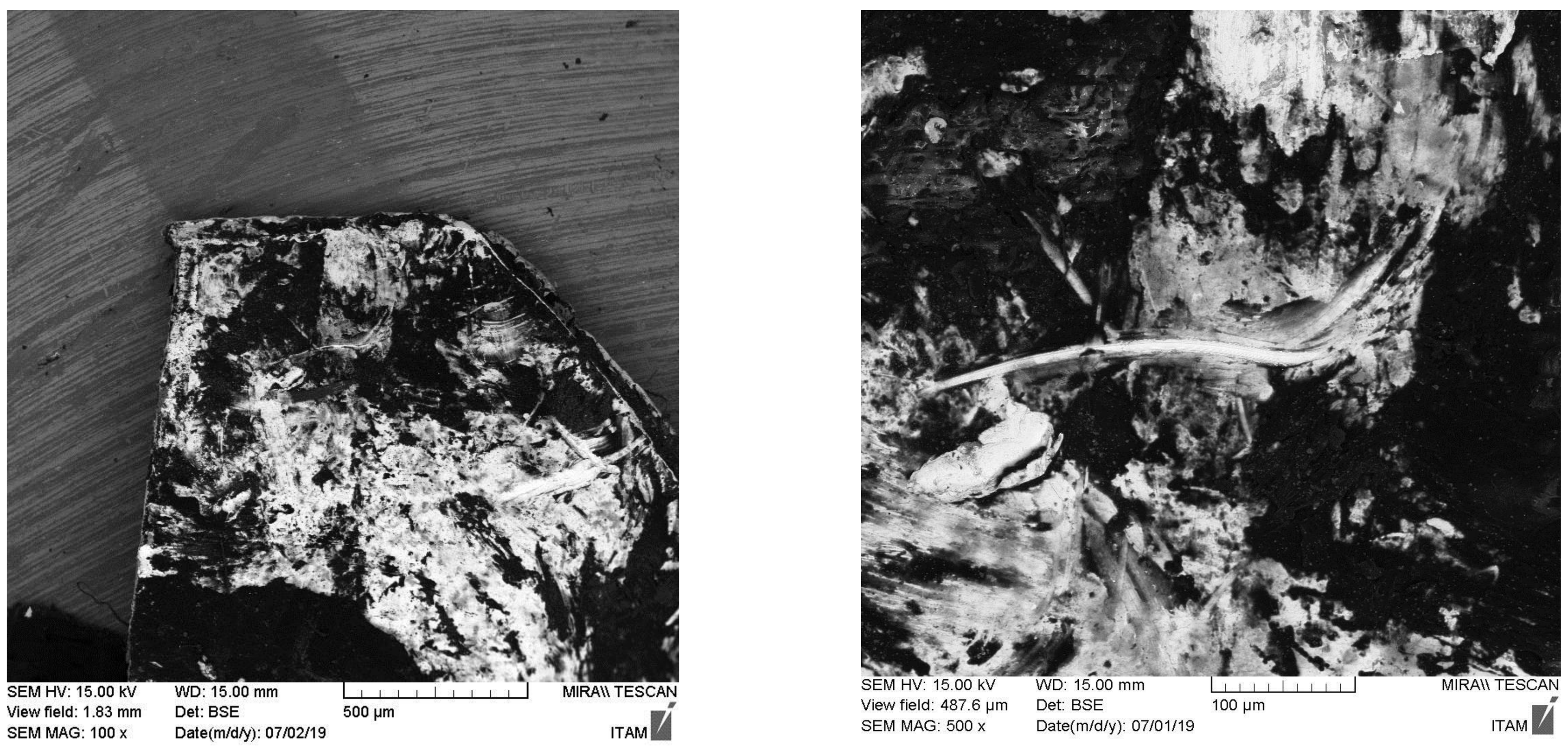

Figure 4. Scanning electron microscope(SEM) image of the sample. The figure on the left displays a scan with magnification 100x. Here the whisker not clearly discriminated from the surface. On the right the sample scanned with magnification of 500x. This time the whisker is clearly observed.

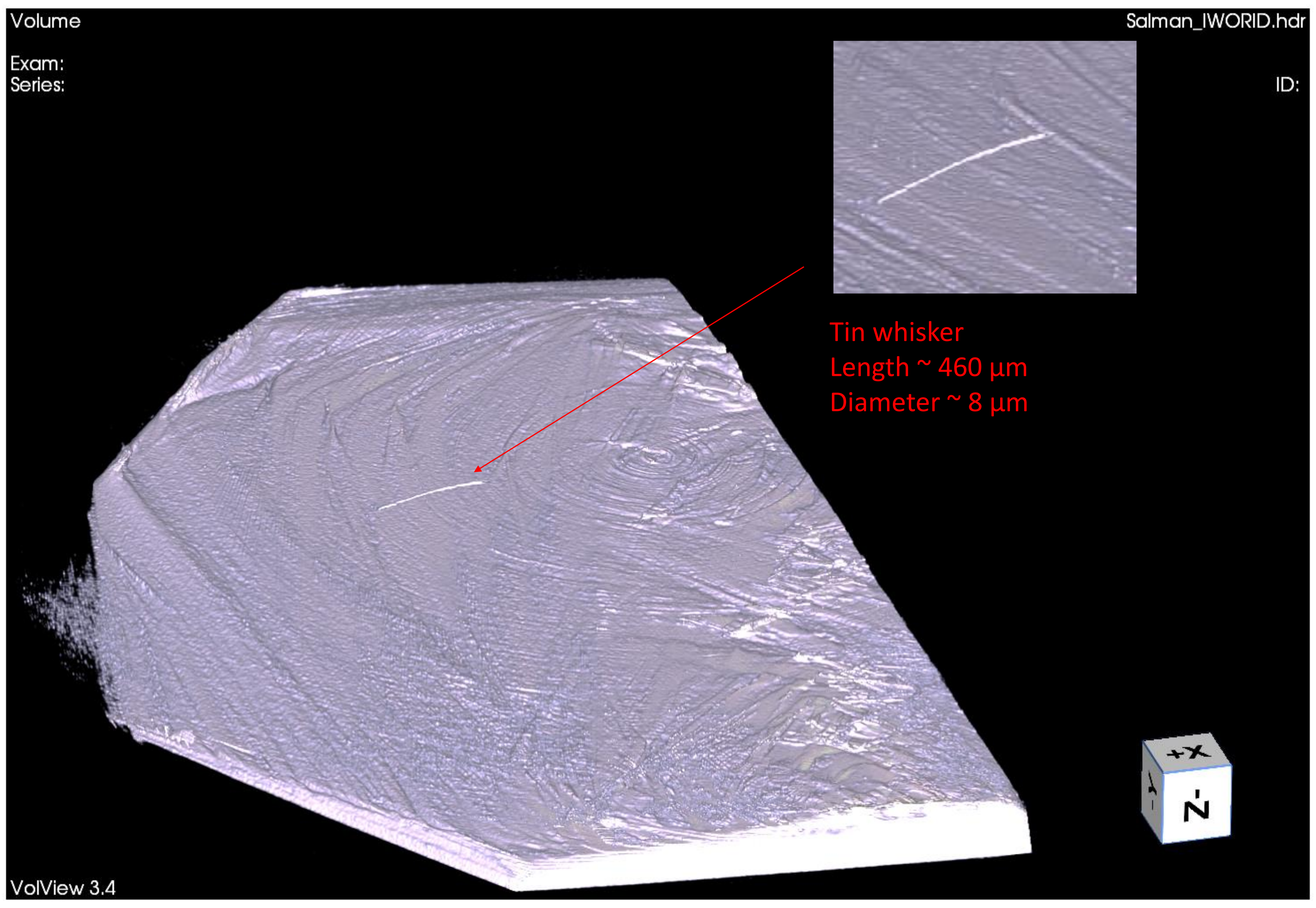

Figure 5. 3D-Tomography of the sample by the Widepix detector. The volume was reconstructed using the OSEM implementation of the speCTive tomographic software [5]. The 3D image reveals a tin whisker emerging from the tin layer on the surface of the copper sample

The SEM of the sample shows the investigated whisker at a magnification of 500x, fig. 4 on the right. The in-plane whisker orientation is observed to be in the [0 0 1] direction, parallel to the X-axis (pressure force axis). The actual 3D morphology of the whisker cannot be determined this way however, since the SEM image represents only one projection onto the sample plane. The projected length of the whisker is about 250µm and the diameter within this plane is <10µm.
Analysis of the micro-tomographic reconstruction reveals the full 3D morphology of the whisker. The whisker protrudes from the tin layer, maintaining an approximately circular cross-section and a constant diameter of ~8µm throughout its entire extent. The total length of the whisker is observed to be ~460 µm.

Conclusion

In this contribution X-ray micro-tomography using direct-converting LADs is shown to be an apt tool for 3D morphology analysis of metal whiskers.
In future experiments a nano-focus X-ray source, combined with advanced spot convolution and image correlation methods, is expected to provide is with yet more accurate 3D information, crucial for the understanding of the underlying growth processes..

References

[1] https://nepp.nasa.gov/whisker/index.html.

[2] https://www.assemblymag.com/articles/84758-trimming-whiskers.

[3] J. Jakubek et al.,*Large area pixel detector WidePIX with full area sensitivity composed of100Timepix assemblies with edgeless sensors*, 2014 JINST 9 C04018

[4] Martin Placek, Karel Dusek, Jan Urbanek. (2014, 7-11 May), Whiskers growth on thick tin layers and various types of surfaces, 37th Int. Spring Seminar on Electronics Technology, Dresden, Germany, IEEE, 10.1109/ISSE.2014.6887591

[5] https://www.spective.de