# *ON THE USE OF IMAGE CORRELATION FOR STABILIZATION PURPOSES IN A SEM-BASED X-RAY TOMOGRAPHY SYSTEM*

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**Summary:** We present recent improvements in a SEM-based X-ray tomography system that optimize the generation of X-rays and improve its detection efficiency. A particularly important element in achieving these targeted improvements has been the use of FFT-based image correlation for stabilizing the X-ray flux through the specimen. Results show that a wide range of spatial resolutions can be selected each with adapted scan times.

## 1. INTRODUCTION

Laboratory X-ray computed tomography (CT) is a well-established technique that allows generating 3D images of a specimen from a sequence of 2D radiographs. It is increasingly being used in materials science thanks to its non-destructive character, its relative easy access (compared to synchrotron X-ray tomography) and its versatility: Micro/nano-metric resolved 3D images can be obtained from a large range of specimen dimensions and materials [1].

When an X-ray magnifying geometry is used, the spatial resolution of reconstructed 3D images is mostly driven by the size of the X-ray source – small sources minimize the well-known penumbra effect in radiographs. However, minimizing the X-ray source size generally leads to a reduced emission of X-rays and, thus, to a degradation of the signal to noise ratio (SNR). Consequently, a compromise between spatial resolution and SNR in images is to be found.

In this work, we aim at improving both the spatial resolution and X-ray flux on a SEM-based X-ray CT equipment [2, 3], in which X-rays are generated by the interaction between the SEM electron-beam and an X-ray target material. These improvements are realized by using X-ray targets with nanoscale dimensions and by increasing the beam brilliance of the electron beam. When using nanoscale X-ray targets, however, e-beam drift compensation becomes mandatory to obtain the required long term stability of the X-ray flux during the acquisition of the radiograph series; therefore, drift of the e-beam is corrected in-line before each radiograph acquisition. This presentation will show the improvements in system performance and demonstrate the potential of the technique for a wide range of applications spanning from microelectronics to biology. Perspectives are presented for further improvements of the versatility of the system.

## 2. EXPERIMENTAL SET-UP

The system is basically composed of a FEI Quanta 450 FEG scanning electron microscope (SEM), a motorized 3-axis piezo stage that holds tungsten nanowires of various sizes (used as anode), a motorized sample sub-stage and an X-ray camera. All these components are placed inside a vacuum chamber. Our recent system analyses and improvements concentrated on the following topics:

- *Nanowire dimensions*: a study has been conducted to determine the optimal dimensions of nanowires for a best compromise between (highest) resolution, (maximum) X-ray flux and (optimized) heat conductivity – the latter to avoid excessive target heating.

- *E-beam to nanowire alignment*: X-rays are generated when the e-beam is focused and centred on the surface of the nanowire, following the electron-matter interaction. Considering the long exposure times associated

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to tomography, long-term drifts of the e-beam may lead to a decrease of X-ray flux or deterioration of spatial resolution. To circumvent this issue, an original, in-line and closed-loop control based on FFT image correlation is integrated into the general tomography routine, which allows stabilizing the generation of X-rays during data acquisition.

- *X-ray camera performance*: A cooled, indirect scientific CMOS X-ray camera (manufactured by Photonic Science) is used as an indirect detection system. It includes a 2048x2048 pixel grid with physical pixel size of 11 µm (active input area of 5.07 $cm^2$) and a 45 µm thick Gadox scintillator. Compared with direct CMOS camera's, it allows to reduce noise levels and improve the detection efficiency especially for higher energy X-rays. An analysis has been carried out to quantify the actual detector performance in terms of detection efficiency using both binned and non-binned images.

## 3. RESULTS

With the recently implemented improvements, the presented system is able to perform stable tomographic scans with a large range of spatial resolutions and reduced acquisition times. Typically, the total scan time is comprised between 3 and 8 hours, depending on the required spatial resolution and the X-ray attenuation length of the specimen. The diameter of samples varies from 30 µm to 1 mm, and details down to ~200-300 nm are well detected. Two examples are shown in Figure 1 for a CMOS integrated circuit sample and an Aluminum specimen containing Zn particles and voids.

## 4. ACKNOWLEDGMENTS

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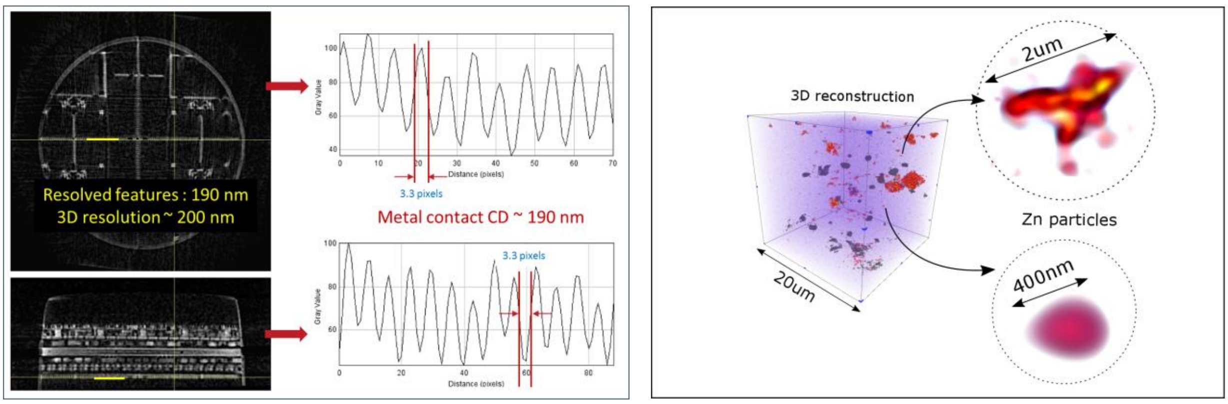


**Figure 1:** (left) analysis of metal lines in a semiconductor integrated circuit. Total acquisition time ~ 4.5 hrs, 200 nm metal contacts are detected; (right) analysis of Zn particles and voids in Aluminum matrix. Total acquisition time ~ 6 hrs, Zn particles down to 400 nm are detected.