Breakthrough Technology to Improve X-Ray results

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ABSTRACT

Last time my paper shared data and results from Excillum labs and those of their technology partners which came from tube technology advances, within our industry

This tube is based on advanced electron optics and the latest very thin tungsten- diamond transmission target technology. Automatic e-beam focusing, and astigmatism correction ensures that the smallest possible, truly round focal spot is achieved. The NanoTube also has the unique feature of internally measuring and reporting the current spot size. In addition, advanced cooling, and cutting-edge thermal design results in extreme stability over time. This enables an unprecedented true resolution of 150nm lines and spaces. The true round spot of the tube is demonstrated by the highly symmetric images of a ‘Siemens star’ resolution target, the innermost features are 150 nm.

The NanoTube is the focus of this paper and work is currently on going, Excillum have already purchased a leading high-end manufacturers off-line system which has become our ‘real life’ test bed, so far, we have benchmarked the source and have upgraded it to the highest current industry specification. We have now replaced the source with the recently developed Excillum NanoTube, running at higher power, offering all the advantages listed, plus further improved electron optics, reliability, and redesigned exterior for easier installation into existing cabinets. I will show sample images from this system during my live presentation at SMTAi 2021, but unfortunately Covid 19 has slowed our progress so they will not be in this paper

The paper will contain comparison data and images from the current industry best vs. the latest Nano Focus tube, plus data from reliability and stability tests using a real-life system and not test rigs.

Key words; x-ray, electronics inspection, Lab6, Nano tube, FOD, radiation damage, flux density, open transmissive.

INTRODUCTION

X-ray technology has been with us since 1875 with the Crooks Discharge Tube, however X-rays were discovered in 1895 by Wilhelm Conrad Roentgen (1845-1923) who was a Professor at Würzburg University in Germany. Working with a cathode-ray tube in his laboratory, Roentgen observed a fluorescent glow of crystals on a table near his tube, he named it *X-radiation* to signify an unknown type of radiation, and the rest, as they say, is history.

In 1956 the open transmissive, solid anode tube was born, which allowed filament changes and higher magnification of images. In 1986 Fein Focus launched a range of systems for the electronics manufacturing industry, after spending 3 years developing them. These systems used small 625-line TV sets for viewing and images were saved either on film or by using thermal printers. From here the changes were more evolution than revolution.

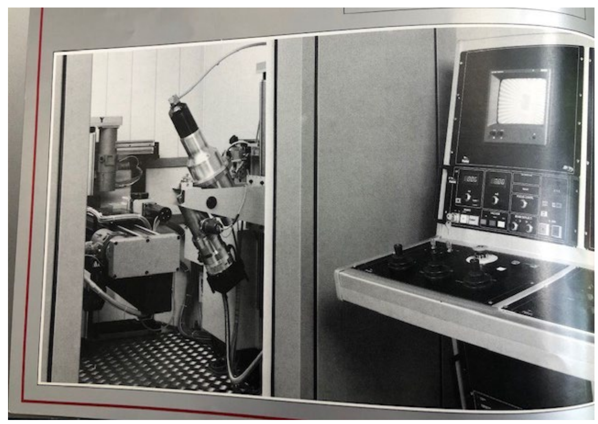

Figure 1, Early Fein Focus system

NANO FOCUS TECHNOLOGY TUBE

For many years high end electronics industry x-ray systems have faced many challenges Feature sizes becoming ever smaller, needing ever higher magnification to see them. Low atomic number difference in materials making greyscale images harder to interpret. The use of slimmed down dies which are then stacked making minute features harder to see.

Complex heatsinks are now appearing at component level, leading to the need for higher power and better resolution combined. Stacked Die, PoP, FOWLP, FIWLP, SiP, MeMs and other complex technologies are making it harder to see faults, in 2D, 2.5D, laminography and even with CT.

Very large devices, with over 1,000 small balls, which contain a high number of dies at differing levels, as in the complex components we now see going into Servers, AI and other demanding applications put immense demands on conventional x-ray technology.

Flux increase

This new source achieves an impressive increase in flux, even compared to its predecessor which was a market leading product, the 110kV tube achieves more than 3 times higher flux. The example below shows a tomographic slice from a Nano CT of an SD-card, performed with the earlier tube (top image) and the new improved nano tube (bottom image), achieving a voxel sampling of 200nm.

The comparative nano CT measurement was done by keeping a similar level of photon counts. With the increase in flux using the new tube, the measurement time was reduced by a factor of 4. At the same time, the signal-to-noise ratio gave even higher image quality, due to the reduced motion within the CT measurement.

This new tube development is specifically targeted towards advanced industries, research, and development, as well as high end inspection of components in automotive, aerospace, medical, electronics and semiconductor back-end to image and analyse hidden features. It combines world leading resolution with high throughput and speed, thereby enabling very small and demanding features to be imaged and inspected accurately and repeatably. Furthermore, the new NanoTube features fully automated focal spot size control and exceptional focal spot stability over time, which makes the x-ray source an optimal component for the future of highly automated inspection systems.

This new tube technology enables industry-leading resolution and geometric magnification, its technology is based on advanced electron optics and the very latest tungsten-diamond transmission target technology. Automatic e-beam focusing, and astigmatism correction ensures that the smallest possible, truly round, and stable focal spot is achieved.

The new nano tube also has the unique feature of internally measuring and reporting the current focal spot size and allowing accurate recalibration, if required. In addition, advanced cooling, and thermal design results in extremely good stability over long exposures or long operation cycles, for instance running 24/7 in production environments. This enables an unprecedented resolution of 150 nm lines and spaces; the true round spot of the tube is demonstrated by the micrograph of a Siemens star and a projection radiograph captured using the new tube is shown on the right of the image.

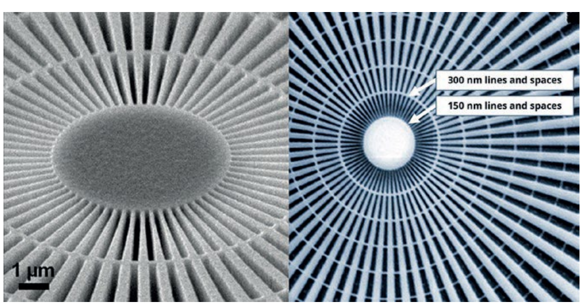

Figure 2, Siemens Star, imaged by a Scanning Electron Microscope on the left and the latest development of NanoTube on the right

Thanks to the advanced e-beam control system of the new tube and the integrated thermal management, excellent long-term stability is achieved. The graph below illustrates the motion of the focal spot relative to a fixed point on the anode over 14 hours, as measured internally by the source, when at thermal equilibrium. Naturally, great care must be taken regarding the stability of the imaging system to maintain the same stability throughout the imaging chain.

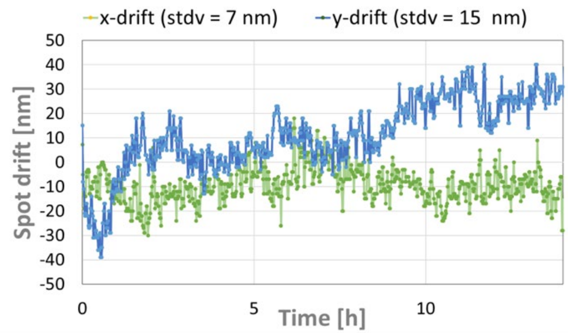

Figure 3, Graph showing tube stability over 14 hours

Excellent geometrical access

The end of the transmission target is the most protruding surface to allow a sample to get as close as possible to the X-ray focal spot. The front is furthermore cone-shaped to allow for a sturdy cone-shaped sample holder, or for a sample table to contact it for maximum magnification with no chance of damage to the transmissive target.

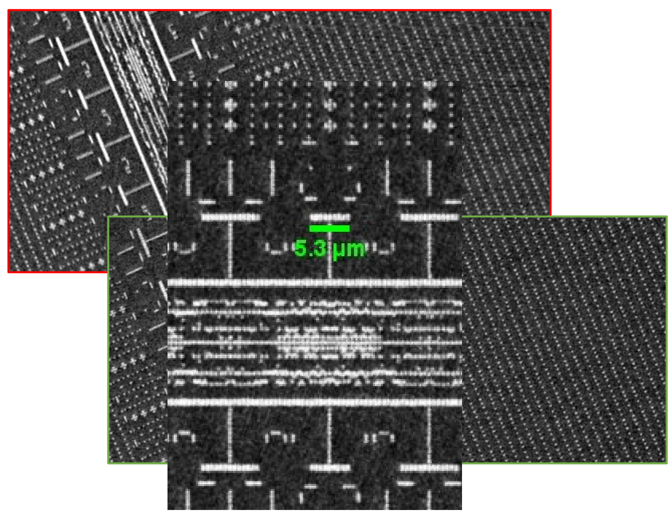

Figure 4, SD card images produced 4 x faster than previous tubes with much improved resolution. Reference, Fraunhofer EZRT (Würzburg).

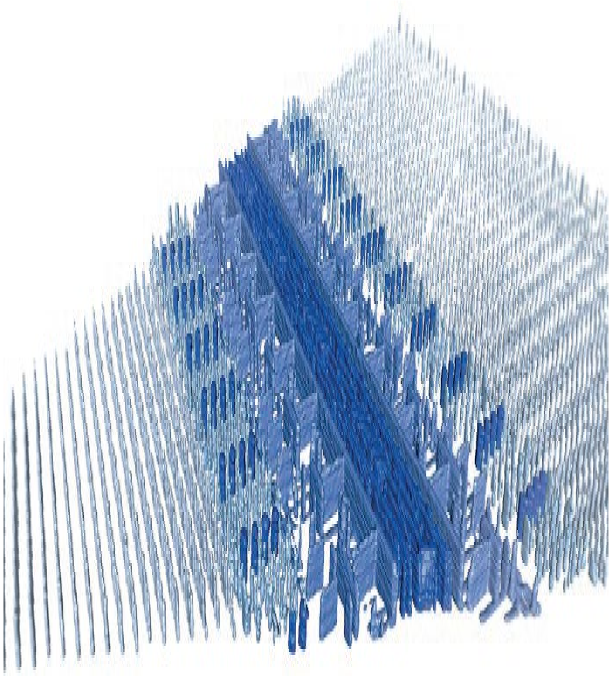

Figure 5, A 3D rendering of an SD card, showing the full reconstruction of the internal features and structures. Voxel sampling, 200nm. Reference Fraunhofer EZRT (Würzburg).

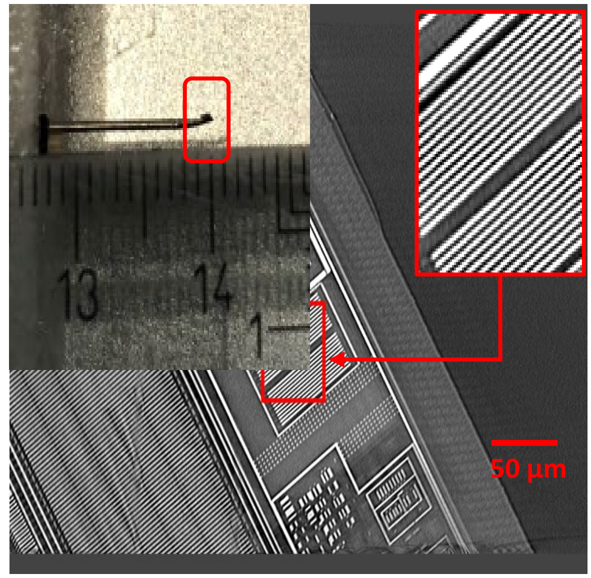

Figure 6, One nano CT slice of a microchip sample 1mm long, 40µm thick. Reference, Fraunhofer EZRT (Würzburg).

EXPERMENTAL DATA AND IMAGES

This was gathered using two 'best in class' sources which were compared to the current generation of NanoTube, using the best and most accurate measuring systems available. They were compared by the same team using the same testing environment and equipment, so all results are totally comparable. I stress this is not the final configuration as the NanoTube product is still under development and being further improved.

Table 1, Comparison of the main properties of high-end X-ray tubes

	Parameter	NanoTube	Tube 2	Tube 3
1	**Cathode type**	LaB6	LaB6	Tungsten Filament
2	**Target type**	Transmission	Transmission	Transmission
3	**Target design**	Diamond (100 um) / Tungst (0.5 um)	Diamond (300 um) / Tungst (1 um)	Diamond (250 um) / Tungsten um)
4	**Min. FOD, um**	100	300	250
5	**Cooling method**	water	water	No cooling
6	**High voltage range, kV**	20 - 110	20 - 100	20 - 160
7	**Min. X-ray resolution, nm**	150	250	1000
8	**X-ray resolution adjustment rang nm**	150 – 600 (continuous)	3 fixed operation modes (25 750 and 1750 for HV > 60 kV	1000 – 20000 (continuous)
9	**Max. e-beam power density, W/u**	5.1	2.3	0.6
10	**Long-term e-spot position stability at 100-110 kV, um**	< 0.05	< 10	< 6

The table above illustrates the key results of a 'head-to-head' comparison between 3 high end x-ray sources and is easy to compare data and abilities. The Nanotube used is the latest development source from Excillum, Tube 2 is a commercially available source which is considered to be the 'best in class' open tube using a LaB6 filament. Tube 3 is from a high-end system used in electronics inspection today, using a tungsten filament, again considered to be 'best in class'. All data is recorded on the same equipment by the same team, in the same environment, so even if there is a belief that the numbers may be incorrect, they are still comparable. These are actual measured results and not taken from specification sheets.

Key parameters to note are (4) the much lower Focus to Object Distance (FOD), this allows much smaller features to be seen more clearly and at higher magnification. Also (7) the much higher resolution, again giving the ability to image very small features and with very low contrast separation.

In (8) we see that the resolution range is much better with the Nanotube and it's not in the data displayed but it is able to have a much better resolution at much higher and kV where the other tubes fall away quite dramatically, so even at high power and kV this tube is able to resolve very small features.

Then (9) shows that this tube has much higher e-beam power density, in fact more than double the nearest comparison, this equates to higher quality of the image on screen so for a given amount of power the Nano tube produces a better image, this is needed to look through high contrast materials, but more importantly, it means that less radiation is absorbed by the sample as the e-beam power density is higher. Lastly and key to any automated or repeat inspection (AXI) the e-spot is a huge factor more stable than both other systems, meaning that it is much more stable and repeatable even over a long-time frame, as you can see also in figure 3. Figure 10 shows an internal image of a chip with a comparison image from a good currently available system to its left, it is easy to see the advantages here.

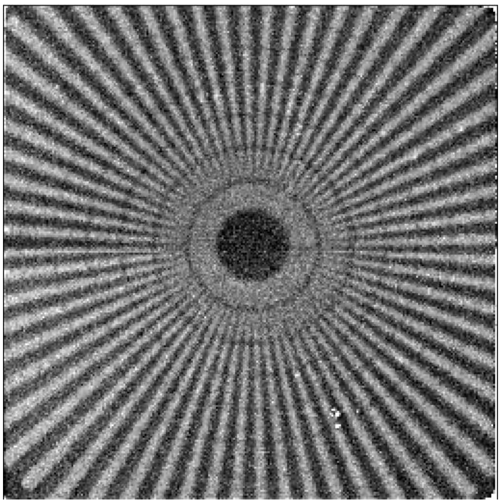

Figure 7, Siemens star imaged by tube 2 at 100kV

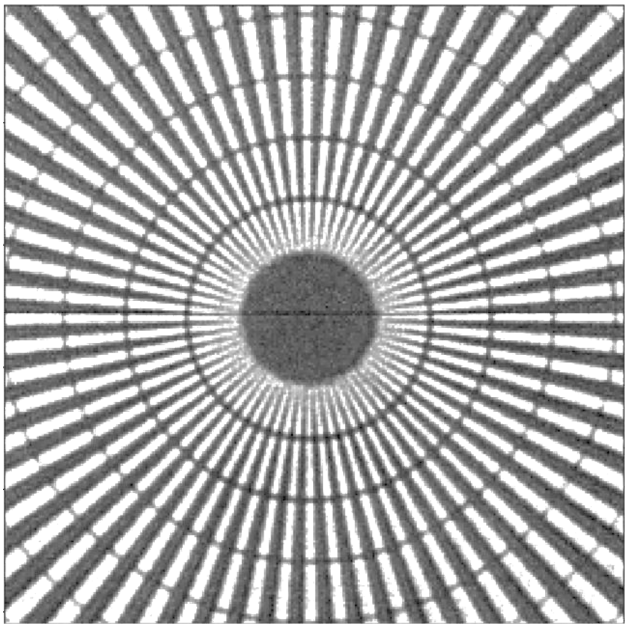

Figure 8, 110kV NanoTube image of the same star showing more clarity, brightness, and higher magnification due to better FOD.

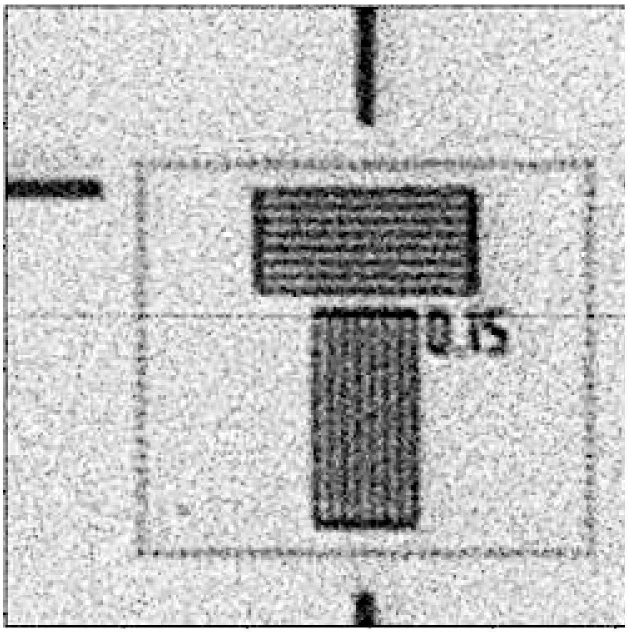

Figure 9, 0.15nm area of a JIMA Gauge imaged by the latest development of NanoTube

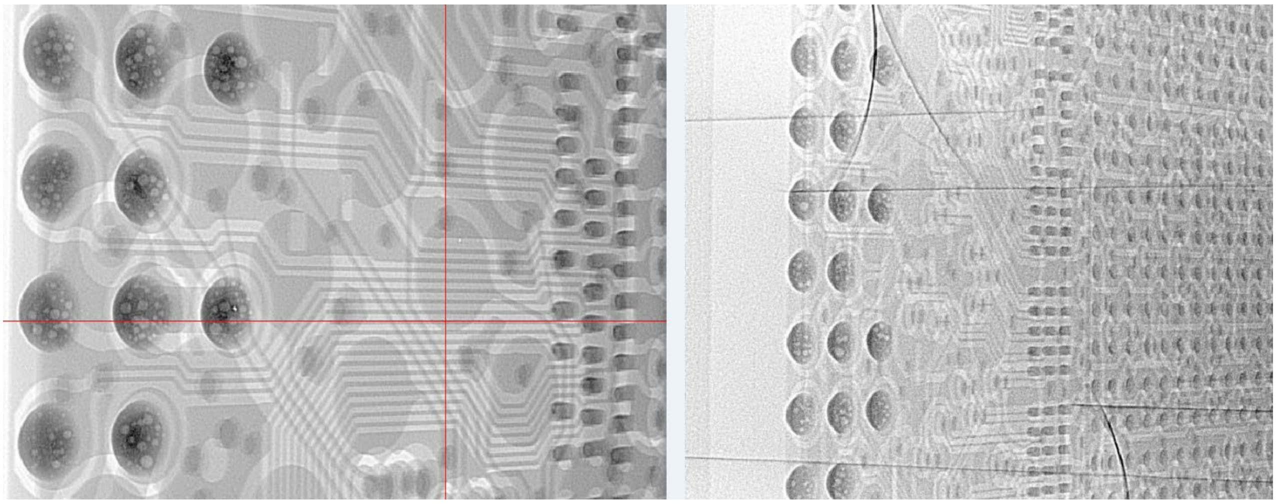

Figure 10, An image from the N3 on the left and a good open tube on the right

SUMMARY AND CONCLUSIONS

As can be clearly seen from the images and data contained in this paper, this new development in x-ray source is definitely 'Best in Class'. Figure 7 (below) is blurred towards the centre where the smaller lines are and this if due to Tube 2 reaching the limit of its capability, whereas image 8 (below) is far clearer, brighter, and crisper, this would translate to smaller features on a sample being seen more clearly and inspected. A further confirmation of NanoTube ability is figure 9 (below) which shows crispness and clarity of the image even at maximum resolution.

In all the key metrics the NanoTube outperforms the other two sources compared here, beating them comprehensively. It can therefore be expected that the higher technology sources currently under development will perform even better and put Excillum at the forefront of source technology for the most demanding of SMT and Semiconductor inspection applications.