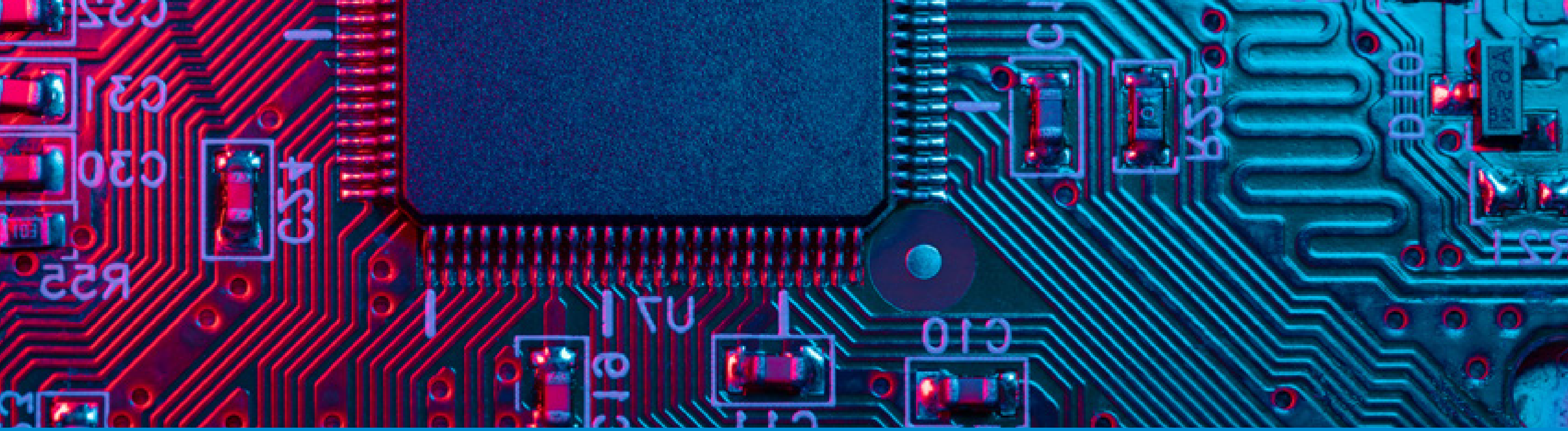


X-ray Inspection for Nano-technology

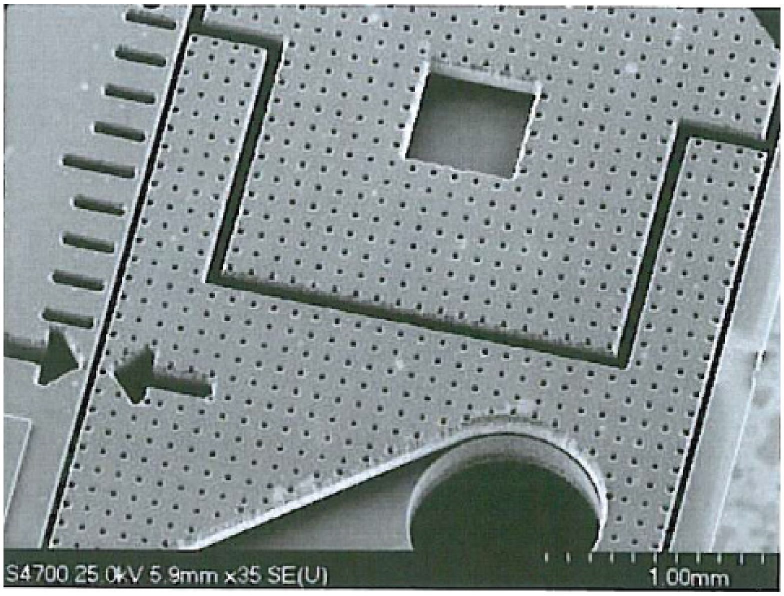
By Keith Bryant and Dr David Bernard

Introduction

I should start by pointing out that the wording “nano-technology” has become very popular and is used to describe many types of research where the characteristic dimensions are less than about 1,000 nanometers. For example, continued improvements in lithography have resulted in line widths that are less than one micron: this work is often called “nano-technology.” This is the definition I shall be using; I will not be addressing atomic level structure growth for biomechanics or similar technologies that are not linked to electronics.

The Arrival of Nano-Technology

The size of a single transistor has been reducing in an exponential manner for several decades, leading to integrated circuits containing tens of millions of transistors. But as the size of the transistor decreases a physical limit is encountered where the transistor becomes too small and quantum effects become significant. When this limit is reached the exponential growth in computing power that has been characteristic of the 1980s and 1990s will come to an end. This event is expected to occur somewhere between 2010 and 2020. This will be the end of the road for pure silicon technology. At this point completely new technologies will be needed. So the question is, what is coming next?



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Micro-Electro-Mechanical Systems (MEMS) is the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through microfabrication technology. While the electronics are fabricated using integrated circuit (IC) process sequences (e.g., CMOS, Bipolar, or BICMOS processes), the micromechanical components are fabricated using compatible " micromachining" processes that selectively etch away parts of the silicon wafer or add new structural Layers to form the mechanical and electromechanical devices.

MEMS promises to revolutionise nearly every product category by bringing together silicon-based microelectronics with micromachining technology, making possible the realisation of complete systems-on-a-chip. MEMS is an enabling technology allowing the development of smart products, augmenting the computational ability of microelectronics with the perception and control capabilities of microsensors and microactuators and expanding the space of possible designs and applications. Microelectronic integrated circuits can be thought of as the "brains" of a system and MEMS augments this decision-making capability with "eyes" and "arms", , to allow microsystems to sense and control the environment. Sensors gather information from the environment through measuring mechanical, thermal, biological, chemical, optical, and magnetic phenomena. The electronics then process the information derived from the sensors and through some decision making capability direct the actuators to respond by moving, positioning, regulating, pumping, and filtering, thereby controlling the environment for some desired outcome or purpose. Because MEMS devices are manufactured using batch fabrication techniques similar to those used for integrated circuits, unprecedented levels of functionality, reliability, and sophistication can be placed on a small silicon chip at a relatively low cost.

There are numerous possible applications for MEMS and Nano-technology. As a breakthrough technology, allowing unparalleled synergy between previously unrelated fields such as biology and microelectronics, many new MEMS and Nanotechnology applications will emerge, expanding beyond that which is currently identified or known. Here are a few applications of current interest:

Communications

High frequency circuits will benefit considerably from the advent of the RF-MEMS technology. Electrical components such as inductors and tuneable capacitors can be improved significantly compared to their integrated counterparts if they are made using MEMS and Nanotechnology. With the integration of such components, the performance of communication circuits will improve, while the total circuit area, power consumption and cost will be reduced. In addition, the mechanical switch, as developed by several research groups, is a key component with huge potential in various microwave circuits. Reliability and packaging of RF-MEMS components seem to be the two critical issues that need to be solved before they receive wider acceptance by the market.

Accelerometers

MEMS accelerometers are quickly replacing conventional accelerometers for crash air-bag deployment systems in automobiles. The conventional approach uses several bulky accelerometers made of discrete components mounted in the front of the car with separate electronics near the air-bag; this approach costs over $50 per automobile. MEMS and Nanotechnology has made it possible to integrate the accelerometer and electronics onto a single silicon chip at a cost between $5 to $10. These MEMS accelerometers are much smaller, more functional, lighter, more reliable, and are produced for a fraction of the cost of the conventional macroscale accelerometer elements

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Challenges for X-ray Technology

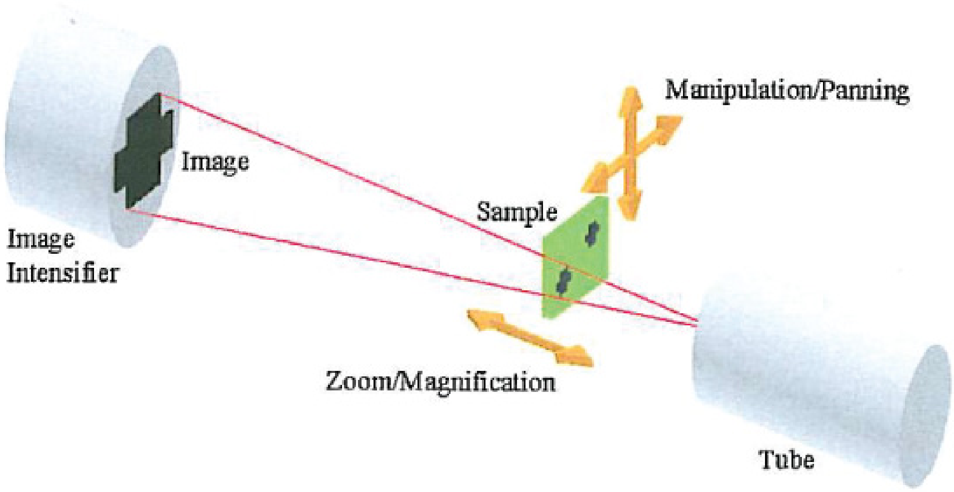
In a similar way to the silicon technology coming to a technology plateau, the current open tube, analogue x-ray system technology has a “real life” minimum feature recognition of around 3,0000 nano-meters or 3 microns.

Standard imaging technology and existing greyscale resolution is also limited in this area, with 8 bit technology, limited pixel counts and poor greyscale sensitivity mean that differentiating between very small and similar density materials is not possible.

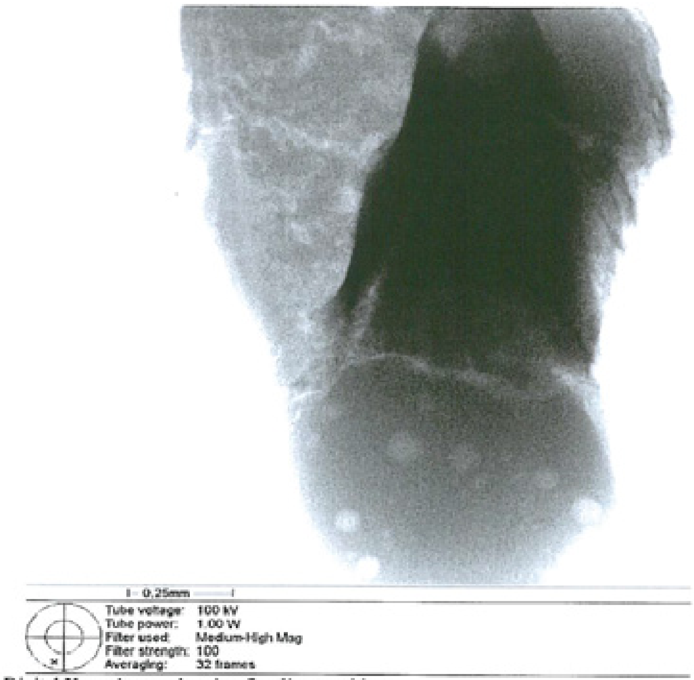
In summary the established equipment will not be suitable for nano-technology inspection.

The way forward

Digital technology brings with it a quantum leap in x-ray ability overcoming the issues of grey scale sensitivity and pixel count, these systems can have up to 65,000 greyscale levels and run 12 or 16 bit technology.

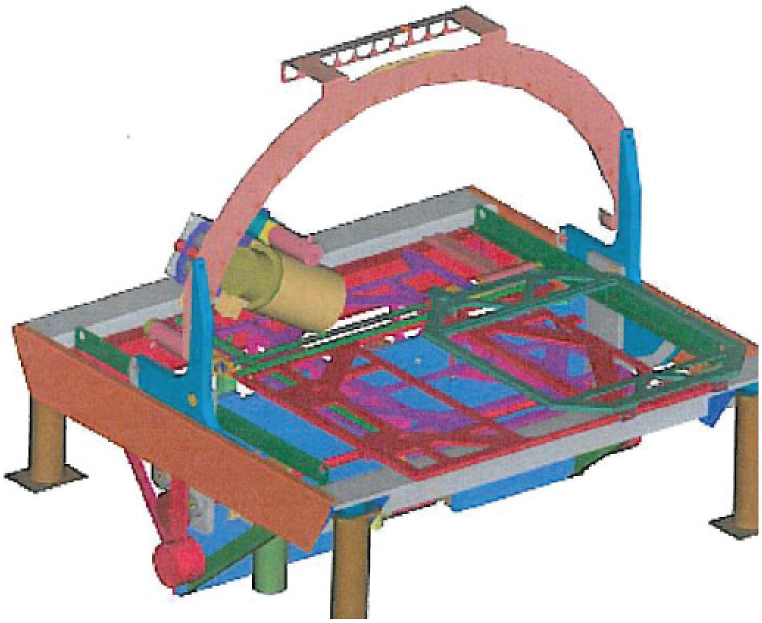


The pathway from the Image Intensifier to the monitor is digital, whereas the earlier systems processed the analogue signal within the PC. This also allows smaller features to become visible and the minimum feature recognition moves down to around 600 nanometers or 0.6 microns. This feature recognition is a major step forward but not really good enough for nano-technology inspection, unfortunately this level is at the limit of existing open tube technology.

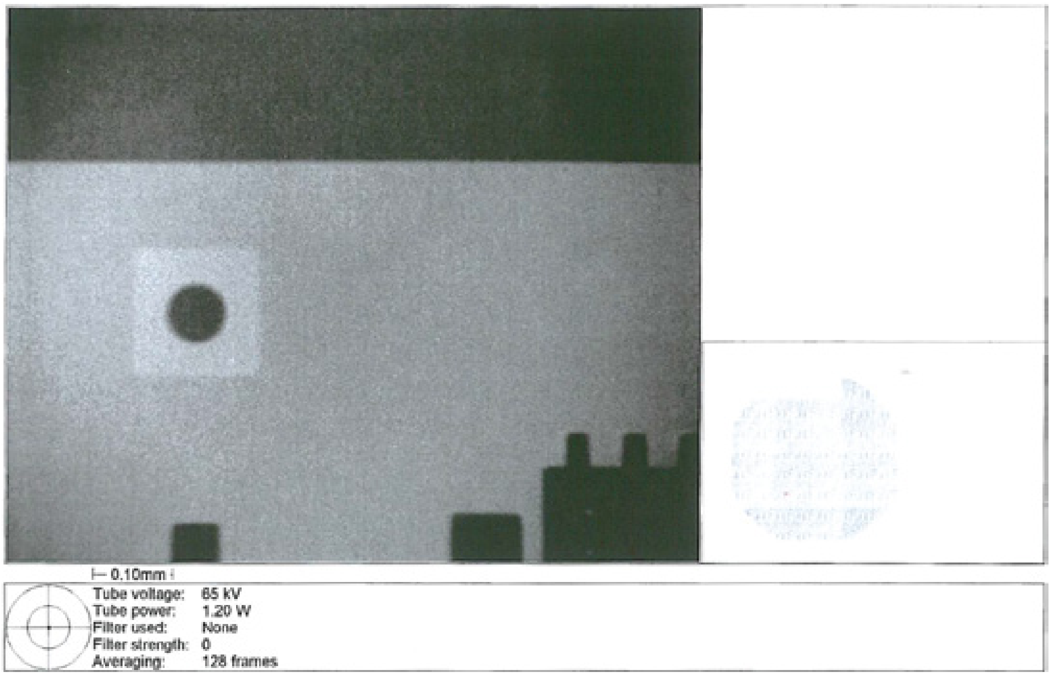


Digital X-ray image showing fine line cracking

However the image can be significantly improved by removing vibration from the sample tray. Vibration can be a major contributing factor to degradation of image quality at high magnification, this is because the image on the screen is an average of many “real time” pictures and the more stable the sample, the clearer the image. Mounting the sample table, x-ray source and digital Image Intensifier on active air mounts dramatically reduces vibration, both from external sources and within the equipment.



This system of vibration damping improved the quality of the image, allowing features which were not previously visible to be seen easily, the picture below shows a clearance area and via within a wafer.



Tube voltage: 65 kV
Tube power: 1.20 W
Filter used: None
Filter strength: 0
Averaging: 128 frames

The Future of X-ray Technology

Clearly if open tube technology has reached the limit of the envelope at about 600 nano-meter feature recognition, we cannot move further without a new method of producing and controlling x-rays. This technology has been developed, unfortunately I cannot go into too much detail on the technology, suffice to say that it is a filament free system with the x-ray source contained in a sealed for life vacuum chamber. However it is not similar to the older "closed tube" systems that were replaced by "open tubes" due to their lack of magnification and resolution.

This exciting new technology can give feature recognition below 250 nano-meters together with superior resolution and improved grey scale sensitivity. The resultant images are a major improvement on current x-ray technology allowing inspection of MEMS and other nano-technologies together with other small features including die cracks.

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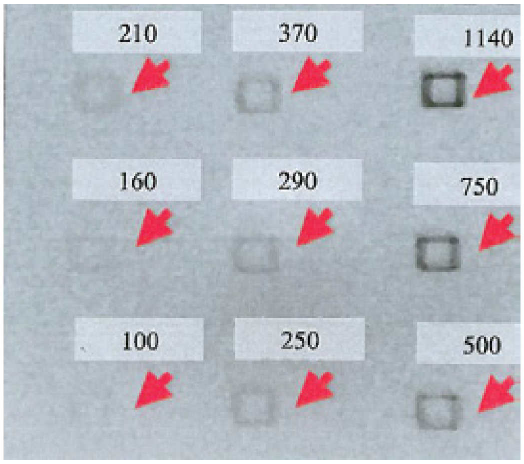

This special sample, whose dimensions have been independently verified by SEM, has 3 rows of three 10-micron squares. The first column (right hand side) from the top down has wall thickness of 1140nm, 750nm and 500nm. Second column (middle) is 370nm, 290nm and 250mm. Third column is 210nm, 160nm and 100nm.

At 250 nm wall size, the walls of this square are only 900,000 atoms wide!

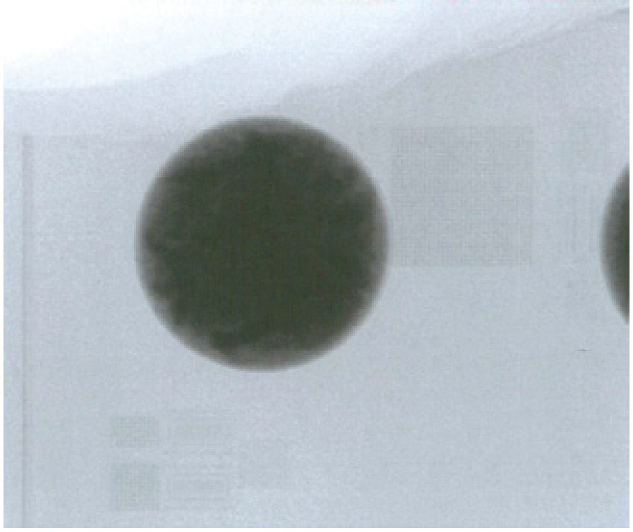

Image of 200 to 300 nano-meter diameter tungsten via holes at wafer level.

For more information, speak with your Nordson representative or contact your Nordson Test & Inspection regional office

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