

# X-ray Computed Tomography for Non-Destructive Failure Analysis in Microelectronics

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## Abstract

In this paper a review of the development of x-ray computed tomography (CT) for non-destructive failure analysis in microelectronics is presented. The general operation principle, key design considerations and technical challenges faced by x-ray CT technology are discussed. A comparison between 2D and 3D x-ray imaging capabilities is presented, and critical failure analysis case studies that are hard or not possible to isolate by alternative methods are also discussed, as well as its unique progressive testing capability.

## Introduction

The assembly package development roadmap has been increasing interconnect complexity, component density, the number of stacked dice, and material composition, while at the same time reducing critical dimensions. As a result of these trends, the isolation and root cause analysis of defects has become increasingly challenging for traditional analytical tools and techniques. In addition, reduced time-to-information and non-destructive approaches have become critical factors, introducing more challenges into the analytical tools development roadmap. One of these analytical capabilities is 2D x-ray imaging, which is also one of the most extensively used tools in the semiconductor industry to isolate and analyze defects in a non-destructive fashion. Some of these capability challenges are the detection of metal migration and dendrite growth, solder joint non-wetting and cracking at both first and second level interconnect, wireboards shorting and breakage, etc. One of the x-ray techniques identified as potentially feasible to fulfill these defect detection gaps was x-ray CT [1]. However, the standard assembly imaging techniques of x-ray CT had important limitations in terms of defect detection capability and time-to-data, and thus it needed to be extended into the next generation [2]. Key technical drivers for x-ray CT are the need to non-destructively and quickly detect micron and sub-micron sized defects.

In this paper, we review key technical challenges faced by x-ray CT technology, leading technical developments that have overcome some of these challenges, as well as application development for critical defect detection case studies.

## X-ray CT Operation Principle

There are several possible configurations to achieve the challenges of the key drivers; however, all of them relay of a basic operation principle of using an x-ray source to radiate the object at different tilt angles, with a rotating stage providing such angular displacement in equally spaced angles, and a detector collecting the 2D x-ray images at each angle. This is schematically shown in Fig. 1. All 2D images are mathematically superimposed and processed to obtain a three dimensional map of the sample, as it is shown schematically in Fig. 1b. Information is typically displayed as a cross-section, slice view and 3D model.

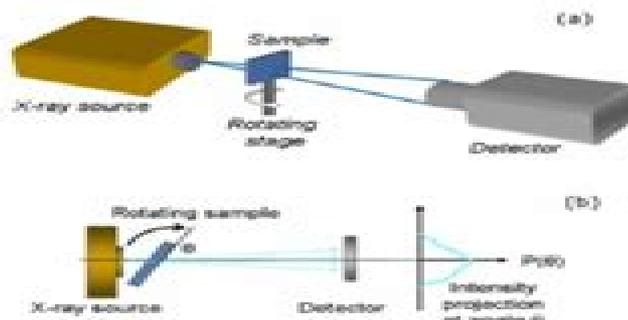


Figure 1: (a) Basic schematic of the x-ray CT setup consisting of x-ray source, rotating stage and detector. (b) The projections at each angle of the intensity of collected 2D x-ray images are superimposed and mathematically processed to generate the three dimensional image.

## Key Design Factors in X-Ray CT

In this section we'll review the critical design considerations for X-Ray CT systems that are targeted for failure analysis in microelectronics applications.

### Resolution

X-ray image resolution depends on several factors, however, geometric magnification, which is given by the ratio between sample-to-source and sample-to-detector distances, is one of the most critical ones, given by the following expression:

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**H Kauffman**



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*Plant Ecophysiology: Responses to Climate Changes and Stress Conditions* Srdjan Stojnic, Nacer Bellaloui, Raul Antonio Sperotto, Yanbo Hu, Georgios Koubouris, Peter Petřík, 2025-10-23 Climate change characterized by amplified frequency and amplitude of heat waves increased evaporative demand and altered precipitation patterns threatening the productivity and stability of ecosystems worldwide Previous research identified a number of abiotic and biotic stressors that affects plant physiology and contributes to natural ecosystems decline as well as crop yield failure Depending on their intensity and duration plant species may display a wide range of strategies and mechanisms to withstand environmental stress including physiological and biochemical responses as well as modulation in structural characteristics such as anatomy and morphology However despite the great progress made in understanding plant responses and tolerance to environmental stress factors a holistic and systematic knowledge on the effect of multiple simultaneous and or sequential stress factors and their interactions is still lacking In addition climate change imposes the alteration of a series of environmental factors simultaneously as well as intensify the severity of different stressful events such as drought floods salinity and heat waves Therefore knowledge of how plants acclimate to multiple stressors is critical in understanding the effects of future climates on natural ecosystems urban greenery and agroforestry systems i e tree crops interaction worldwide

**Transactions on Engineering Technologies** Gi-Chul Yang, Sio-Iong Ao, Len Gelman, 2015-05-07 This volume contains fifty one revised and extended research articles written by prominent researchers participating in the international conference on Advances in Engineering Technologies and Physical Science London UK 2 4 July 2014 under the World Congress on Engineering 2014 WCE 2014 Topics covered include mechanical engineering bioengineering internet engineering wireless networks image engineering manufacturing engineering and industrial applications The book offers an overview of the tremendous advances made recently in engineering technologies and the physical sciences and their applications and also serves as an excellent reference for researchers and graduate students working in these fields

**El riesgo del arbolado urbano. Contexto, concepto y evaluación** CALAZA MARTINEZ, PEDRO, IGLESIAS DÍAZ, M<sup>a</sup> ISABEL, 2016-01-01 Este libro aborda el contexto concepto y metodologías para la evaluación de riesgo de arbolado uno de los problemas más importantes de la presencia de arbolado en nuestras ciudades Se trata de una versión revisada completada y ampliada de la obra Evaluación de riesgo de arbolado urbano Principios indicadores y métodos 2012 ganadora del XX Premio Juan Julio Publicaciones que otorga la Asociación Española de Parques y Jardines Públicos Esta segunda obra persigue exponer el estado de conocimiento a nivel internacional así como facilitar un protocolo de trabajo para la identificación y diagnóstico de arbolado peligroso a los responsables de la gestión de nuestras ciudades carreteras y de todas aquellas zonas donde exista arbolado para intentar conseguir una minimización de riesgos y daños potenciales a personas y o bienes Se ofrecen diferentes alternativas de estudio y comprensión de los indicadores de riesgo y se guía a los lectores sobre diferentes procedimientos de cálculo De esta forma

se pretende dotar a los técnicos gestores ingenieros biólogos arquitectos del paisaje etc de una herramienta de conocimiento y de aplicación práctica que les posibilite una toma de decisiones más certera La obra se presenta en 12 capítulos que incluyen desde conceptos clave legislación beneficios e inconvenientes y la selección de arbolado hasta las tipologías de colapsos y factores biológicos y biomecánicos que influyen en el riesgo Se incluyen las bases técnicas y científicas de la metodología de cálculo de riesgo conceptos de anatomía mecanismos de pudrición de la madera e indicadores de riesgo En los últimos capítulos se profundiza en los métodos y herramientas para el diagnóstico de árboles peligrosos y se presenta un informe tipo mediante la exposición de un caso práctico Esta obra va dirigida a aquellos profesionales con formación técnica en arboricultura Ingenieros Agrónomos de Montes Biólogos ingenieros técnicos y graduados en ramas agrarias y forestales etc y aquellos estudiantes que pretendan desarrollar su actividad profesional en el ámbito del paisajismo la arboricultura la jardinería y la gestión de servicios urbanos

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fault trees the application of Boolean Algebra and the use of probability values in the final algebraic expressions While not the only method which can be used the fault tree technique is considered to be a very effective analytical tool in assessing system safety This report supersedes Picatinny Arsenal Technical Report 3822 Author **Strength and Stiffness Assessment of Standing Trees Using a Nondestructive Stress Wave Technique** ,2000 **Fault Tree Analysis Primer** Clifton A.. Ericson,2011-12-15 One of the most valuable root cause analysis tools in the system safety toolbox is fault tree analysis FTA A fault tree FT is a graphical diagram that uses logic gates to model the various combinations of failures faults errors and normal events involved in causing a specified undesired event to occur The graphical model can be translated into a mathematical model in order to compute failure probabilities and system importance measures A FT can model all aspects of a system including hardware software human actions and the environment FTs are employed to evaluate large complex and dynamic systems in order to understand and prevent potential safety and reliability problems Using the rigorous and structured methodology of FT construction allows the systems analyst to model the unique combinations of fault events that can cause an UE to occur This book provides an overview of the FTA process it describes the symbols terms construction methodology and mathematics of FTA **Systems Failure Analysis** Joseph Berk,2009 Provides product teams with the tools and concepts to get at the root causes of defects and failures in complex manufacturing and engineered systems The techniques described can be applied to assessing and preventing a show stopper failure that brings an organisation to a halt as well as to finding and correcting root causes of unacceptable variations in a system Components' Importance Measures for Initiating and Enabling Events In Fault Tree Analysis ,2010 This report deals with the problem of determining the exact values of the importance indexes of basic events in case of both unavailability and frequency analysis for coherent and non coherent fault trees In particular a new method is described for determining the importance of enabling events in case of frequency analysis Insights are given into the importance analysis implemented in the new software ASTRA 3 0 based on the Binary Decision Diagram approach with Labelled variables LBDD The analysis methods are also described with reference to modularised fault trees Simple numerical examples are provided to clarify how the methods work

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