Electronic Supply Chain

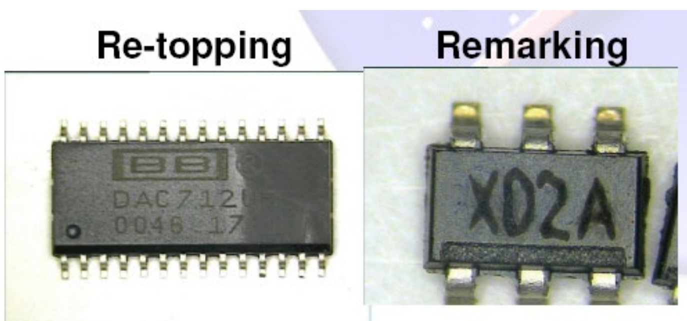
Counterfeit Detection and Avoidance

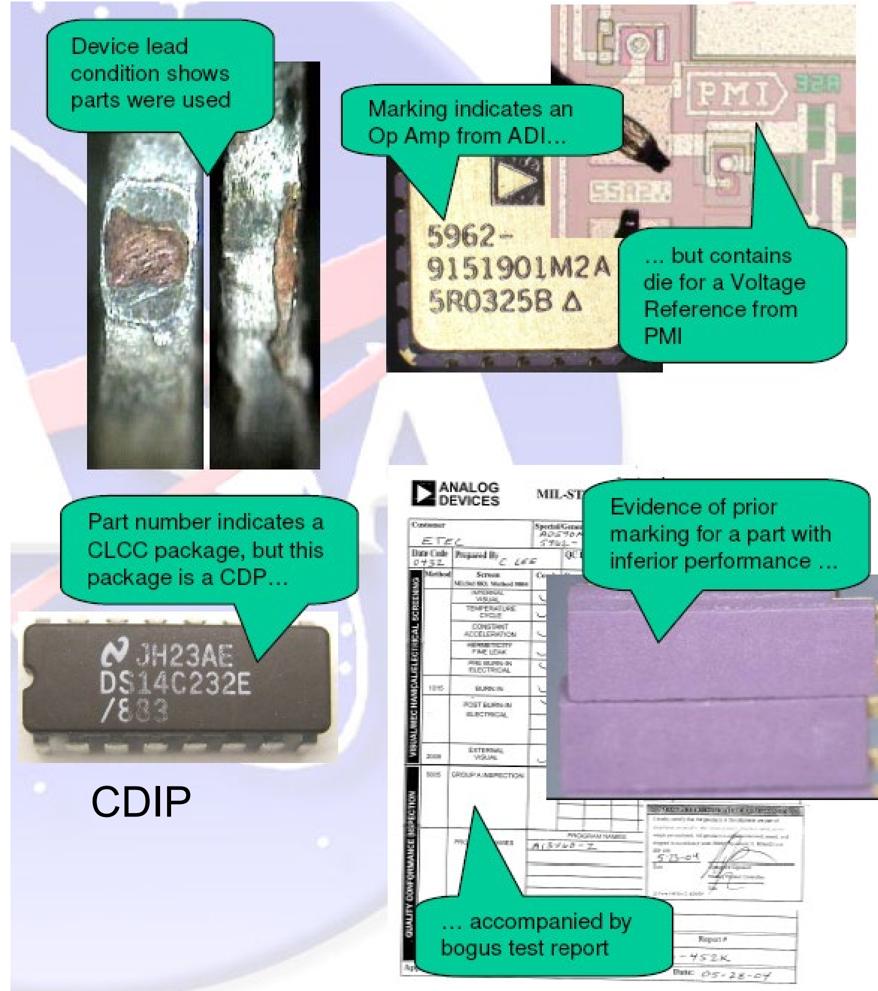
Why Counterfeiting?

- **Lucrative business**
  - Easy money, floating everywhere in the world
  - Easy to make counterfeit components
  - Enough raw material
    - E.g. ever increasing electronic waste.
  - Copy one's design and fabricate components without paying royalty or any R&D costs
- **Criminal Activity**
  - To cripple the supply chain of one countries defense system.
  - To contaminate one company's reputation.
  - To kill the market share of one company.
  - More …

Counterfeit Electronic Parts

- Parts remarked or re-topped
- Defective parts scrapped by the OCM (Original component manufacturer)
- Previously used parts salvaged from scrapped assemblies
- Devices which have been refurbished, but represented as new product.
- Overproduced parts by the foundry
- Cloned IP → IC
- Forged Documentation – Misrepresentation of an IC
- Manufacturer Reject





Counterfeit Electronic Parts

- A counterfeit component [1] [2]
  - is an unauthorized copy,
  - does not conform to OCM design, model, or performance standards,
  - is not produced by the OCM,
  - is out-of-specification, defective, or a used OCM product sold as new,
  - has incorrect or false markings or documentation, or
  - is produced or distributed in violation of intellectual property rights, copyrights, or trademark laws.

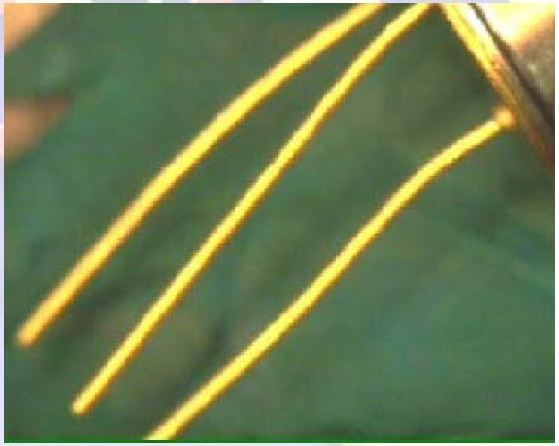
NDAA: National Defense Authorization Act. United States Congress, 2011
OCM: Original Component Manufacturer

Examples

- Incorrect device leads:

Non-gold leads

Gold leads on real device



Examples- Cont.

- Dual Marking:

Examples- Cont.

- Good part has only two lines of marking

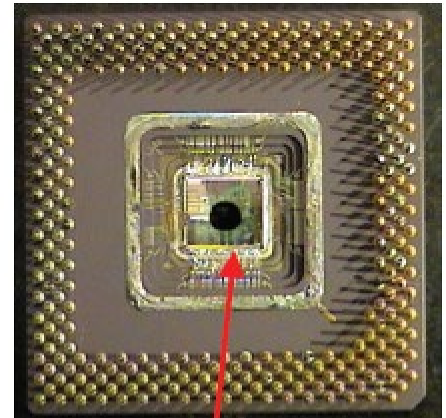
Figure 1: Photo of suspect part.

Figure 2: Photo of Known Good Part

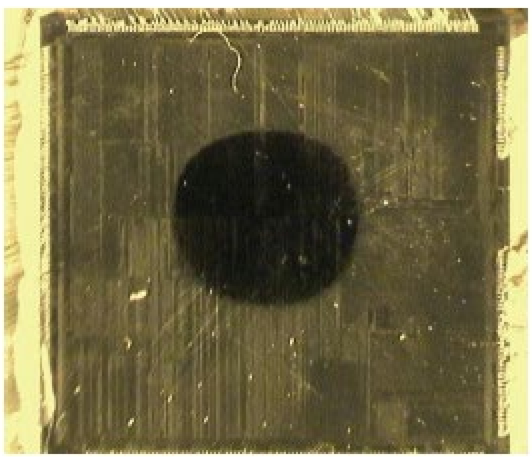
Examples- Cont.

Backside, look at the black shiny paint like substance in the lower right side, the mold pin cavity is almost gone, look at the bent leads, looks like it may have been painted over to hide sanding marks and then fraudulently remarked

Examples- Cont.



Looks simple enough Intel device, marking not too bad, OH OH!!



The ink dot that identifies a reject from wafer sort.

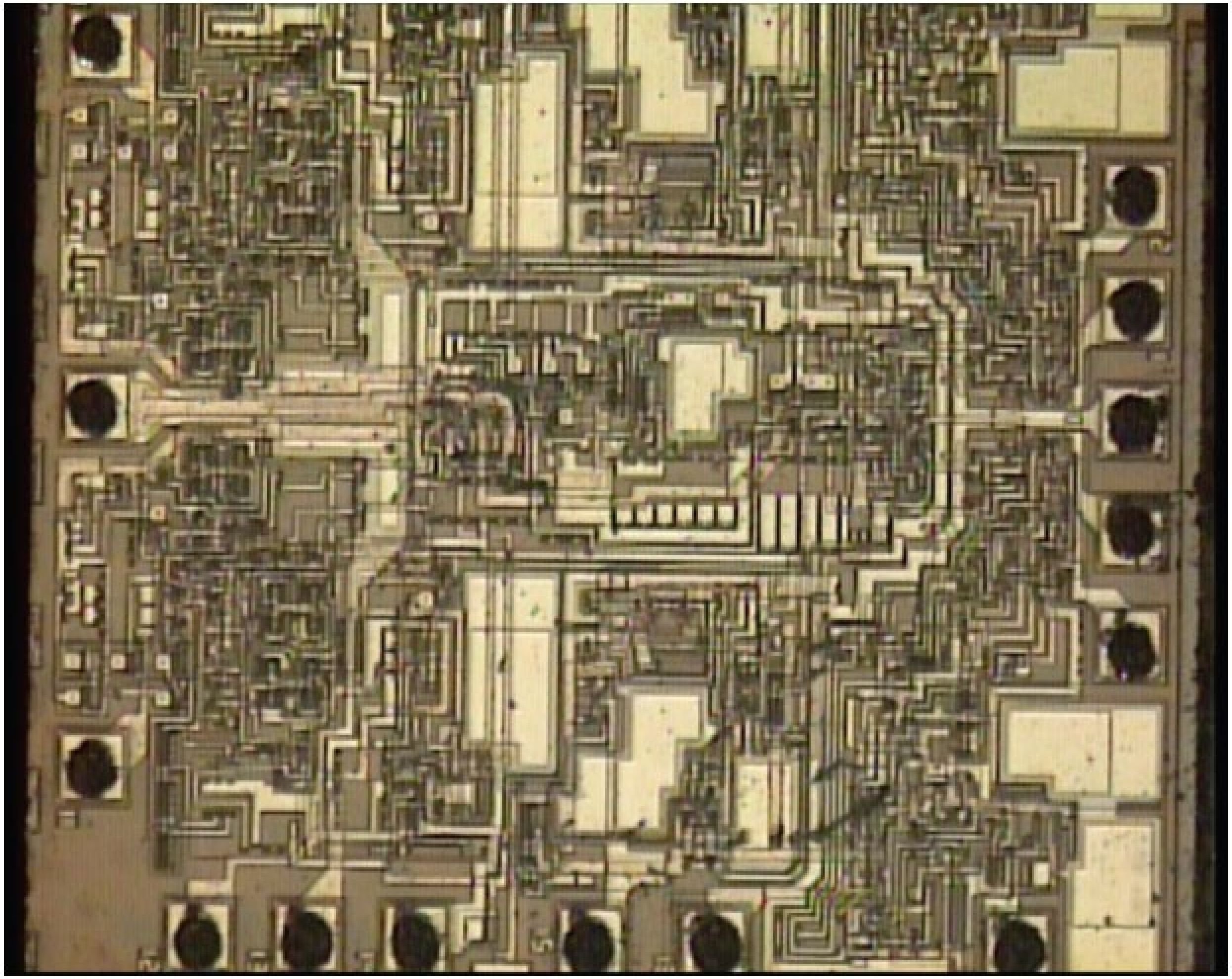
Here is the chip ID found after decap, looks good and matches the package marking

Examples- Cont.

Same lot, same numbers but there is no ink dot

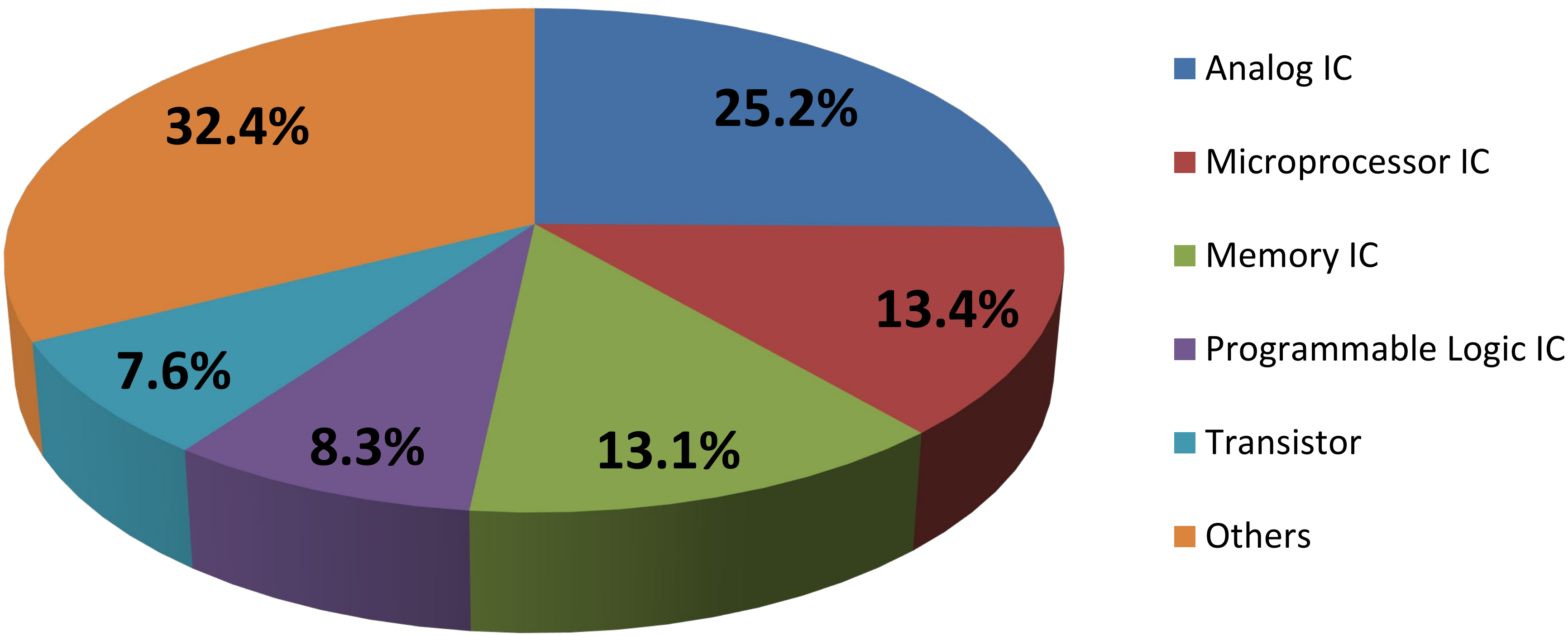
A close look at the characters shows they are backwards

Examples- Cont.



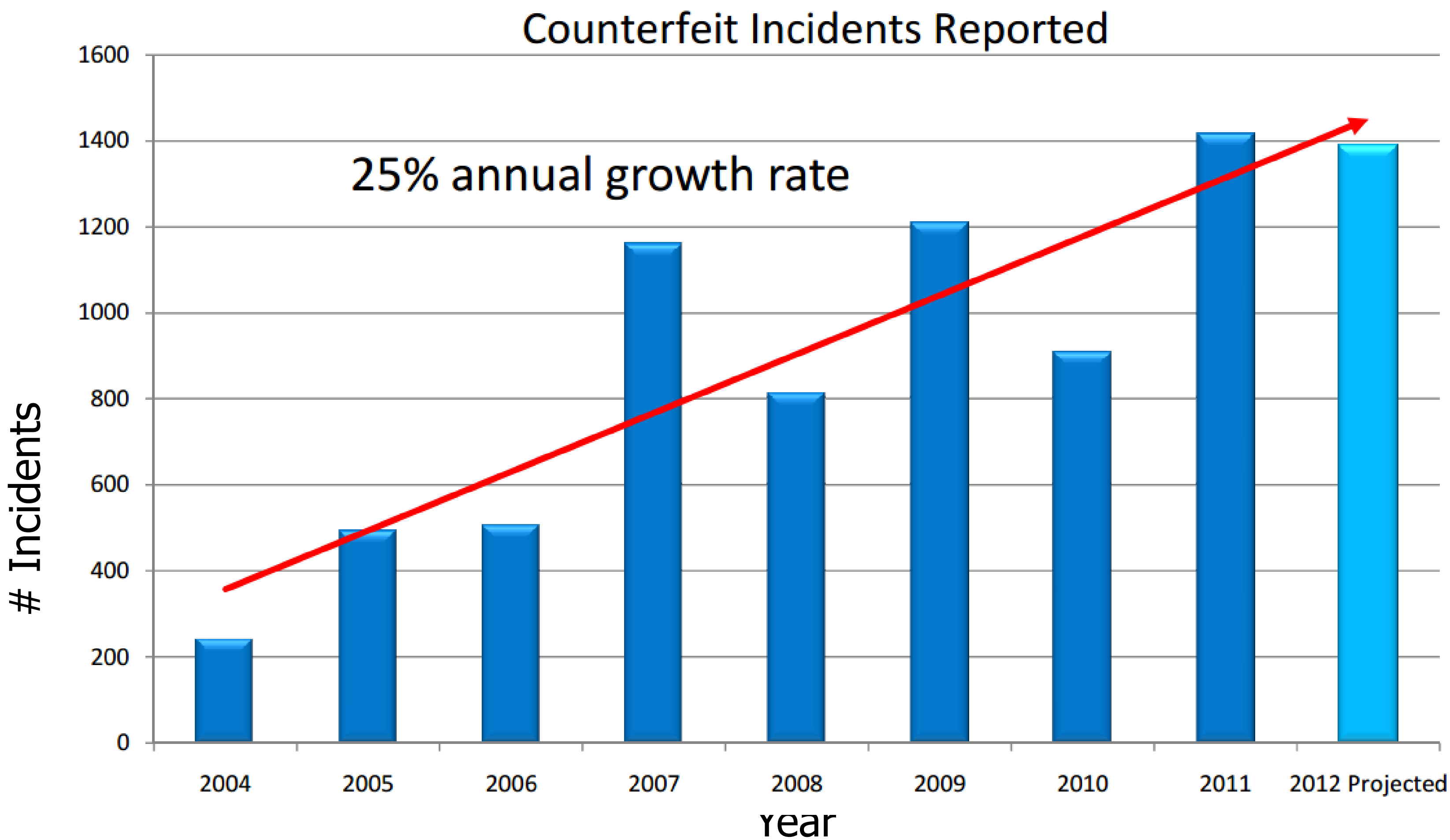
This is a cloned semiconductor chip

Most Counterfeited Parts in 2011 (% Reported Incidents)



IHS reports a $169B annual risk [3]

Reports of Counterfeits

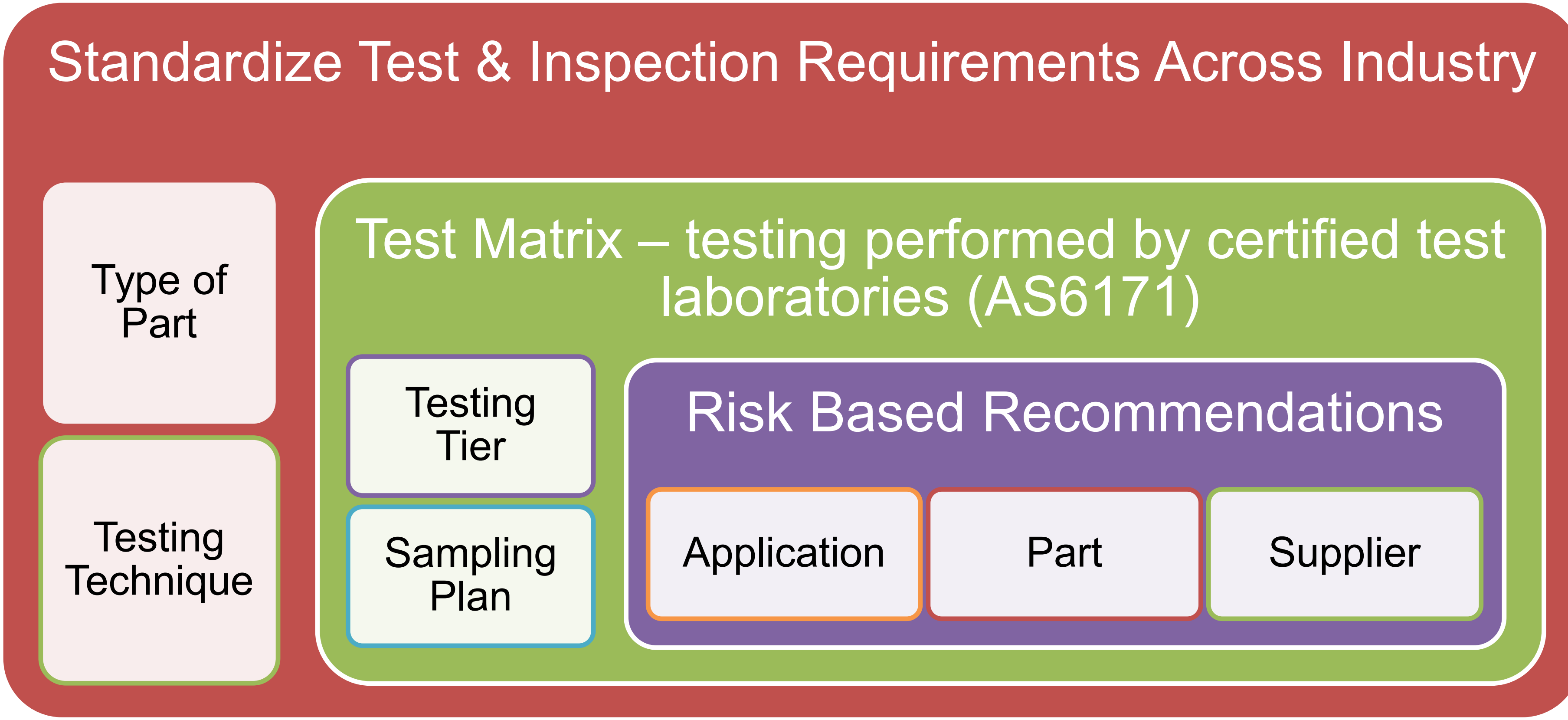


Counterfeit incidents reported by IHS [4]

Detection Standards

- SAE G-19A Test Laboratory Standards Development Committee
  - **AS6081** - Counterfeit Electronic Parts; Avoidance Protocol, Distributors
  - **AS5553** - Counterfeit Electronic Parts; Avoidance, Detection, Mitigation, and Disposition
  - **AS6171** - Test Methods Standard; Counterfeit Electronic Parts
  - **ARP6178** - Fraudulent/Counterfeit Electronic Parts; Tool for Risk Assessment of Distributors
- CTI CCAP-101 --CTI (Components Technology Institute, Inc) CCAP – Counterfeit Components Avoidance Program
- IDEA-STD-1010
  - Inspection standard addressing the needs for the inspection of electronic components traded in the open market

SAE G-19A Test Laboratory Subcommittee



- ***System intended to create standardized testing methodology and consistency throughout industry***

Testing Level Based on Risk

CRITICAL	•Electrical Test: Active Devices- DC, key AC/Switching parameters, and full Functional Test over temperature, Burn-in (240 hrs. for Space Grade Microelectronic products, for other products and applications BI time may vary) and Final Electricals to include limits and delta limits; Passive Devices-Key Electrical Parameters Test over temp., Burn-in (BI time to be specified by Components Engineer for Space Grade Microelectronic products, for other products and applications BI time may vary), Final Electrical including limits and delta limits •Temp Cycling •Optional:/Misc. (RAMAN, FDIR, DSC, TMA, etc.)
HIGH	•Key (AC, Switching, functional) At Ambient Temp •Electrical Test: Active Devices DC, key AC/Switching parameters, and full Functional Test over temperature; Passive Devices-Key Electrical Parameters Test over temperature.
MODERATE	•Basic functional at Ambient Temp •Electrical Test: Active Devices- DC, key AC/Switching parameters and key Functional, at ambient temperature; Passive Devices-Key Electrical Parameters Test at ambient temperature.
LOW	•Delid Physical Analysis •Radiographic Inspection/X-RAY •Acoustic Microscopy (AM) •Seal (hermetic devices) •Electrical Test ; Active Devices- DC Test at ambient temperature; Passive Devices-Value measurement at ambient temp.
VERY LOW	•External Visual Inspection, $EVI_{G,}$ General Inspection •Remarking & Resurfacing •XRF, Lead Finish •External visual Inspection, EVID Detailed Inspection •Electrical Test: Active Devices-Curve Trace at ambient temperature; Passive Devices-Value measurement at ambient temp

CCAP-101

- Integrated Circuits
  - Digital logic:
    - DC parameters, 25^0C and min/max temperature
    - Other tests useful to verify authenticity
  - Linear, Op Amps & Mixed logic
    - Full power & voltage conditions
    - DC parameters, 25^0C and min/max temp
    - AC parameters 25^0C
  - Microprocessors, DSPs, Microcomputers & similar
    - Key DC parameters at 25^0C and min/max temperatures
  - Memories, RAM, SRAM, FPGA, etc.
    - Input and output pins, open and short
    - DC parameters at min/max temperature
    - FPGAs are unprogramed
    - Write and read to memory and speed, for RAM and FPGA
    - Other applicable tests
  - Other Type Devices
    - Similar parameter verification based upon datasheet

Drawbacks

- Drawbacks
  - All these **standards**
    - Deal only two types of counterfeit parts (recycling and remarking)
    - Works on the sampling basis.
  - **Test time** is extremely high (several Hrs/parts).
  - The **test methods**
    - can detect only physical defects.
  - **Electrical test methods**
    - are too simple to address the detection of counterfeit integrated circuits (ICs).

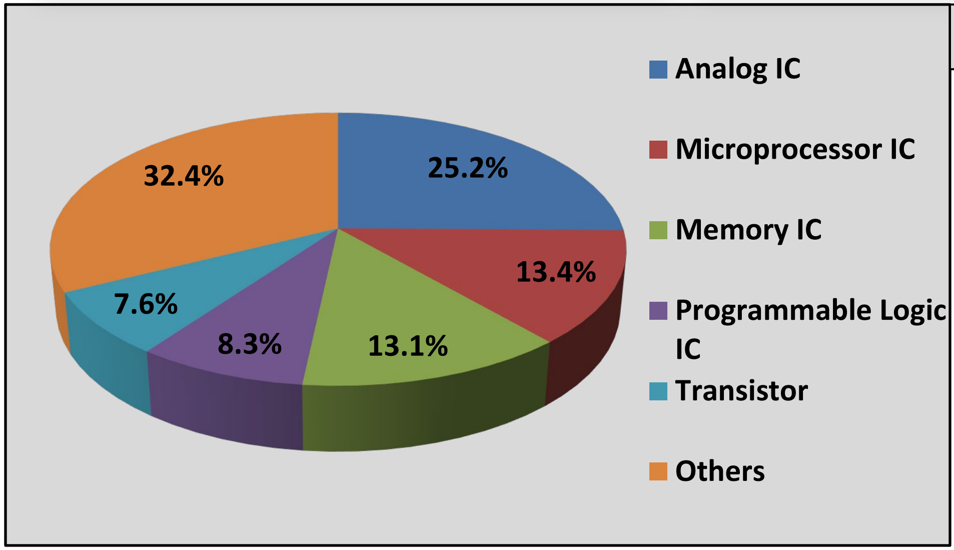
Components

Types of Components

Digital
Memory, Programmable Logic Devices, Microprocessor, ASIC, etc.

Analog
Amplifiers, Filters, ADCs, DACs, Mixers, Phase Shifters, etc.

Discrete
Resistors, Diodes capacitors, inductors, Transistors, sensors, etc.



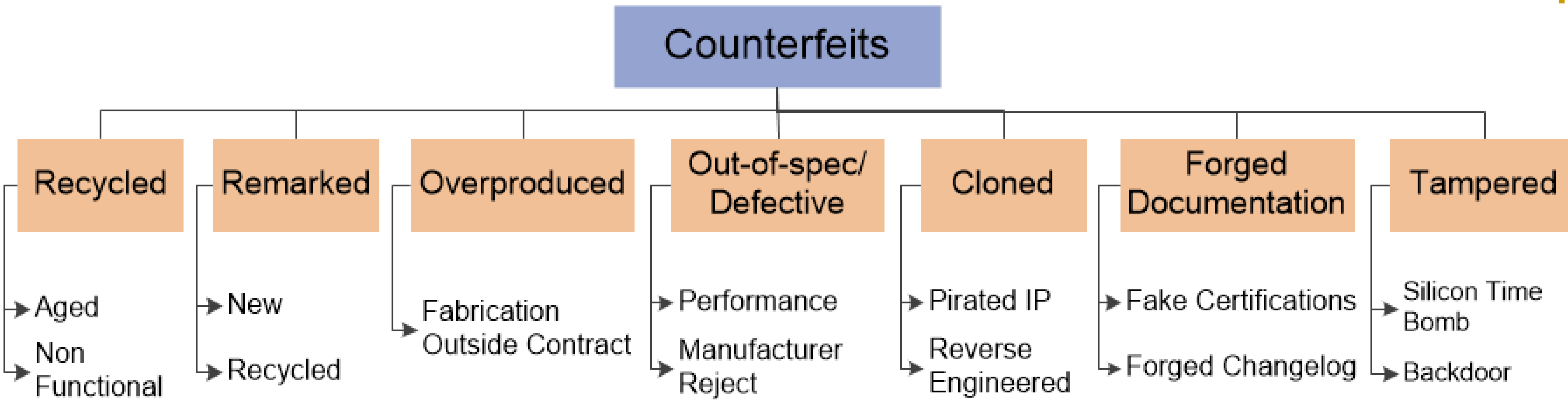
IHS reports a $169B annual risk

Where Used →

Top Part Type Reported in Counterfeit Incidents	*Industrial Market*	*Automotive Market*	*Consumer Market*	*Wireless Market*	*Wired Market*	*Compute Market*	*Other*
Analog IC	*14%*	*17%*	*21%*	*29%*	*6%*	*14%*	*0%*
Microprocessor IC	*4%*	*1%*	*4%*	*2%*	*3%*	*85%*	*0%*
Memory IC	*3%*	*2%*	*13%*	*26%*	*2%*	*53%*	*1%*
Programmable Logic IC	*30%*	*3%*	*14%*	*18%*	*25%*	*11%*	*0%*
Transistor	*22%*	*12%*	*25%*	*8%*	*10%*	*22%*	*0%*

The top five represent $169 billion of semiconductor revenue in 2011, according to IHS iSuppli Application Market Forecast Tool (AMFT)

Counterfeit Types



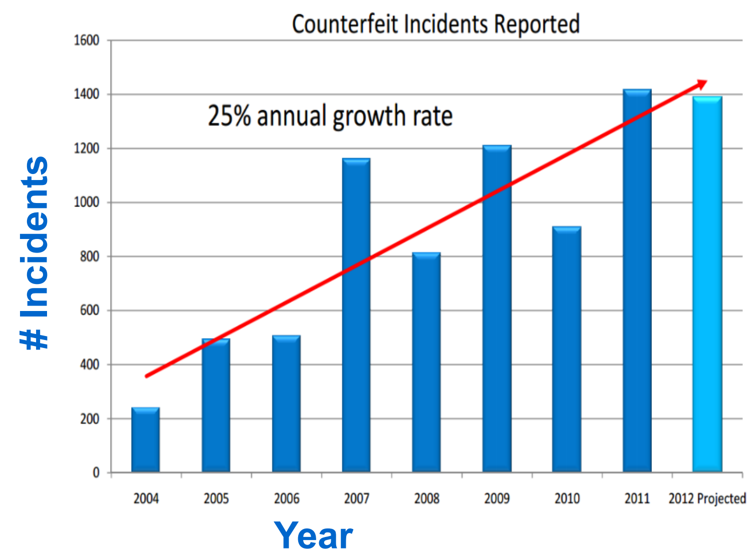
- **Recycled** and **remarked** types contribute to majority of counterfeit incidents.
- Untrusted foundry/assembly can introduce **overproduced** and **out-of-spec/defective** parts
- **Cloning** can be done by a wide variety of adversaries (a small entity to a large corporation)
- **Tampered** parts act as a backdoor where secret information from the chip or sabotage system functionality

Recycled Parts

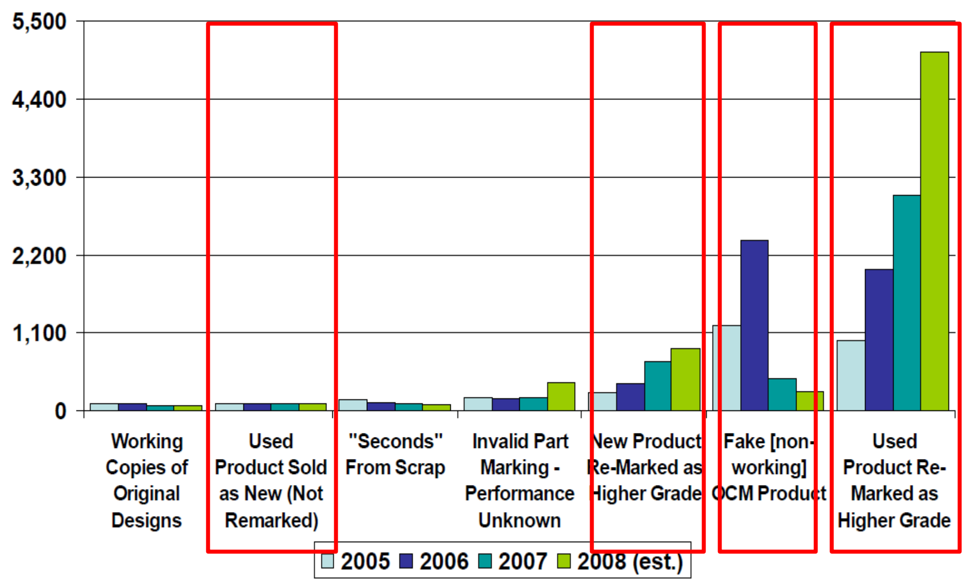
- More than **80% of the counterfeit** components are recycled [5]
- In 2005, the United States only properly recycled 10-18% of all electronic waste. That number has risen to 25% as of 2009.
- Most of the recycled parts are at the end of life
  - Damaged considerably due to usage and aging
- **Recycled Parts**
  - A genuine OCM part is manufactured and used in some equipment, device, or electronic gadget for a period of time
  - The user discards the device for any number of reasons
  - Scrap electronics are collected and sold to developing countries or other reclaiming facilities
  - Scrap devices are broken down into bare circuit boards and components
  - Components are crudely extracted from circuit boards under very high temperature and prepared for resale

Recycled and Remarked ICs

- Recycling and remarking of ICs have become major security and reliability problems
- IC Recycling: $9-$15 billions every year



IHS: All counterfeit Incidents since 2004



Counterfeit type incidents in 2005-2008 reported by US Dept of Commerce Bureau of Industry and Security Office

Remarking

- Recycling and Remarking are the most discussed counterfeit parts
- **Remarking parts are of two types**
  - Recycled components
  - New Components
    - To change the specification of the component (commercial grade → military grade)
- **Remarking Process**
  - packages are sanded or grounded down to remove old markings
  - a new coating is created and applied to the parts
    - thermal or UV-cured epoxy

Remarking- Example

Overproduction

- The complexity of the integrated circuits (ICs) goes up exponentially as the feature size scaled down.
- Building and maintaining a modern fabrication unit costs more than $3B and increasing day by day.
- Semiconductor business model shifted to contract foundry business model (horizontal business model.
- Example:
  - TI and AMD have outsourced their sub-45 nm fabrication to major contact foundries worldwide

Out-of-spec/ Defective

- Untrusted Foundry can sell
  - **Defective parts**
    - A chip may fail at one particular structural test pattern (The number of test patterns may vary in between several thousands)
    - It is highly unlikely that defect will appear in normal operation of the chip in first few hours or days or months.
    - Eventually, it will fail at some point of time.
  - **Out-of-spec parts**
    - Fail to perform at the design specification (leakage current, dynamic current, performance, etc.)
    - The chip might fail at extreme physical/environmental conditions.

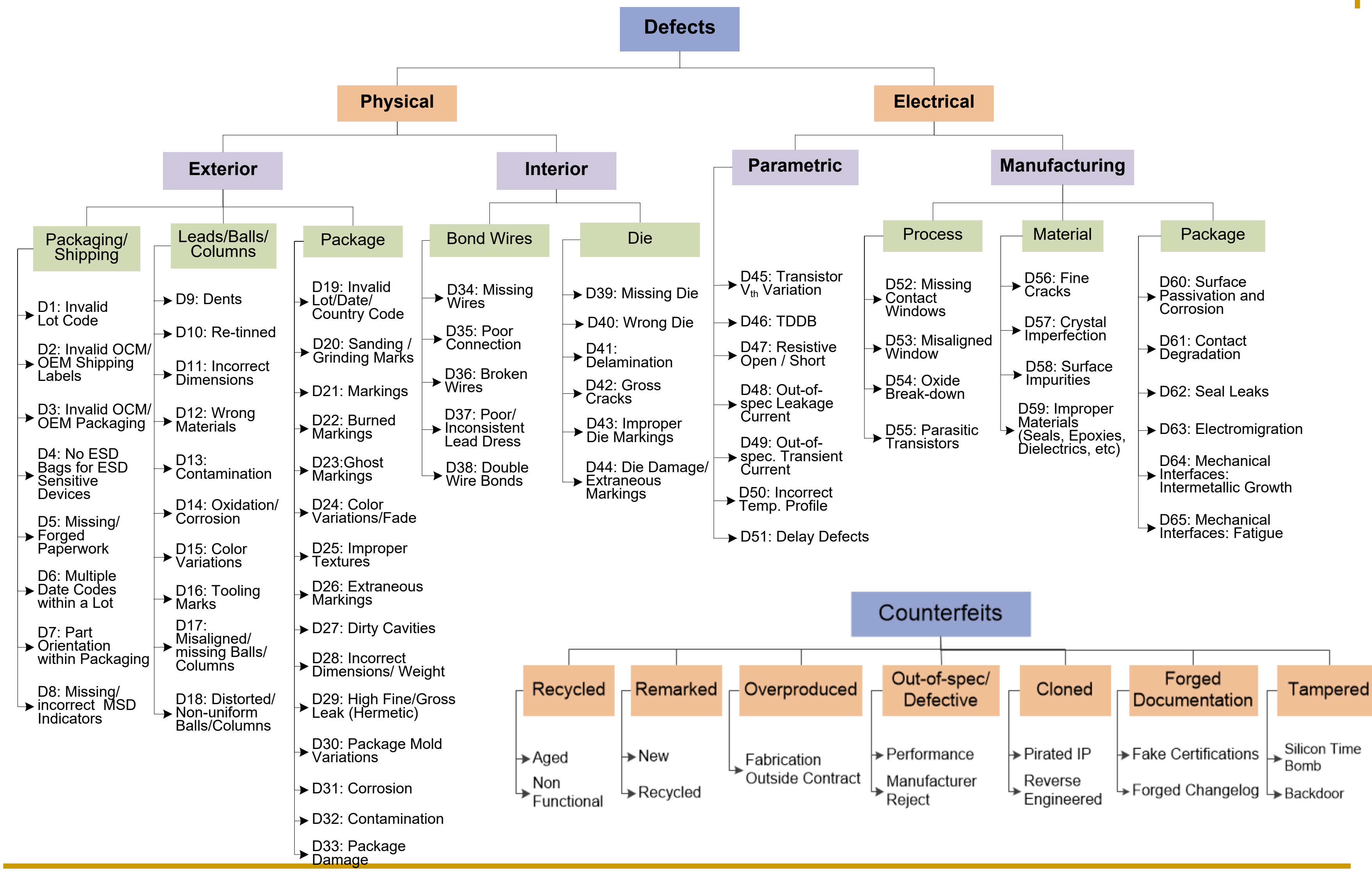
Cloned

- **Unauthorized production of a part**
  - Difference between overproduction and cloned is that cloned parts do not have the authorized IP, could be fabricated in a different foundry
- **Cloned parts**
  - Pirated IP
    - Counterfeiters acquire the IP in an illegal manner (Saved the design cost of the IP).
  - Reversed Engineered
    - Counterfeiters reverse engineer the design and make a new one just like the original design.

Forged Documentation

- The mismatch of specification documents between the purchased parts with the OCM (Original component manufacturer).
- Easy to detect as usually the original documents are present somewhere...
- Old parts (parts in the supply chain for around several years) have the higher probability of getting counterfeited.

Counterfeit Defect Taxonomy



External Visual Inspection (EVI)

EVI:

- All devices shall be optically examined at a suitable magnification (3X to 100X) and with suitable lighting.
- A portion of inspection (sampling) shall be performed at 40X or higher.
- IDEA specification IDEA-STD-1010-A is a good reference.

Burned markings from low quality laser

Detailed EVI Inspection:

- A sample size of 119 devices shall be selected to undergo the detained EVI Inspection. Normally 116/c samples would be inspected to give a 90% confidence that the failures is at most 2%. The additional 3 samples are to be later used for marking permanency, lead finish (XRF), and Delid Physical Analysis (dpa).

Verification of:

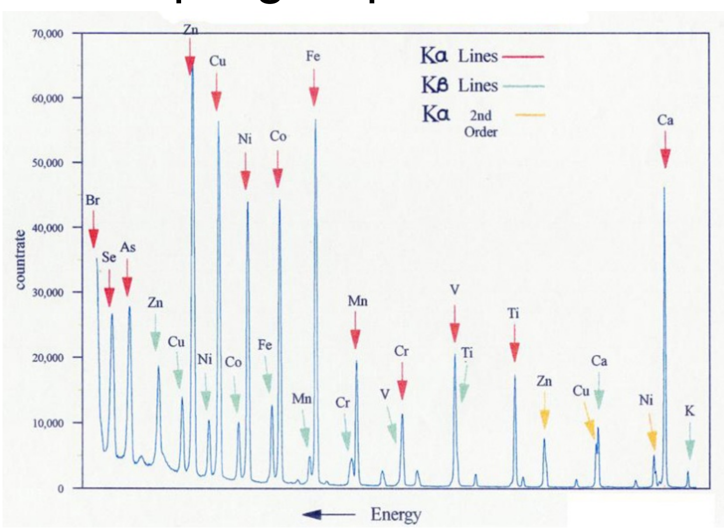
- Date and Lot Codes
- Low Power Microscopy
- High Power Microscopy
- OCM Shipping labels
- Lead quality
- Dimensions & Weight
- Marking Quality

EVI Cont.

- Test for Remarking and Resurfacing.
  - The first set of tests focus on the part marking and is a resistance to solvents test
    - The markings should not smear or be removed by the solution.
- Test for Resurfacing
  - This test uses the same 3 devices, and consists of three separate chemical tests.
    1. Acetone Test,
    2. 1-Methyl 2-Pyrrolidinone Test, and
    3. Dynasolve 750 Test
  - The inspection process is to look for indicators of package resurfacing and recoating.
  - The 3 devices that pass this inspection are then to undergo the Delid Physical Analysis Inspection.

X-Ray Fluorescence

- X-ray Fluorescence (XRF) Spectroscopy
  - Tool for material composition detection
  - Can be a handheld instrument or a full lab system
  - Can be on external surfaces or de-lidded/de-capsulated
  - Non destructive
    - Destructive for internal material composition (e.g., wire bond, passivation, and metallization)
  - Sampling required.



XRF-Cont.

- **Lead finish examination**
  - Shall be performed on the 3 sample devices
  - Examined for Remarking and Resurfacing, to verify that the Lead Finish / Solder Ball & Column composition matches the device specifications or datasheet
- **Plating material(s) identification**
  - verify the plating layer thicknesses, presence of barrier materials, and possibly the base material

Delid/Decapsulation Physical Analysis

- **The inspection**
  - Component's internal structure
  - The top surface of a microelectronic die
  - Metallization traces of a thin-film resistor
- **Apparatus & Equipment**
  - Chemical Decapsulation Process
    - Use of hazardous chemicals (Nitric acid and sulfuric acid)
  - Mechanical Disassembly Tools
    - This includes cross-section tables and associates epoxy mounting material and other supplies, fine-tipped picks, x-acto blades, bladed saws, diamond wire saws, etc.
  - Radiographic Tool
    - X-ray images
  - Metallurgical Microscopes and Photodocumentation Equipment
  - Scanning Electron Microscope (SEM), Energy Dispersive X-ray (EDX) tool

Description of the Procedure –Microcircuits, Hybrids, Diodes, and Transistors

- **External Optical Examination**
- **X-ray**
  - Images (top and side surface of the devices)
  - Information to be obtained for decapsulation (x-ray images to be 1:1 ratio – the die location within the case)
- **Decapsulation of Plastic Parts and Delidding of Cavity Devices**
  - Plastic Parts
    - Nitric acid and sulfuric acid
  - Manual delidding of ceramic devices
    - Two types of ceramic devices
      - two ceramic plates sandwiched around a glass seal (“cerdip” tool).
      - hermetically sealed metal cover that is soldered in place over the die area (x-acto knife)
  - Care to be taken to expose the die without damaging the other internal structures (bond pads, bond wires, lead frame, die attach material, substrate, etc.)

Description of the Procedure –Microcircuits, Hybrids, Diodes, and Transistors-Cont

- **Inspection and photodocumentation**
  - Overall photo of the decapsulated device shall be obtained. Also obtain a higher magnification photo showing only the die (up to a minimum of 500x). Inspect the die for the information listed below.
    - Manufacturer markings
    - Name and Logo
    - Unique Die part numbers
    - Die mask ID numbers
    - Year of design
    - Bond types
    - Any other markings or features that may help in identifying the origins of the die.

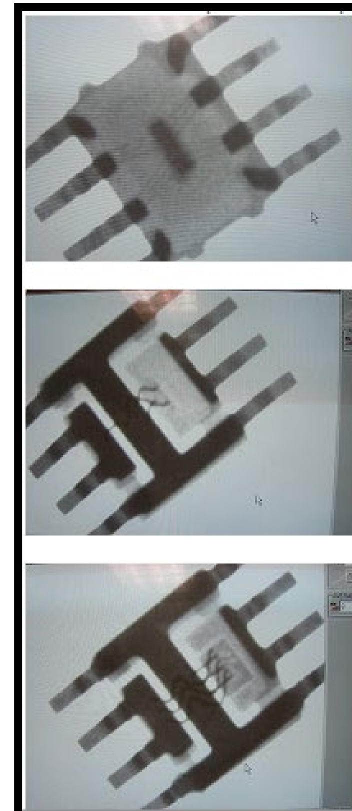
Risk Level Inspection Test

	Critical Risk	High Risk	Moderate Risk	Low Risk
	4	3	2	1
Optically Inspect/Photo document	X	X	X	X
Wire Pull	X	X	X	(optional)
Die Shear (hermetic)	X	X	(optional)	(optional)
Ball Shear	X	X	(optional)	(optional)
SEM Inspection	X	(optional)	(optional)	(optional)
Perform EDX	X	(optional)	(optional)	(optional)
Delayer/Inspect Metalization	X	(optional)	(optional)	(optional)
Glassivation Layer Integrity Testing	X	(optional)	(optional)	(optional)

X-Ray Inspection

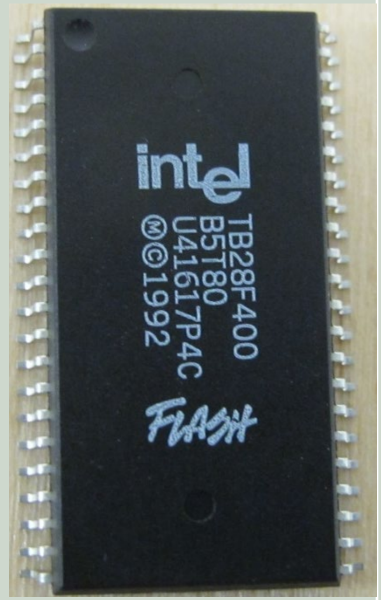
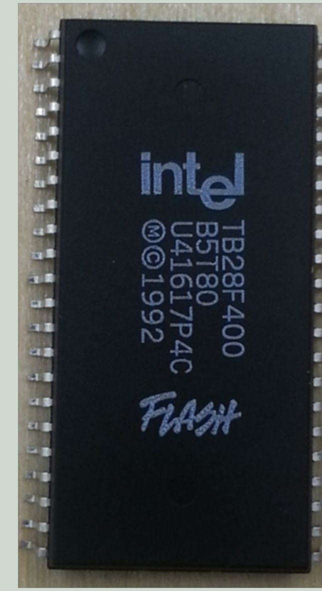
Determines:

- If the package contains a die
- Consistent size/shape of the die
- Consistent internal construction
- If the die has all wire bonds attached
- Exact die and bond wire location
  - To avoid damage during decapsulation



"The value of X-ray is increased when there is a known good OCM device available for comparison of internal details" –*CCAP-101 Certified Document Rev D*

Low Power Visual Inspection

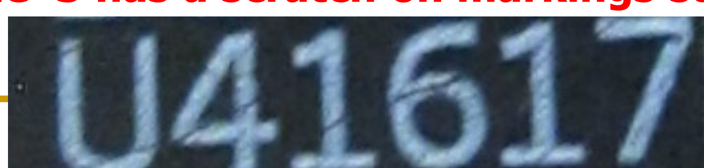
Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
				

Observations:

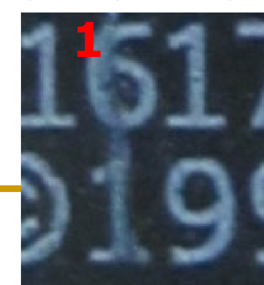
All Samples look the same at Camera level

Except for :

Sample 3 has a scratch on markings starting with U

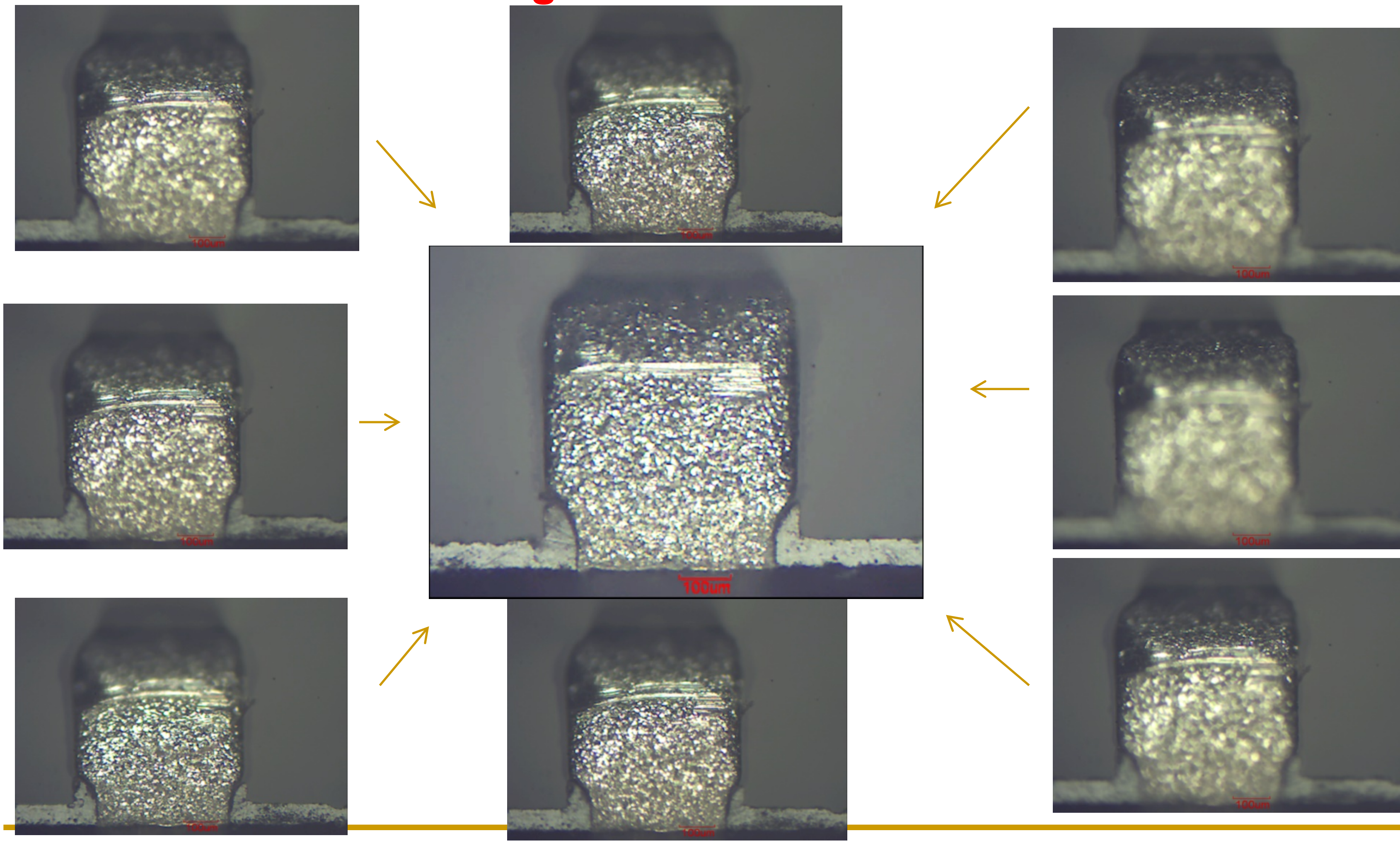


Sample 2 scratch on marking over numbers 6 and 1



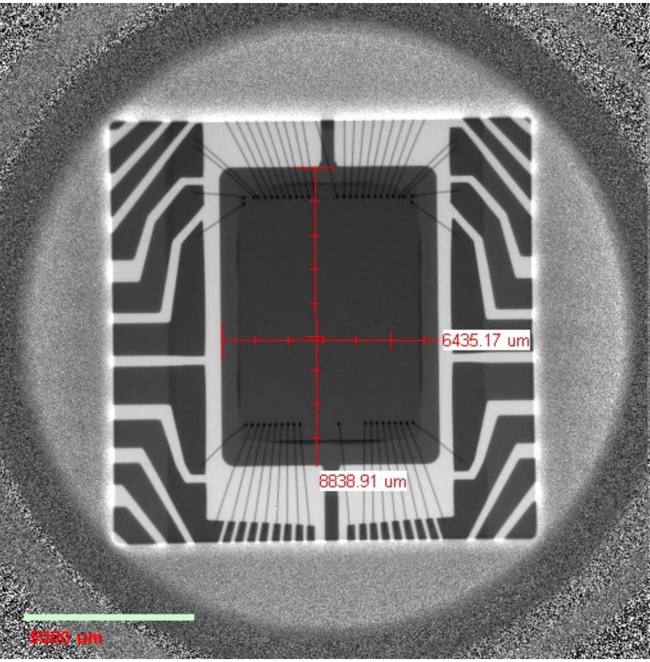
Optical Microscope + Z stack Improved Depth of field

All optical microscope image shown is the reconstruction of at least 8 images at different focus

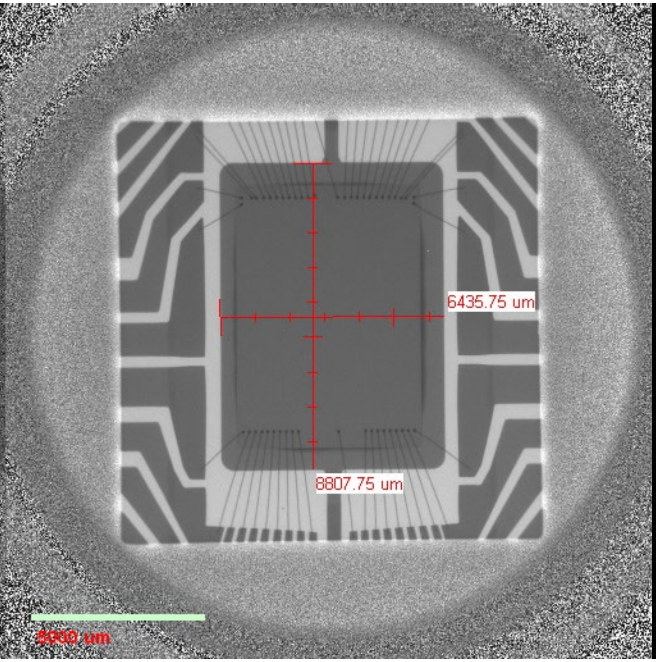


2D X-ray Radiography

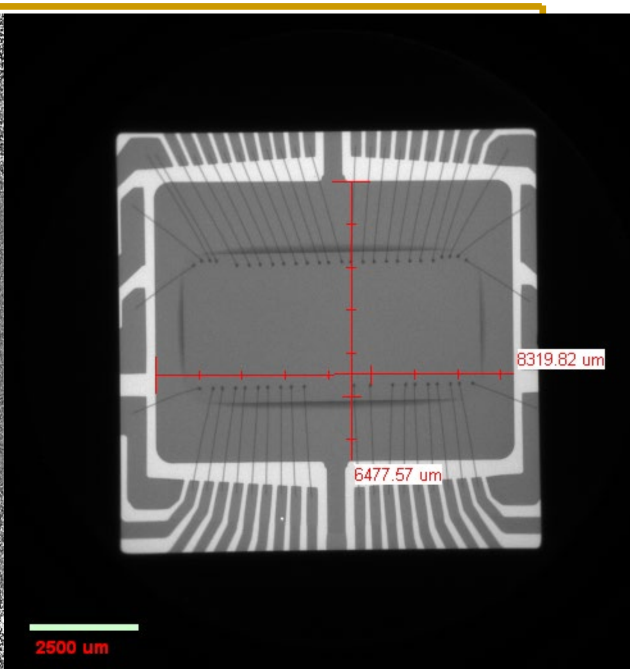
Sample 1



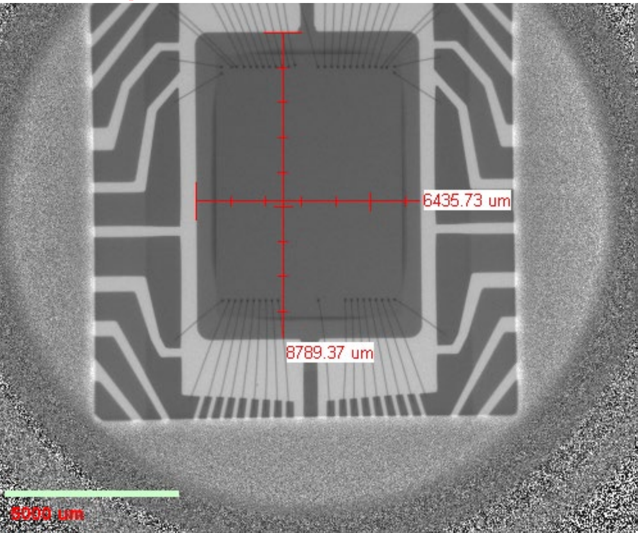
Sample 2



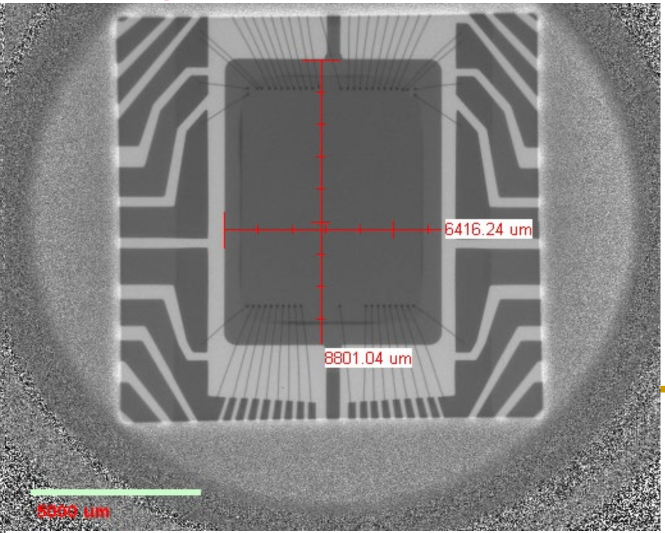
Sample 3



Sample 4



Sample 5



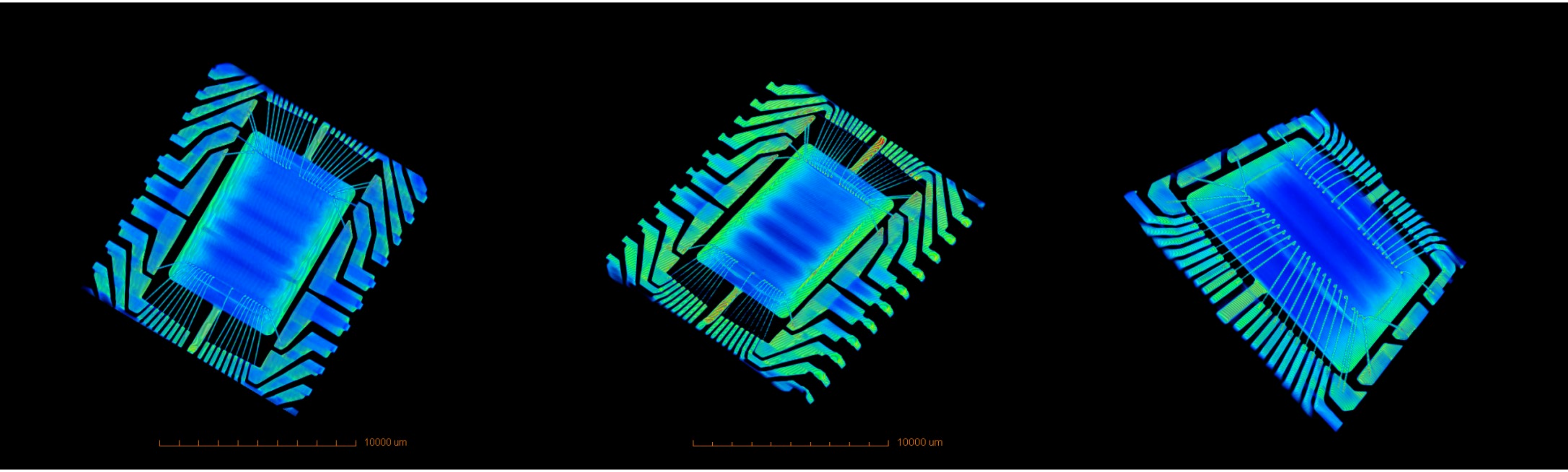
Observation:

Sample 3 has a different Die and bond wires

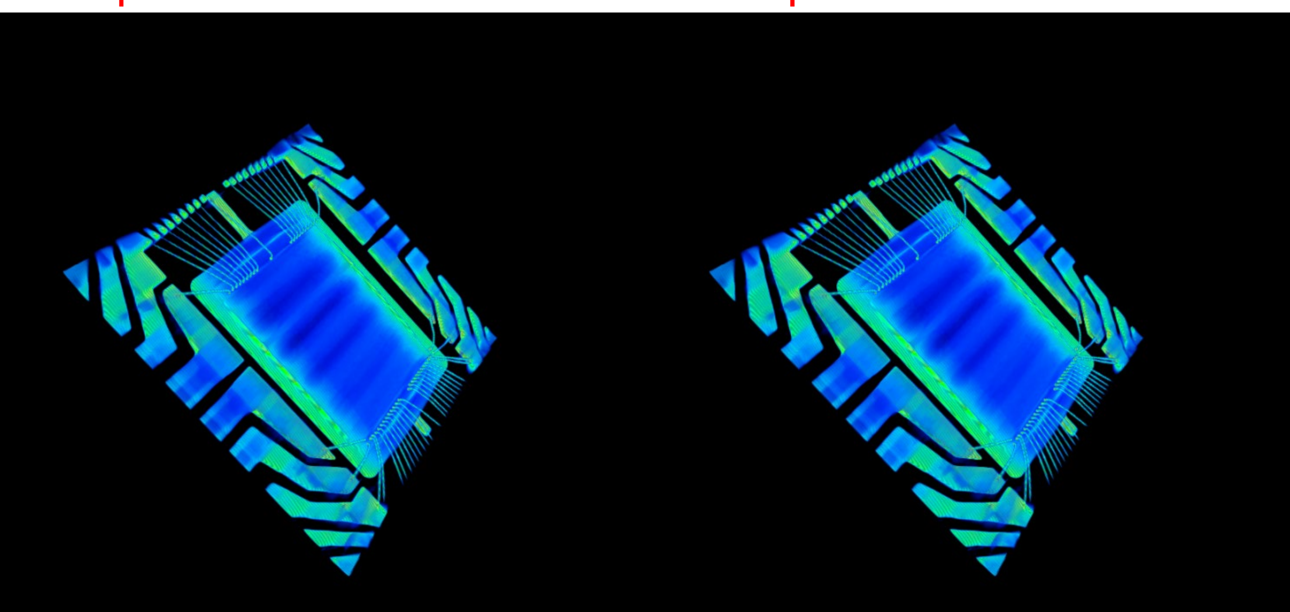
Samples 1,2,4,5 look very similar

3D X-ray Tomography

Sample 1 Sample 2 Sample 3



Sample 4 Sample 5



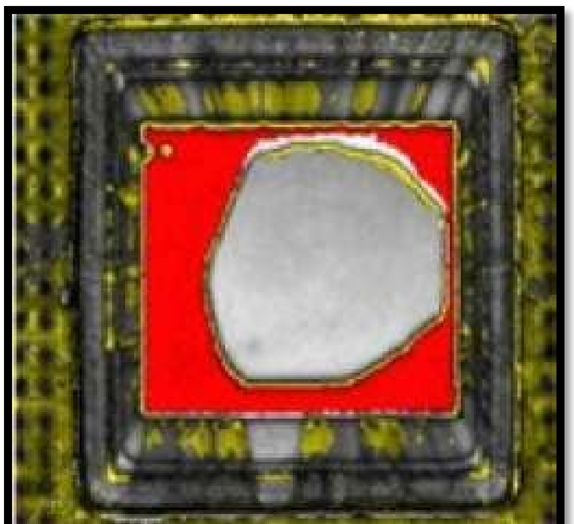
Observation:

All connections are Checked and look fine on all samples

Sample 3 lacks One connection which is believed to be the ground wire. (possible grade issue)

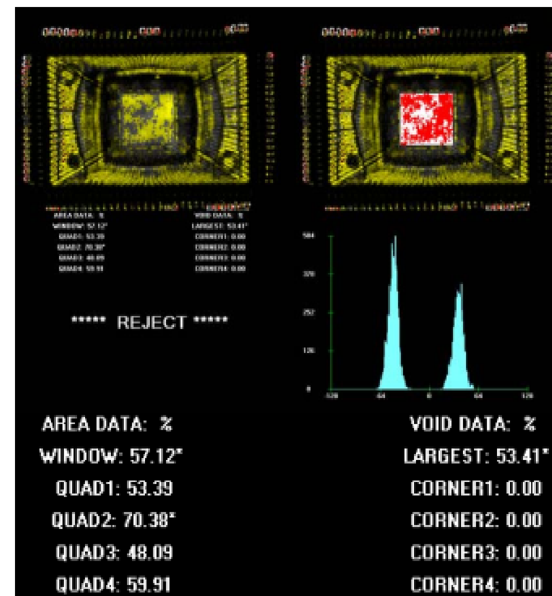
Scanning Acoustic Microscopy

- Acoustic is non-invasive
  - Reveal cracks, voids, and delamination
  - Non destructive die inspection
  - Uses de-ionized water or IPA as medium



MuAnalysis look deeper

Red areas indicate delamination

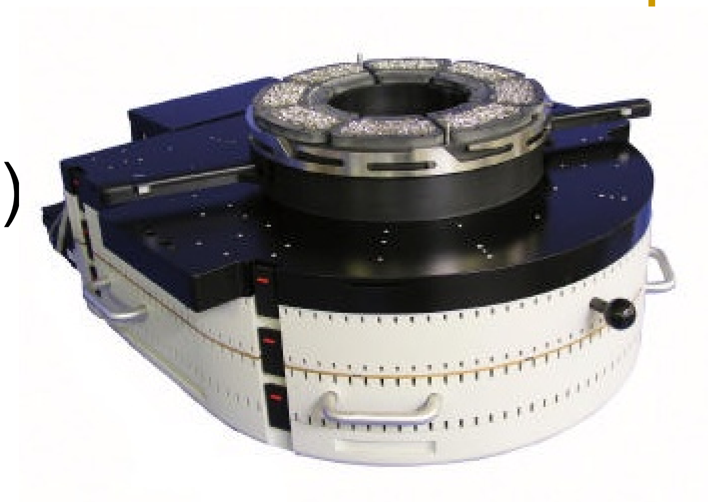


Electrical Tests

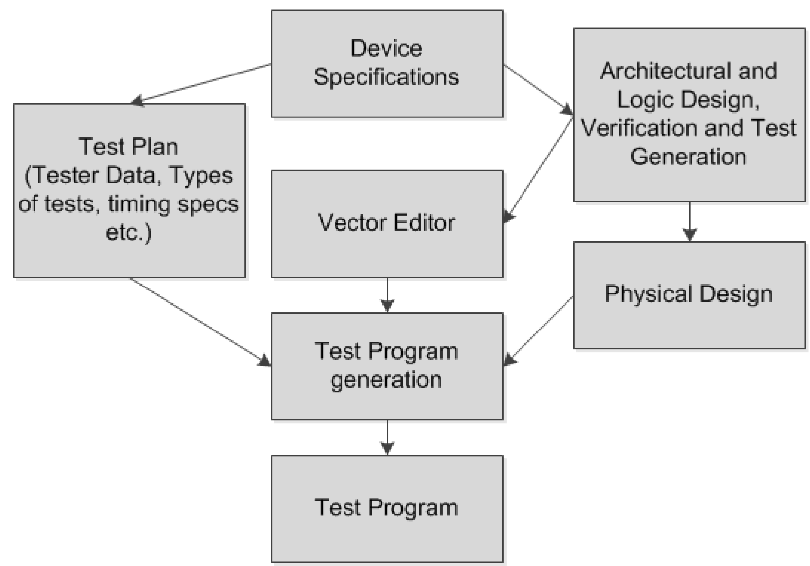
- Mainly focus on large scale integrated circuits
  - Microprocessor, Memory, and Programmable Logic chips account for almost 35% of counterfeits
- As these are high cost parts, counterfeiter will probably put much effort to counterfeit and physical detection will be extremely difficult (merely impossible)
- No definite test methodology either electrical or physical (without destroying the chip) to detect counterfeit with 100% confidence level.

Electrical Tests

- Tester
  - ATE (Automated Test Equipment)
    - Specification:
      - Speed (clock rate of the device)
      - Timing (strobe) accuracy
      - Number of input/output pins, etc.



- Test Programming
- Limitation
  - HDL description of test module must be available to test ICs
  - No definite methodology to detect counterfeit ICs



Recycled Parts: Aging

- Recycled parts are around 80% of total counterfeit parts.
- Most of the defects in recycled parts are due to aging.
- Aging
  - Negative bias temperature instability (NBTI)
    - NBTI occurs in p-channel MOS devices stressed with negative gate voltages and elevated temperature due to the generation of interface traps at the Si-SiO_2 interface
  - Hot carrier injection (HCI)
    - HCI occurs in NMOS devices caused by the trapped interface charge at Si=SiO2 surface near the drain end during switching
  - Time-dependent dielectric breakdown (TDDB)
    - The carrier injection with high electric field leads to a gradual degradation of the oxide properties which eventually results in sudden destruction of the dielectric layer
  - Electromigration
    - Mass transport of metal film conductors stressed at high current densities

Parametric Test

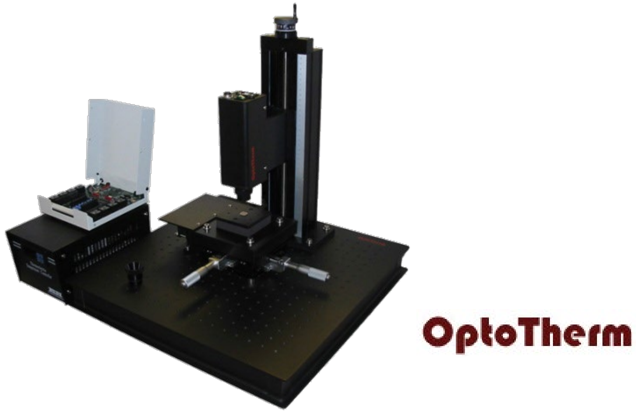
- **DC Parametric Test**
  - Contact Test
  - Power Consumption Test
  - Leakage Test
  - Output Short Current Test
  - Output Drive Current Test
  - Threshold Test
- **AC Parametric Test**
  - Propagation delay test
  - Setup/hold time test
  - Access time test
  - Rise and fall time test

Functional Tests

- **Functional testing**
  - The most efficient way of verifying the functionality of a component.
  - Function Verification of a Component
    - Determines whether individual components, possibly designed with different technologies, function as a system and produce the expected response.
  - Memory Tests
    - Read/write operations are performed on a memory to verify its functionality. MARCH tests can be applied for counterfeit detection.
  - Microprocessor Tests
    - Microprocessors are binned in different groups depending on the maximum functional frequency (f_{max}).

Temperature Cycling/ Burn-In

- Testing the chip at extremes of operating range
- Tester Ranges:
  - Military Grade: -65°C to 175°C
  - Industrial Grade: -25°C to 85°C
  - Commercial Grade: -10°C to 70°C



- Burn-in
  - The device is operated at an elevated temperature (Stressed condition)
  - To find infant mortality failures and unexpected failures to assure reliability.
  - Test methods
    - MILSTD-883 for integrated circuits and
    - MIL-STD-750 for other discrete components.
  - Very useful as it can easily weed out the commercial grade components marked as military grade.
  - Can remove defective components or those components that were not designed to perform over the stressful conditions.

Structural Tests

- **At-speed tests**
  - To detect gross and spot delay defects
  - Transition delay fault test / Path delay fault test
- **Stuck-at tests**
  - To detect spot delay defects
- **Bridging tests**
  - To detect physical bridging defects