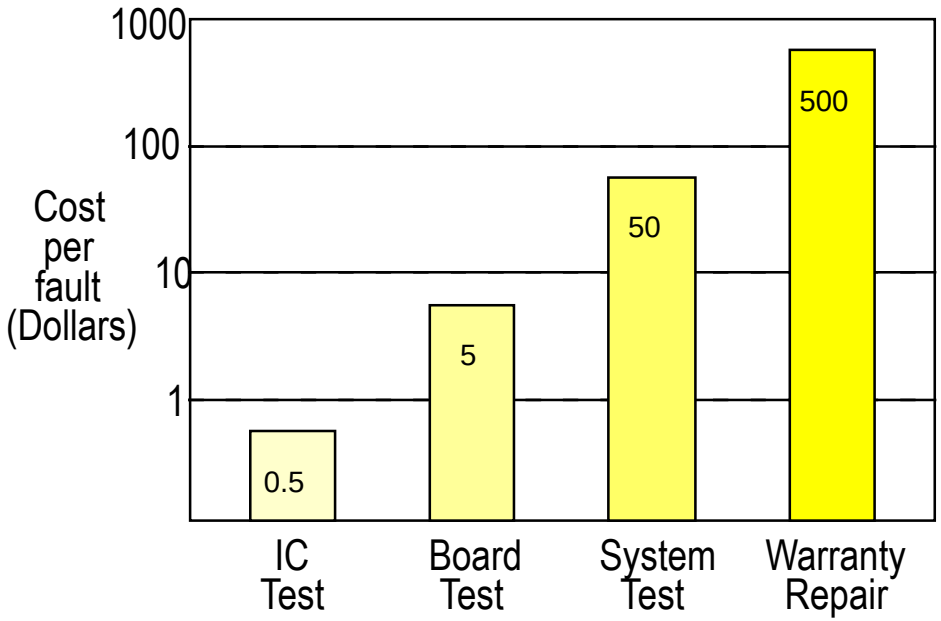
Introduction

- What Is Testing
- Types of Testing
- Test Quality
- **Test Economics**
  - **Why and Who Invests in Test?**
    - **Global Semiconductor Industry**
  - **How to Make Optimal Test Decision?**
- **Important Research Topics**
- **Conclusion**

Why Invest in Testing?

- **Although testing is expensive**
  - **Repair cost is even more expensive!**
- **Rule of Tens [Davis 82]**



A Stitch in Time Saves Nine

15% Semiconductor Market Goes to Test

- 2019 global semiconductor market $412.3B USD WSTS)
  - Packing and test about 15%
- 2019 Taiwan $86.3B USD, ~21% of global market
  - Fabless design $22.4B USD
  - Manufacture $42.5B USD
  - Packaging $11.2B USD
  - Testing $5.0B USD

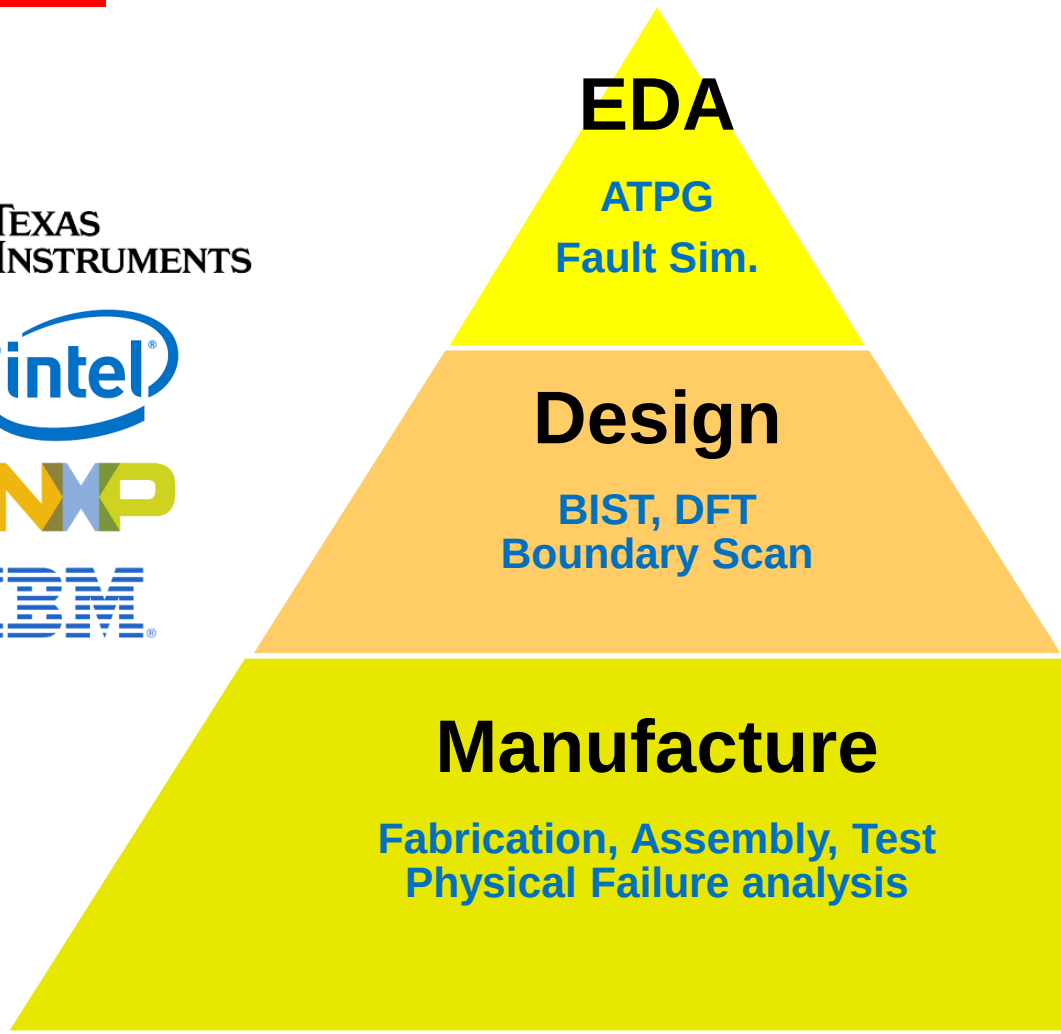
Source TSIA
單位：億新台幣

億新台幣	2016	2016 成長率	2017	2017 成長率	2018	2018 成長率	2019	2019 成長率	2020 (e)	2020 (e) 成長率
IC 產業產值	24,493	8.2%	24,623	0.5%	26,199	6.4%	26,656	1.7%	27,742	4.1%
IC 設計業	6,531	10.2%	6,171	-5.5%	6,413	3.9%	6,928	8.0%	7,227	4.3%
IC 製造業	13,324	8.3%	13,682	2.7%	14,856	8.6%	14,721	-0.9%	15,285	3.8%
晶圓代工	11,487	13.8%	12,061	13.8%	12,851	6.6%	13,125	2.1%	13,649	4.0%
記憶體與其他製造	1,837	-16.8%	1,621	-11.8%	2,005	23.7%	1,596	-20.4%	1,636	2.5%
IC 封裝業	3,238	4.5%	3,330	2.8%	3,445	3.5%	3,463	0.5%	3,615	4.4%
IC 測試業	1,400	6.5%	1,440	2.9%	1,485	3.1%	1,544	4.0%	1,615	4.6%
IC 產品產值	8,368	2.9%	7,792	-6.9%	8,418	8.0%	8,524	1.3%	8,863	4.0%
全球半導體市場(億美元)及成長率(%)	3,389	1.1%	4,122	21.6%	4,688	13.7%	4,121	-12.1%	4,330	5.1%

Many Companies Invest Heavily in Test

IDM

Fabless/Foundry



Texas Instruments

intel

NXP

IBM

SYNOPSYS

cadence

Mentor Graphics

MEDIATEK

REALTEK

NVIDIA

tsmc

ASE GROUP

World's Top EDA Companies

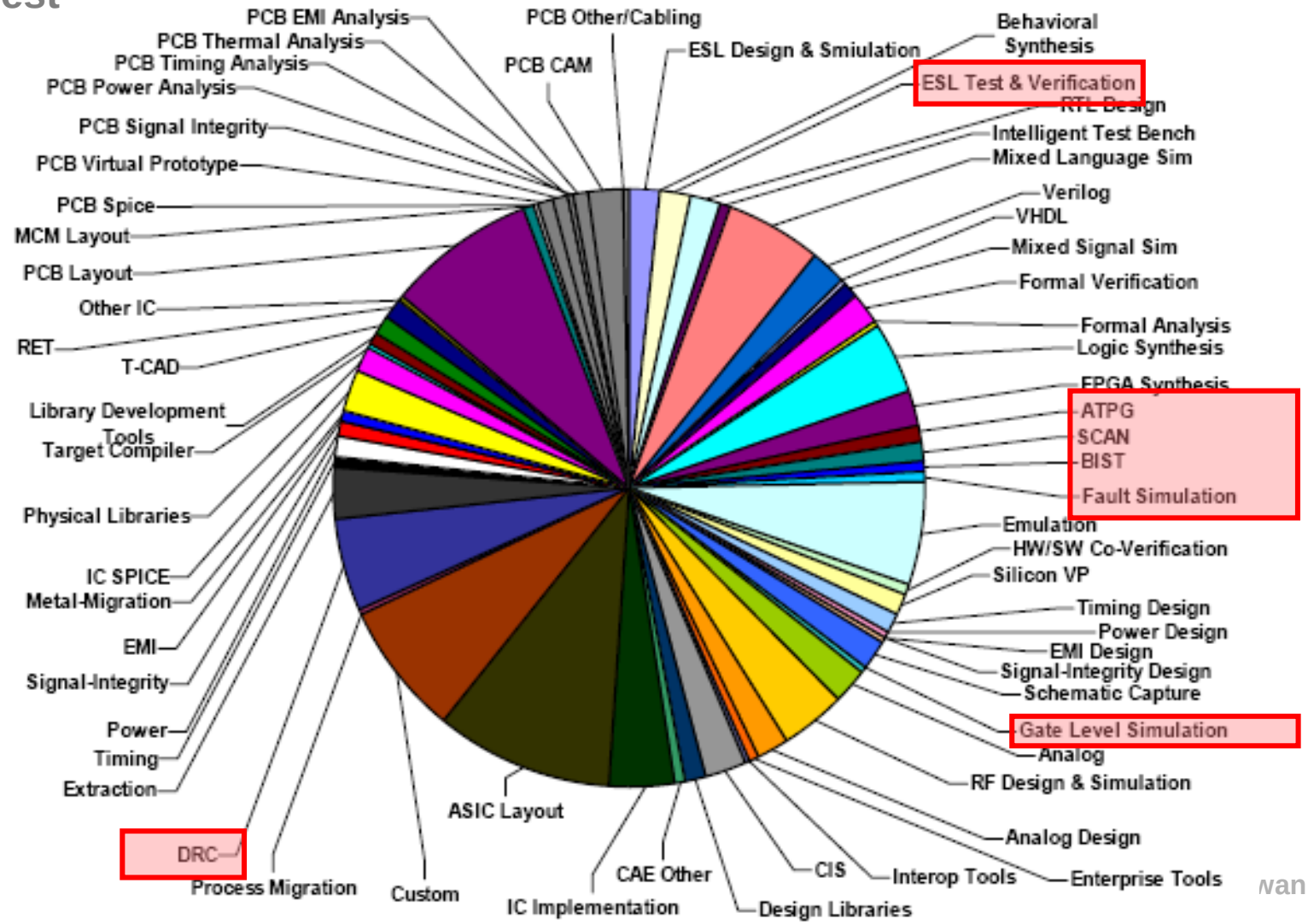
- **2019 global EDA market is about $10B USD**
  - **Growing ~10% each year**

Company	Rank	Revenue	Country
Synopsys	1	$3.36 B	USA
Cadence	2	$2.33 B	USA
Mentor Graphics (now Siemens EDA)	3	$1.28 B (*2017)	Europe

EDA Market by Tool

- **Test-related tools are about 5~10% EDA revenue**

dataquest
2012



World's Top OSAT Companies

- *OSAT* = outsourced semiconductor assembly and test
- About 1/2 IC tested by Taiwan

Analysis, 2020

Company	Rank	Market	Country
日月光 ASE	1	21.8%	Taiwan
艾克爾 Amkor	2	18.5%	USA
矽品 SPIL	3	14.4%	Taiwan
長電科技JCET	4	13.4%	China
力成 PTI	5	10.3%	Taiwan

Test Important for IC Industry

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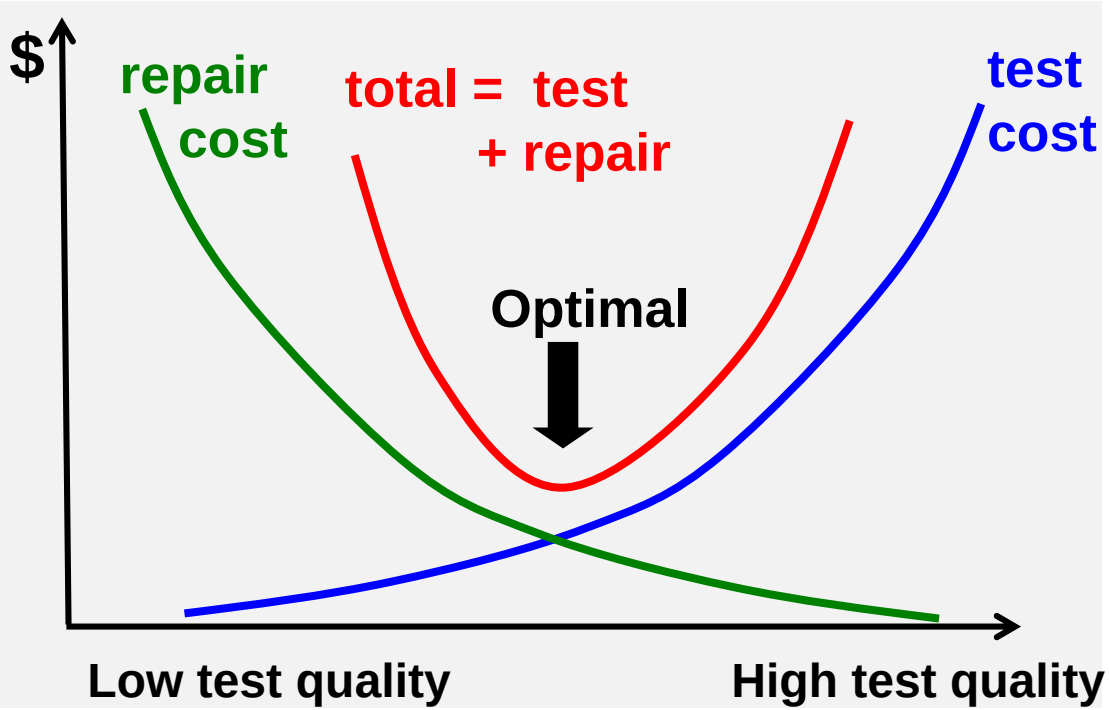
How to Make Optimal Decision?

- Optimal test not only technical issue, but also economics issue
  - Trade off between test cost and repair cost
- Different product has different optimal decision
  - No single best decision for all products!



What Cost Can We Optimize?

- **EDA: ATPG, fault simulator …**
  - **Typically 10K ~ 100K USD**
- **Design: insert DFT/BIST circuitry**
  - **Area/power/delay overhead about 5~10%**
- **OSAT:**
  - **Equipment**
    - **Tester (Automatic Testing Equipment, ATE)**
      - **Typically 0.5~3 M USD**
    - **Handler, probe station, Burn-in oven**
  - **Test application time (TAT)**
    - **Around $50 to $300 USD per hour**
    - **ASIC takes 2~3 seconds. CPU can be 0.5~1 minute**
  - **load board, probe card**
    - **$1K ~ 20K USD**

Many Decisions to Make

Case 1: DFT or Not?

Q1: Without DFT
Y=98%, FC=70%. DL=?

$$DL = 1 - Y^{(1-FC)}$$

A: 6,043 DPM

Q2: With DFT
Y=97%, FC=99%. DL=?

A: 304 DPM

Technically, DFT Improves DPM
Economically, Is DFT Worth Doing?

Case 1: DFT or Not? (Cont'd)

- Q: Is it economical to insert DFT?
- A: Yes. This is true for many products.
  - Although Y drops, DL improves significantly

$$DL = 1 - Y^{(1-FC)}$$

Item	w/o DFT	with DFT
Total # of Dies	1,000,000	900,000
Yield	98%	97%
FC fault coverage	70%	99%
DL =1-Y$^{(1-FC)}$	6,043 DPM	304 DPM
Sales=D x Y x $1	980,000	873,000
Repair cost=D x Y x DL x $100	592,163	26,587
Profit = S – R	387,837	846,413

DFT Is Worth Doing!

Case 2: Wafer Test or Not?

Item	bad yield = 64%		good yield = 81%	
	with WT	no WT	with WT	no WT
Total # of Dies	1,000,000	1,000,000	1,000,000	1,000,000
C_{WT}= D x \$0.02	20,000	0	20,000	0
Y_{WT}	80%	100%	90%	100%
C_{PK}= D x Y_{WT} x \$0.1	80,000	100,000	90,000	100,000
C_{FT}= D x Y_{WT} x \$0.06	48,000	60,000	54,000	60,000
Y_{FT}	80%	64%	90%	81%
Sales=D x Y_{WT} x Y_{FT} x \$1	640,000	640,000	810,000	810,000
Cost=C_{WT}+C_{PK}+C_{FT}	148,000	160,000	164,000	160,000
Profit=S - C	492,000	480,000	646,000	650,000

WT or not Depends on Yield

Case 3: To Burn or Not To Burn?

Q: Is it worth doing burn-in (BI)?
BI cost is $2 per die. BI improves quality by 1,000DPM.
Fabrication cost is 30% of price. Repair cost is 30 times price.

Item	ASIC, Price per die= $10		CPU, Price per die= $100	
	with BI	no BI	with BI	no BI
D_F=# of Dies fab	1,000,000	1,000,000	1,000,000	1,000,000
D_S=# of dies sold	999,000	1,000,000	999,000	1,000,000
D_B=# of bad dies sold	0	1,000	0	1,000
Sales = D_S x P	9,990,000	10,000,000	99,900,000	100,000,000
C_{FB}=D_F x P x 30%	3,000,000	3,000,000	30,000,000	30,000,000
C_{BI}=D_F x $2	2,000,000	0	2,000,000	0
C_{RP}=D_B x P x 30	0	300,000	0	3,000,000
Profit=S-C_{FB}-C_{BI}-C_{RP}	4,990,000	6,700,000	?	?

BI or not Depends on Price

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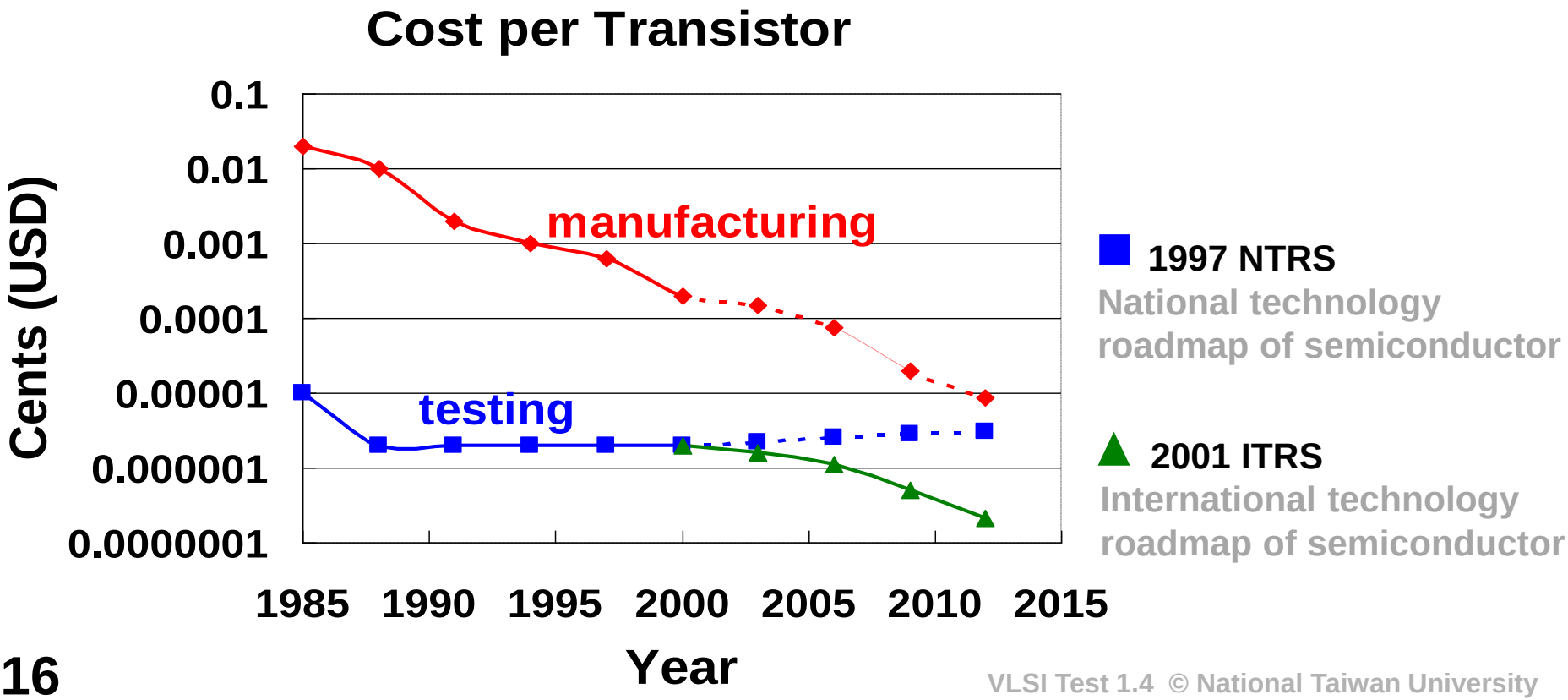
Test Needs Continuing Improvements

- NTRS 1997 predicted test cost will be greater than manufacturing cost
  - assume that historical trends continued
- ITRS 2001 revised the prediction
  - Significant research efforts applied to push test cost down



Important Research Topics

- **Reduce test cost**
  - **Reduce test equipment cost**
    - ***Built-in Self Test (BIST)***
  - **Reduce test data volume, test application time**
    - ***Test compression, ATPG, Memory tests***
- **Improve test quality**
  - **Better *fault models, delay tests***
  - ***Design for testability (DFT)***
- **Improve yield**
  - ***Diagnosis***
- **Better/faster EDA tools**
  - **ATPG, Fault simulator, optimization algorithms**

Major Conferences and Journals

- International Conferences
  - IEEE Int'l Test Conference (ITC)
  - IEEE/ACM Design Automation Conference (DAC)
  - IEEE VLSI Test Symposium (VTS)
  - IEEE Asian Test Symposium (ATS)
  - IEEE European Test Symposium (ETS)
  - IEEE Design and Test in Europe (DATE)
  - IEEE Int'l Conference on CAD (ICCAD)
- Journals
  - IEEE Trans. On Computer-Aided Design (TCAD)
  - IEEE Trans. On VLSI Systems (TVLSI)
  - IEEE Trans. On Computers (TC)
  - ACM Trans. On Design Auto. of Electronic Systems (TODAES)
  - Journal of Electronic Testing : Theory and Application (JETTA)
- IEEE Design & Test Magazine (D&T)

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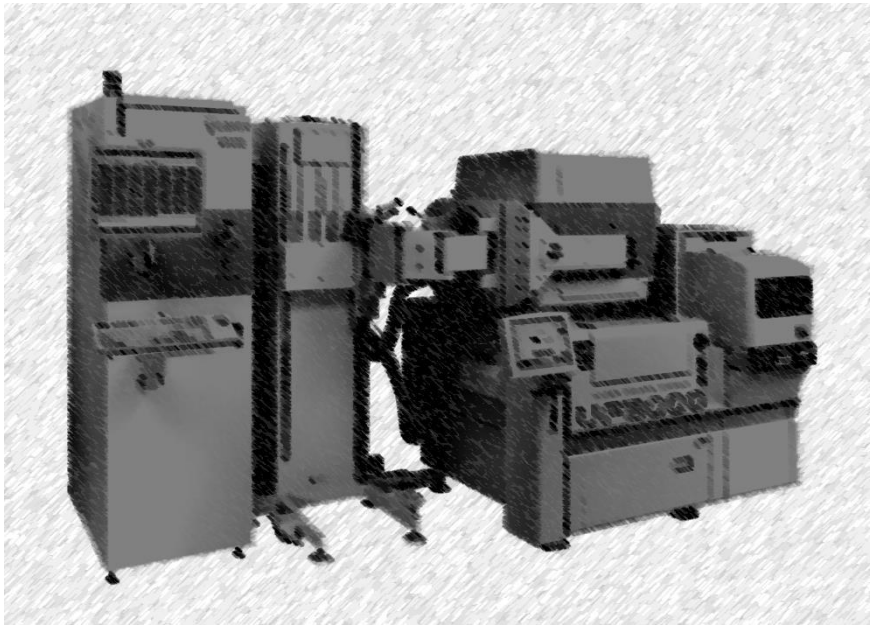
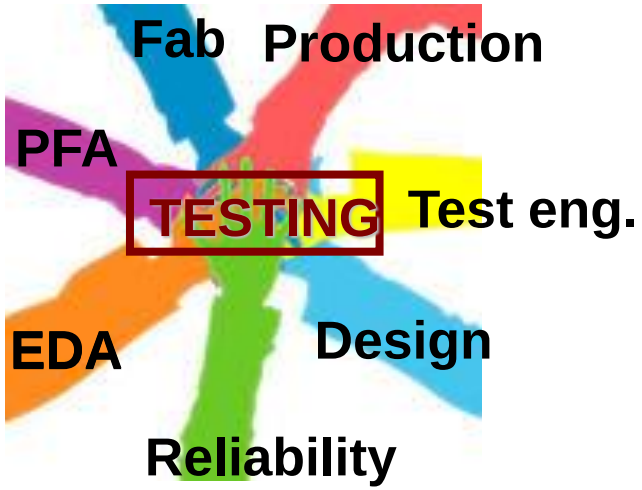


Conclusion

- WHY test?
  - It is important to invest in test because of rule of ten
- HOW to test?
  - Optimal test not only technical issue, but also economics issue
  - No single best test solution for all products!
- WHO responsible?
  - Testing is joint responsibility of everybody



Without Testing, It Is a Gamble!

Testing Does, and Also Will, Play Very Important Role in High-tech Industry.

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