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PIONEERS IN
COLLABORATIVE
RESEARCH®

The Unprecedented Power of Collaborative Research

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October 21, 2009

Outline

- The Economic/Research Landscape ~1982
- The Case for Collaborative Pre-Competitive Research:
    - SRC Model
- The Impact of Pre-competitive Research
- Research Needs Assessment: The International Technology Roadmap for Semiconductors
- Citation Studies on R&D Pipeline Latency
    - Basic Research Life Cycles in Technology
- How might we collaborate in pre-competitive research for future memory technologies?

1950-1980: I will do the research myself!

- Major semiconductor companies often conducted fundamental research internally
  - Costly facilities
  - Significant duplication due to restrictions on cross-industry sharing
  - Ineffective value extraction
  - We weren’t close to fundamental physical limits for scaling

Economics forced a change in this paradigm

Economic Landscape in 1982

- **The Recession of 1980-1982**
  - **the most severe and the most significant in terms of economic impact of the post-World War II recessions.**

U.S. Unemployment Rates Month-by-Month, 1982

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1982	8.6	8.9	9.0	9.3	9.4	9.6	9.8	9.8	**10.1**	**10.4**	**10.8**	**10.8**

Sept. 2009

SRC formed

Gross Private Domestic Investment in the U.S., 1982

Quarter	**Investment Purchases (Billions $ 1972)**
1982I	204.7
1982II	200.4
1982III	194.3
1982IV	177.8

Source: Economic Reports of the President, 1981,1983 & 1984.

Semiconductor Landscape in 1982

256 Kbit DRAM in production

2 µm minimum features

64 Kbit UV-EPROM in production

No flash memory as we know it today yet exists

SRC 1982 challenges:

64 Mbit DRAM

0.25 µm minimum features

Vision (circa 1982):

- "It is doubtful that one can scale the device dimensions to **below 0.1 μm** and gain any advantage in circuit performance because of several **basic limitations**"

Proc. IEEE (1983): *A systems approach to 1 μm NMOS* by M.P. Lepselter, D.S. Alles, H. J. Levinstein, **G. E. Smith** (2009 Nobel Prize Recipient), H. A. Watson

- "MOS gate lengths of about **0.25 micrometer** are **the practical scaling limit"** (1st SRC Annual Report–1984)
    - The SRC 0.25 micrometer CMOS research thrust is centered at Cornell University, with contributing projects at Wisconsin, Illinois, Stanford, Colorado State, Arizona, Yale, and Notre Dame

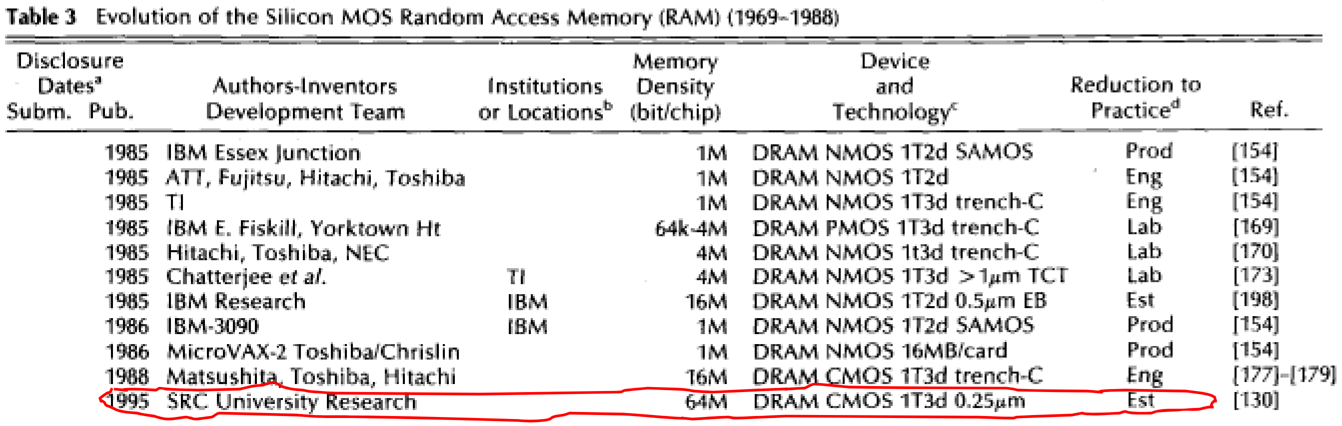

Table 3 Evolution of the Silicon MOS Random Access Memory (RAM) (1969–1988)

Disclosure Dates[a] Subm.	Pub.	Authors-Inventors Development Team	Institutions or Locations[b]	Memory Density (bit/chip)	Device and Technology[c]	Reduction to Practice[d]	Ref.
	1985	IBM Essex Junction		1M	DRAM NMOS 1T2d SAMOS	Prod	[154]
	1985	ATT, Fujitsu, Hitachi, Toshiba		1M	DRAM NMOS 1T2d	Eng	[154]
	1985	TI		1M	DRAM NMOS 1T3d trench-C	Eng	[154]
	1985	IBM E. Fiskill, Yorktown Ht		64k-4M	DRAM PMOS 1T3d trench-C	Lab	[169]
	1985	Hitachi, Toshiba, NEC		4M	DRAM NMOS 1t3d trench-C	Lab	[170]
	1985	Chatterjee *et al.*	TI	4M	DRAM NMOS 1T3d >1μm TCT	Lab	[173]
	1985	IBM Research	IBM	16M	DRAM NMOS 1T2d 0.5μm EB	Est	[198]
	1986	IBM-3090	IBM	1M	DRAM NMOS 1T2d SAMOS	Prod	[154]
	1986	MicroVAX-2 Toshiba/Chrislin		1M	DRAM NMOS 16MB/card	Prod	[154]
	1988	Matsushita, Toshiba, Hitachi		16M	DRAM CMOS 1T3d trench-C	Eng	[177]–[179]
	1995	SRC University Research		64M	DRAM CMOS 1T3d 0.25μm	Est	[130]

CT Sah, *Proc. IEEE* (1988)

The iPod was un-imaginable circa 1980

2006

iPod(5G)
80GB

126 IBM 3350
units needed!

$9,000,000 !!!
in 1976 dollars
(storage only)

Best available storage technology in 1976: IBM 3350

Do Basic Research and Applications/Markets will follow!

How can industry sustain its science base and technical infrastructure?

- Acquire smaller companies
- Depend on government-funded research
- Develop internal basic research infrastructure
- Invest in research contracting organizations
- Collaborate with competitors to fund stand-alone research organizations
- Collaborate with competitors to fund relevant research in universities (The SRC model)

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The Case for Collaborative Research

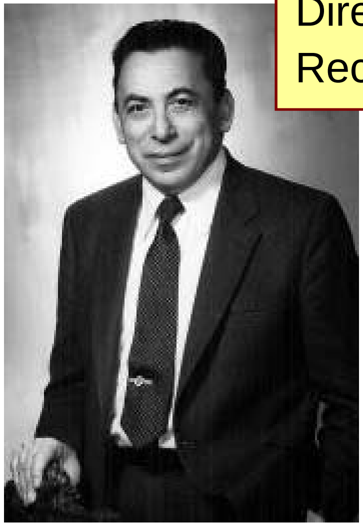
27 Years of Semiconductor Research Corporation

1982- current: “Managed Research”

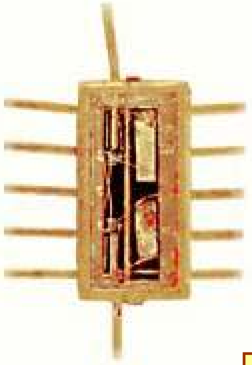
- The Semiconductor Research Corporation (SRC) was established in 1982 as a consortium of semiconductor companies to manage high priority university research
  - Concept of **pre-competitive research** defined
    - Shared resource, e.g. funding, technical directions etc.
  - Later, SRC emphasized enhanced interaction with government agencies to focus basic research
  - Concept of Needs Statements led to global collaboration,e.g.:
    - **National Technology Roadmap for Semiconductors**, *which later became:*
      - **International Technology Roadmap for Semiconductors**

SRC's "Founding Fathers"

Erich Bloch, **IBM** vice president
Director of the National Science Foundation,
Recipient of the National Medal of Technology



Robert Noyce, "the Mayor of Silicon Valley", co-founder of **Intel** and co-inventor of the integrated circuit.



Jack Kilby, Nobel Prize Laureate for the invention of the integrated circuit at **TI**

Pre-Competitive Research by Industry and Consortia Enables Future Business Opportunities

Examples of the Impact of 1980's Basic Research on Products Widely Used Today

Basic research conducted in the 1980s resulted in remarkable changes in society today

SRC-supported Research Helped to Break the 0.1 μm Barrier (FET)

Precise Control of Atoms in Semiconductor Materials

- To make microchips with hundreds of millions and even billions transistors, it is critical to precisely control positions of impurity atoms and atom-size defects in semiconductor materials

- A complete understanding was developed in 1981-1989 as result of basic research by Prof. Plummer's group at Stanford under support of SRC and U.S. government

- This basic research has enabled shrinking the critical dimensions of devices on chip to 10-100 nanometers and let to production of e.g.
  - Micron 2 Gbit memory chip
  - Intel® Pentium®
  - AMD Athlon™

SRC-supported Research Helped to Break the 0.1 μm Barrier (FG/Flash)

Hot-electron injection in thin films of insulators

To make a reliable and small FLASH memory with **very high capacity**, it was necessary to understand the physics of hot-electron injection in thin films of insulators

The physics of hot-electron injection in thin insulator films was understood in 1984-1990 from basic research by Prof. Hu's group at Berkeley supported by SRC and U.S. government

This basic research has enabled today's digital cameras, pocket memory sticks, iPod nano etc.

Nobel Prizes in Physics for Industrial Research in Electronics (Selected Examples)

Basic Industrial Research Enables Business Opportunities

1956	Shockley Bardeen Brattain	**AT&T**	*Semiconductor transistor*
1973	Esaki	**Sony(**Tokyo Telecom Eng) **IBM**	*Semiconductor Tunnel Diodes*
2000	Kilby	**Texas Instruments**	*Semiconductor Integrated Circuit*
2009	Boyle Smith	**AT&T**	*Imaging semiconductor circuit – the CCD sensor*
201*	???		*FLASH* memory? *Advanced Semiconductor Memory?*

Environmental requirements for successful collaborative research

- Growth-oriented industry
- Sufficient industry revenue base to support research
- Common/congruent technical interests
- “Can-do” attitude of industry participants to transform pre-competitive research into competitive advantage
- Benign government policies with respect to pre-competitive research collaboration

SRC: A “Virtual” Global Laboratory

Agility by Structure

- **Research conducted at ~100+ universities throughout the world**
    - **Employ best *current* experts anywhere in the world**
    - **Over 40% of research performers are new in 5-year time horizon**
    - **~ 1/3 of projects turned over every year**
    - **No permanent research staff**
- **Programs can be started, adjusted and/or stopped quickly**
    - **Each project reviewed annually by member companies**
    - **Allows for rapidly changing needs of member companies**
- **No capital costs**
- **Minimum overhead costs (best of any consortia in the world)**

SRC Research Management Methodology

- Member-driven creation of *needs document*
- Request and submission of *white papers*
- Member review and *selection* to seek *proposals*
- Request for *proposals*
- Member review and *selection of proposals* to fund
- Internal SRC Research Management Committee review
- *Three-year contract* start (Typical) of core programs and research customization projects (RCP) selected by individual companies
- *Annual member reviews* of progress
- Submission of *reports and “deliverables”* by researchers

Lessons Learned About Collaborative Research

1. **Industry can change technical directions/business model quickly; consortia must be agile; e.g., transitions from IDM to fabless by many companies**

2. **A company can speak with many voices; consortia need to work with top-management to the extent possible**

3. **Don't over-manage university research for in so doing creativity could be limited; knowledge and learning is their forte'**

4. **Enter co-sponsorship with other entities only when adequate assurances that the integrity of the research program and member interests are safe-guarded.**

5. **Consortia must be able to quantify the value of return to members on their investments**

Lesson Learned About Collaborative Research

6. The resolution of pre-existing background intellectual property issues is perpetual, but very important in order for industry to utilize research results

7. The importance of knowledge transfer to members cannot be overemphasized

8. Use the time of member advisory boards wisely; they have day jobs!

9. Control operating expenses for they are in direct conflict with maximizing member leverage

10. Recruiting new members is a way of life for a consortium; the industry landscape constantly changes

11. The ability of a collaborative program to generate critical breakthroughs cannot be over-estimated

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The power of setting goals

International Technology Roadmap for Semiconductors

Collaborative Research Management Requires Strategic Planning and Goal Setting

ITRS Origins

- 1983-1994: SRC announces ten year research goals
- 1990: SRC leadership in establishing NACS resulting in MICRO TECH 2000 for 0.12 micrometer semiconductor technology by 2000
- 1992: National Technology Roadmap for Semicondctors effort led by SRC and SIA to define industry five-year goals
- 1994: NTRS update and extension of horizon to fifteen years
- 1998: Roadmap is internationalized and becomes the International Roadmap for Semiconductors (ITRS)
- Two year major ITRS updates implemented

ITRS Emerging Research Devices Chapter

- Assess and details the potential of emerging nanoelectronic devices
- In 2001-2009 ERD affirmed that no currently proposed device approach to “post CMOS” logic is a likely candidate to continue scaling of information processing much beyond that attainable by CMOS.

- **On the other hand, the assessment for emerging memory device concepts was more encouraging**
  - **Several Emerging Memory Technologies Show Promise**
    - ***Some were addressed in this Forum***

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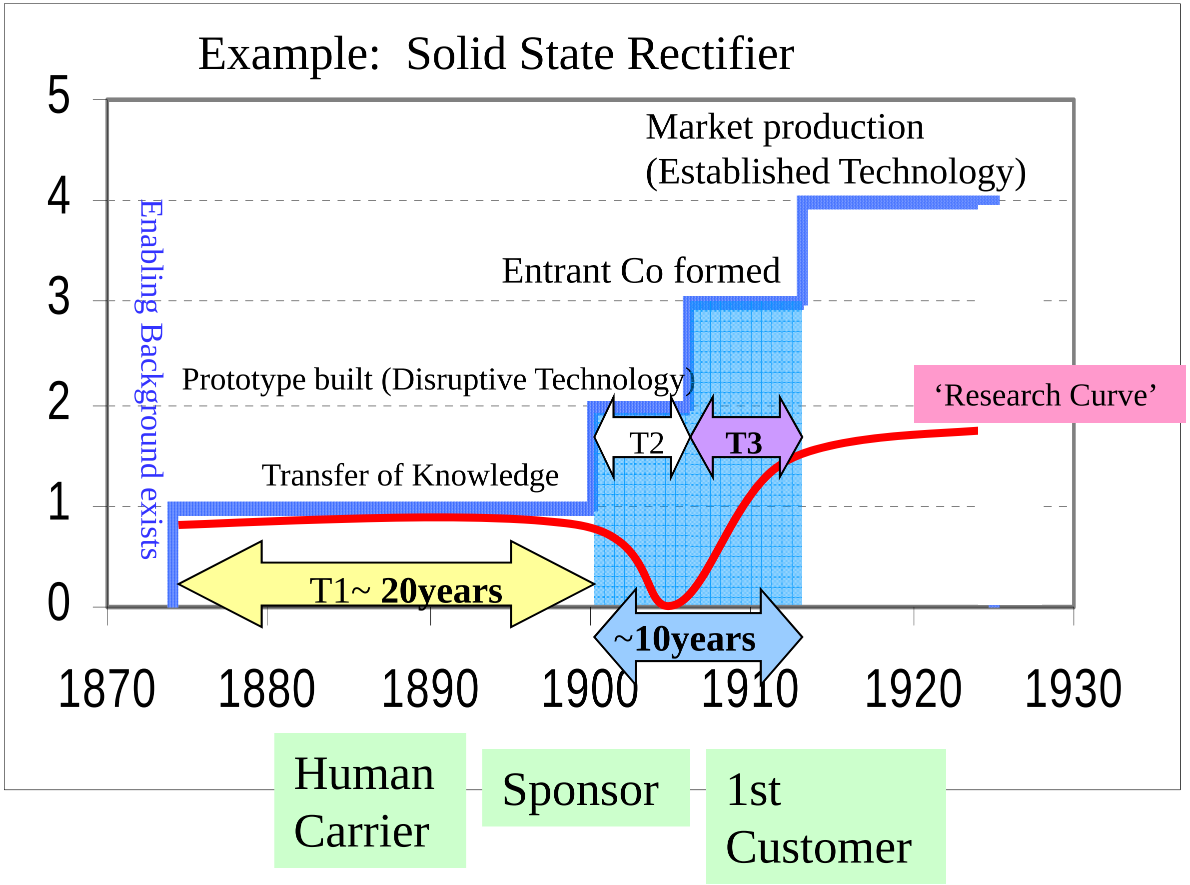
Estimates of R&D Pipeline Latency for the Semiconductor Industry

- A brief review of R&D cycle times for classical electronic technologies
- Selected recent technology cycle times
- The case for continuous re-invention of semiconductor technologies

Message: There is ample time for pre-competitive research prior to marketplace competition

Time Gaps



Solid State Diode
T1 26 (1874-1900)
T2 7 (1900-1907)
T3 6 (1907-1913)
Learning Period 13 years

Vacuum Tube
T1 20 (1884-1904)
T2 9 (1904-1913)
T3 6 (1913-1919)
Learning Period 15 years

Transistor
T1 25 (1923-1948)
T2 6 (1948-1954)
T3 5 (1954-1959)
Learning period 11 years

Integrated Circuit
T1 17 (1942-1959)
T2 3 (1959-1961)
T3 5(1961-1966)
Learning Period 8 years

Study of of R&D Latency for a few Semiconductor Technologies

- CMOS transistor
- Giant Magnetoresistance (GMR)
- Copper Interconnect
- 193 nm photoresist
- Magnetic Random-Access Memory (RAM)

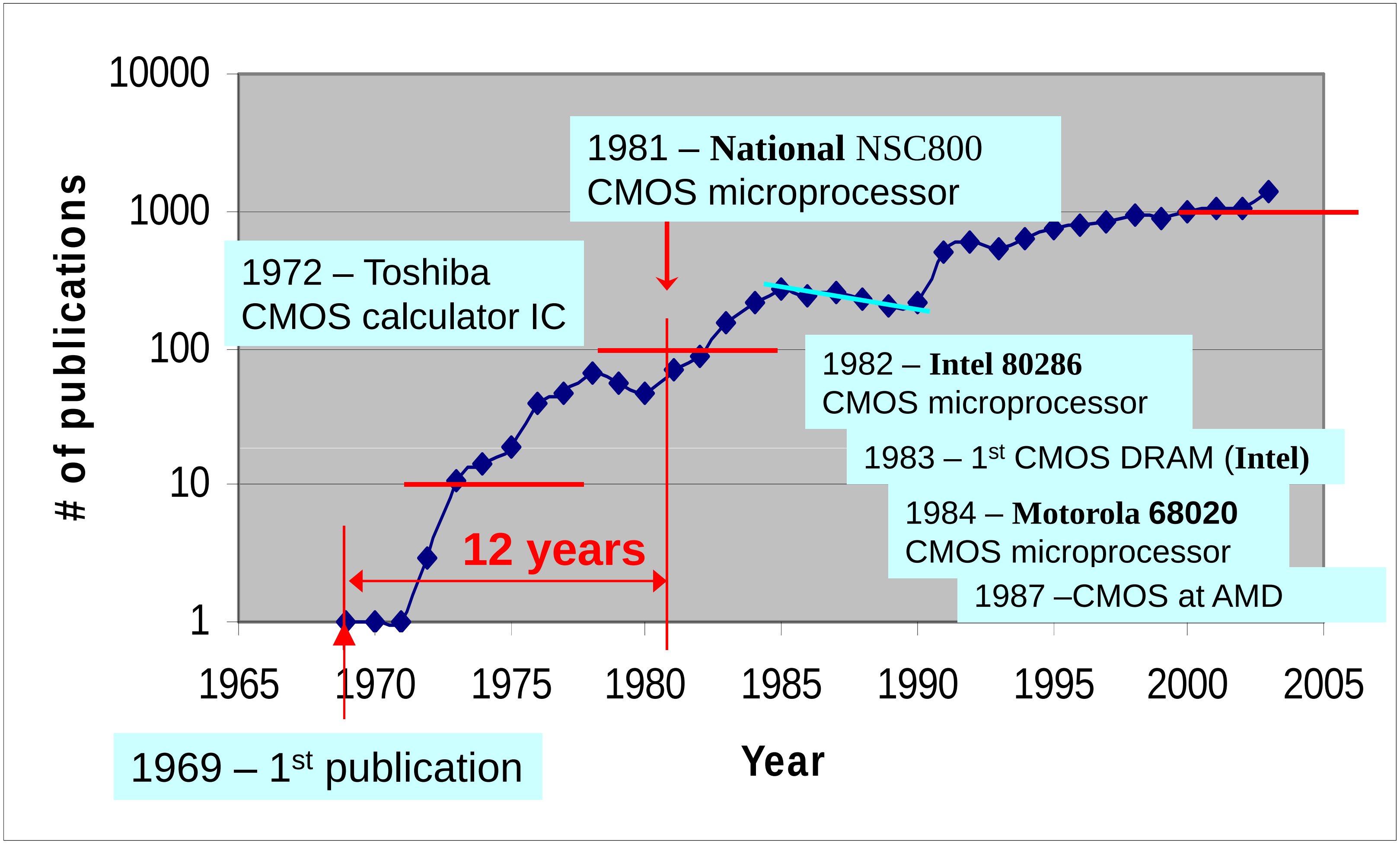
***Method*.** We used the following parameters:

1) The first publication on a given technology that appeared in the **Science Citation Index** database

2) The number of refereed articles in technical journals by year (**Science Citation Index** database)

3) The year of first production for a given technology

CMOS



1981 – **National** NSC800 CMOS microprocessor

1972 – Toshiba CMOS calculator IC

1982 – **Intel 80286** CMOS microprocessor

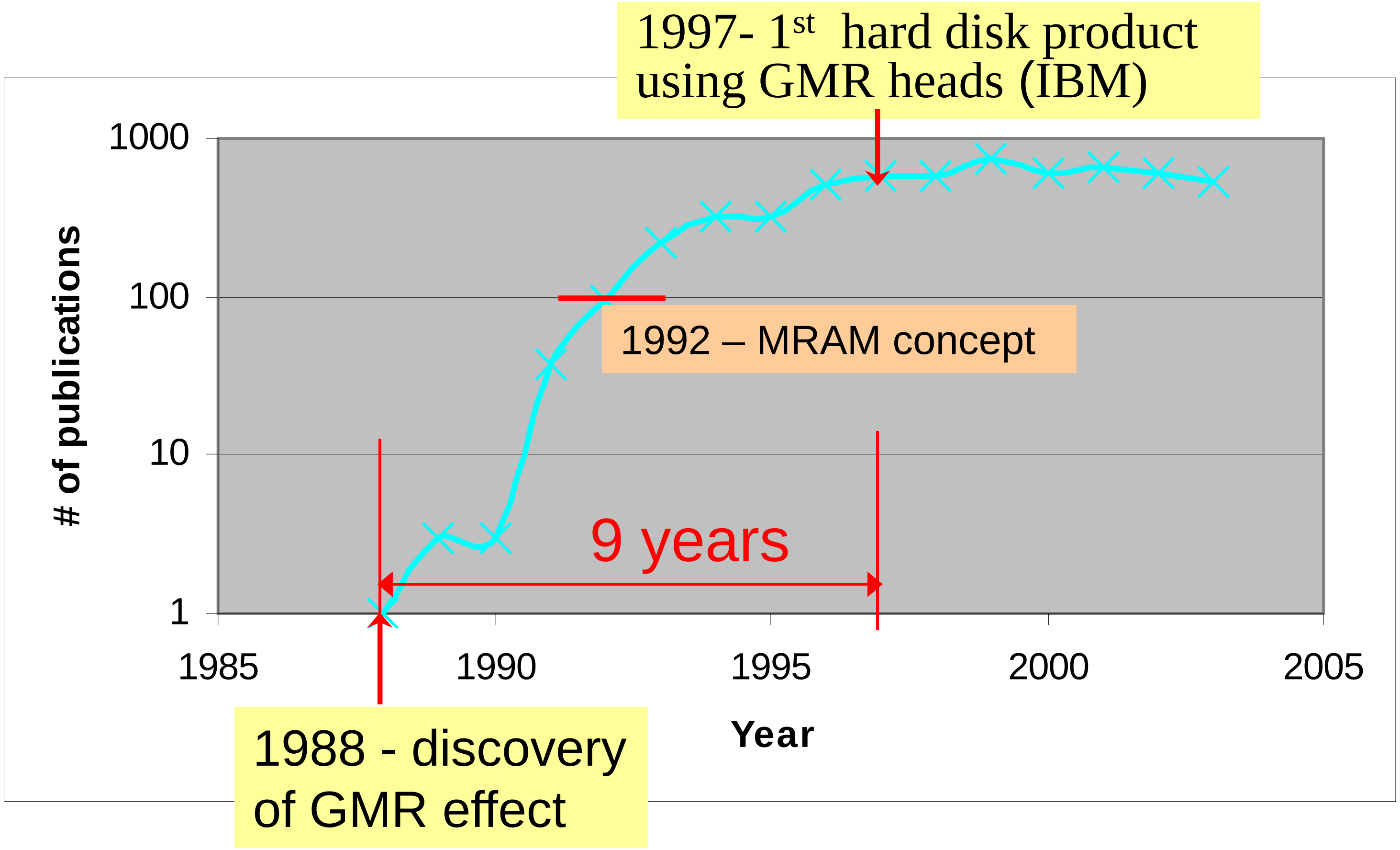
1983 – 1st CMOS DRAM **(Intel)**

1984 – **Motorola 68020** CMOS microprocessor

1987 –CMOS at AMD

1969 – 1st publication

Giant Magnetoresistance (GMR)

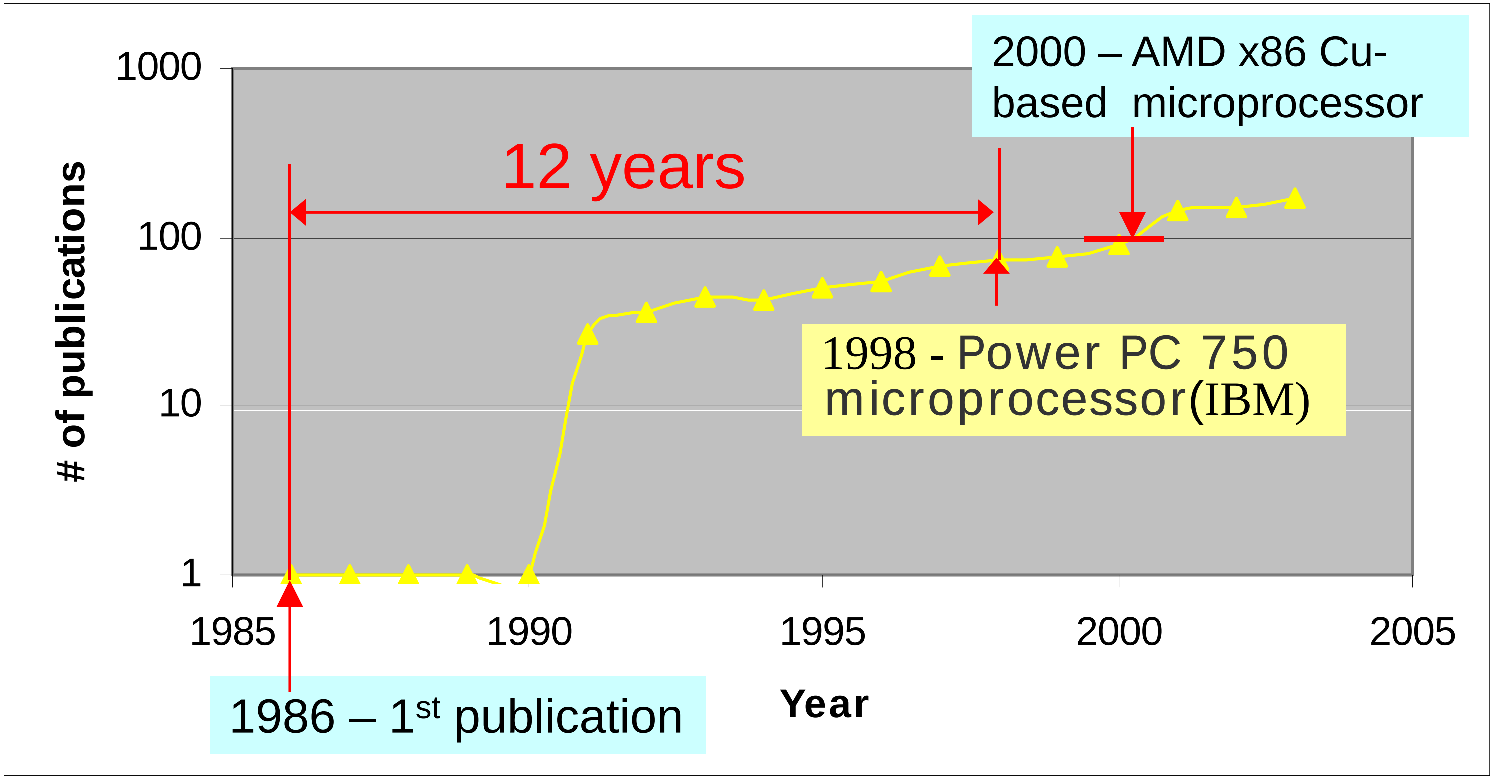


1997- 1st hard disk product using GMR heads (IBM)

1992 – MRAM concept

1988 - discovery of GMR effect

Copper Interconnect

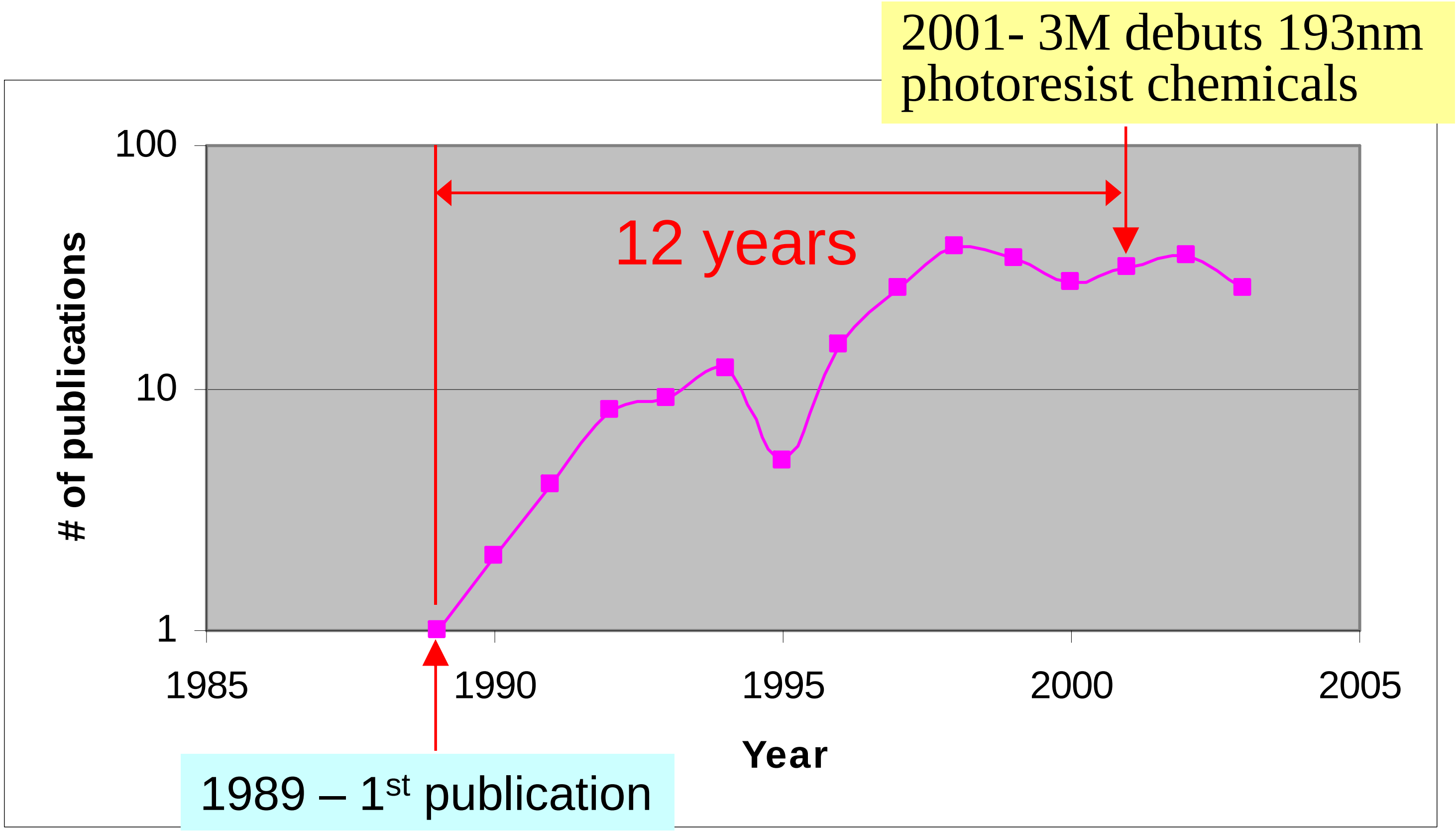


2000 – AMD x86 Cu-based microprocessor

1998 - Power PC 750 microprocessor(IBM)

1986 – 1st publication

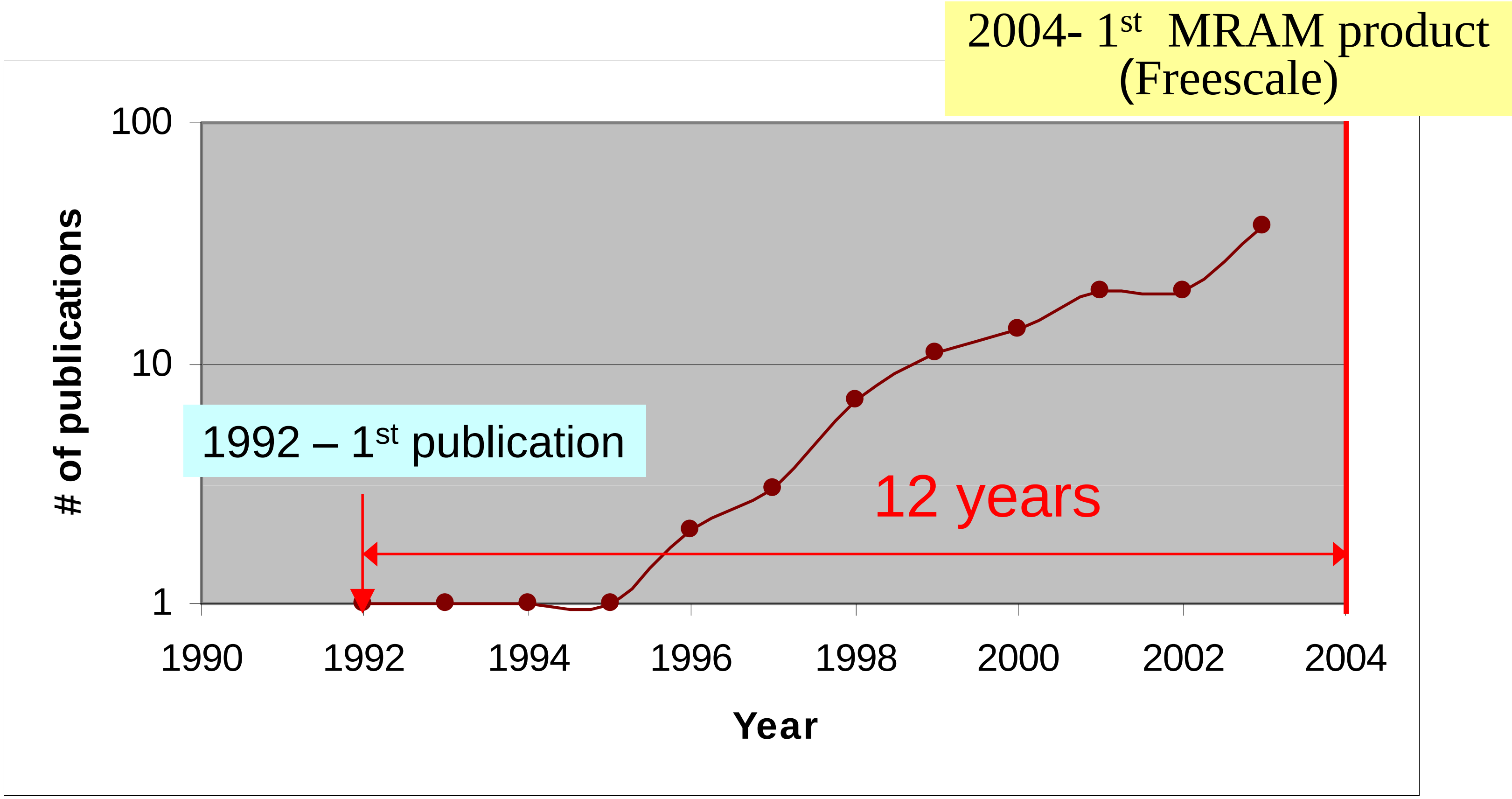
193 nm photoresist



2001- 3M debuts 193nm photoresist chemicals

1989 – 1st publication

Magnetic RAM



2004- 1st MRAM product (Freescale)

1992 – 1st publication

12 years

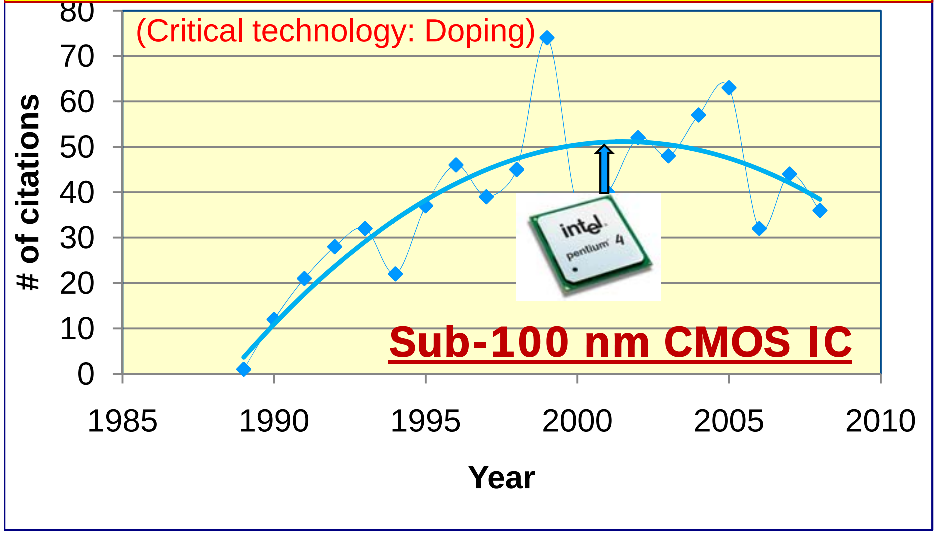
Observation

- A typical latency time from 1st publication to 1st production is about 12 years

- What happens 12 years from now? 2009+12=2021 ?

SRC Influential Papers: Citation Trajectories

“Point Defects and Dopant Diffusion in Silicon”,
by Plummer et al. (1989)

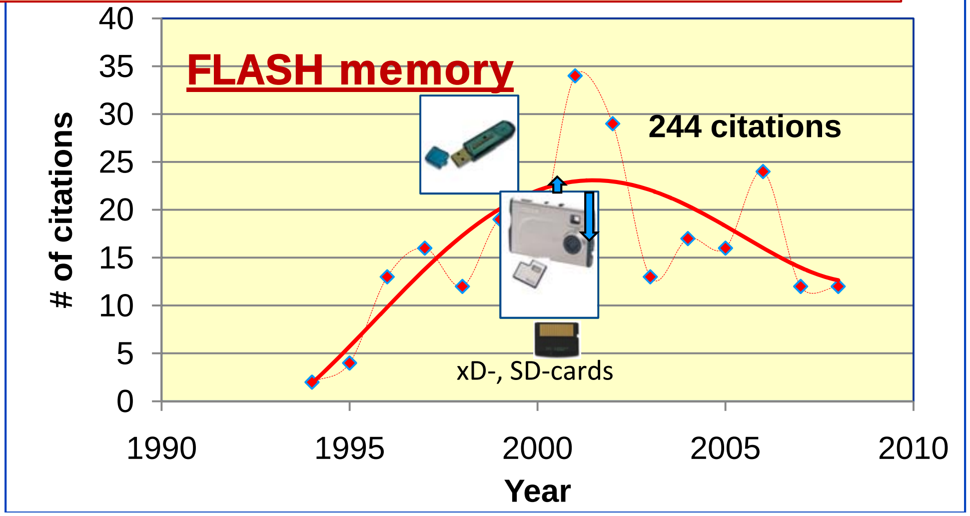


780 citations (33% by industry)

Technology citation trajectories peak about time of product introduction

Demonstrates the need for continuous innovation

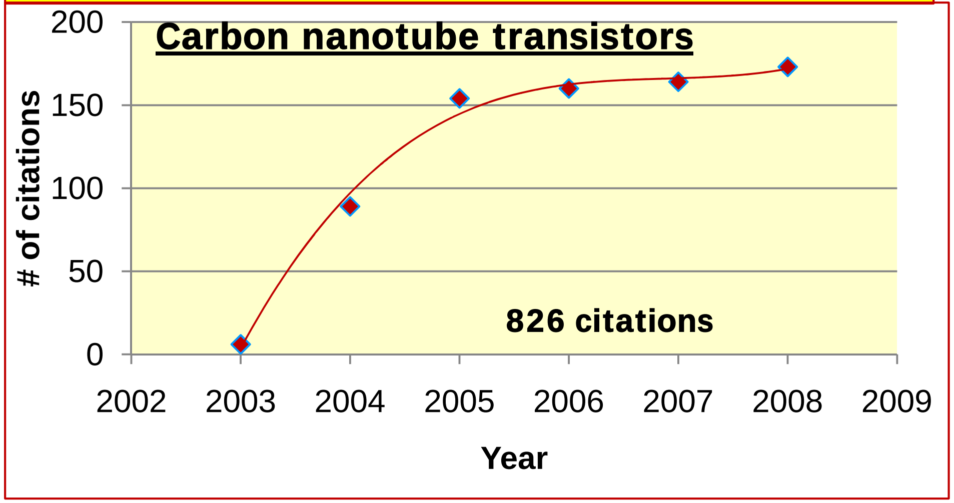
“Hole injection SiO2 breakdown model for very low voltage lifetime extrapolation” , by Schuegraf and Hu (1994)



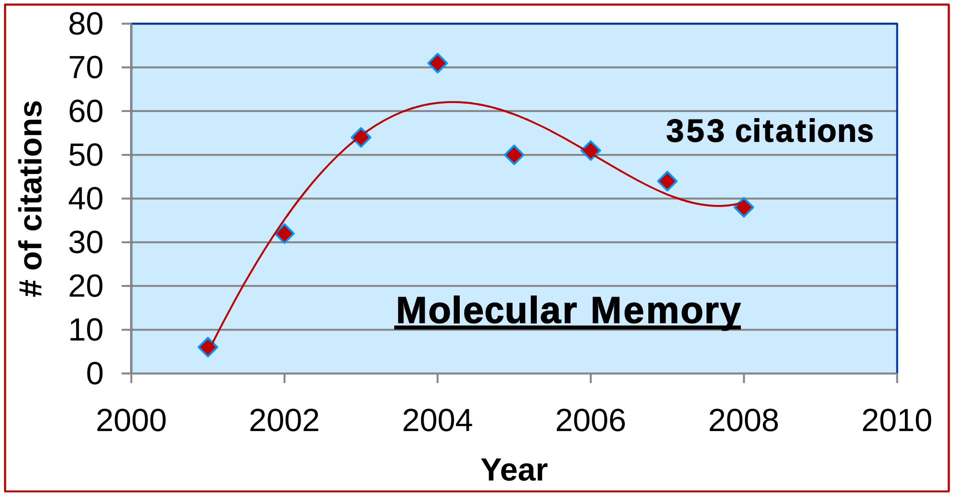
244 citations (40% by industry)

Citation Trajectories: Emerging Nanotechnologies

"Ballistic carbon nanotube field-effect transistors",
by Javey et al. (2003)



Molecular random access memory cell" by Reed et al (2001)



Citation Trajectories are an indication of perceived opportunities

The Case for Research Collaboration in Memory Technologies

- Memory research is fragmented and often lacking critical mass
- The limits for scaling/extension of several classical memory technologies is foreseeable
- CMOS embeddable memory technologies are needed
- Energy consumption from memory operations is becoming a significant fraction of system energy usage
- Processing technologies for extremely scaled memory systems are limiting progress; e.g., lithography
- Novel and more efficient memory systems are needed to support emerging applications; e.g. machine learning

How Might We Collaborate?

- **We think that the SRC model would work**
  - Needs statements by industry partners
  - Fees from member sponsors and from governments
  - Research in university laboratories/institutes
  - Formal program reviews on periodic basis
  - Proof-of-concept in selected facilities?

- **SRC has developed the Topical Research Collaboration (TRC) model to implement targeted programs, e.g.:**
  - **(existing) Energy, Nanotechnology**
  - **(projected) bioelectronics, memory etc.**

Thank you