Why You Should Be Interested in Technology Roadmaps for Compound Semiconductors*

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Outline

- **Roadmap Tutorial**
- **Selected Trends**
- **Lessons Learned from Existing Roadmaps**
- **Candidates for Compound Semiconductor Roadmaps**
- **Conclusions**

What is a technology Roadmap?

A technology roadmap in the context of this talk

is an industrial consensus

with inputs from the
research community and

if appropriate with inputs
from governments.

Technology Roadmaps

" A *roadmap* is an extended look at the future of a chosen field of inquiry composed from the collective knowledge and imagination of the brightest drivers of change in that field."

"Roadmaps allow our industry leaders to communicate convincingly with those in government and business regarding their support of our goals."

"Roadmaps are working now in industry and they are beginning to gain a stronghold in science."

----- Robert Galvin, Chairman of the Executive Committee of Motorola, editorial in *Science* **280**, 8 May 1998, p. 803.

Why is a technology roadmap useful?

A technology roadmap is often an effective technique to:

1) Reduce uncertainties in investments
2) Use changes among competing technologies as opportunities
3) Increase the probability for more robust economic performance
4) Guide critical research
5) Assist in setting priorities for resource allocations and
6) Accelerate the rates of both technology development and deployment.

Why Roadmaps?

- Some compound semiconductors coexist/compete with Si and SiGe (i.e., with CMOS compatible processing).

- Smaller budgets place greater emphases on consensus-based planning for smarter investments.

- Consensus -based planning for semiconductors is critical to determine all costs (R&D, design, testing, maintenance, ownership, and disposal) to meet present and future performance requirements (e.g, frequency, bandwidth, power, noise, and reliability) of systems (e.g., mobile communications and wireless DTV/HDTV).

Why Roadmaps ? (continued)

- Needed to determine the cheapest point in the procurement spectrum from Si/SiGe to other compound semiconductors.

- Identifies what is common knowledge and what is truly intellectual property.

- Participants gain knowledge, broaden their industrial outlook and awareness, and become more valuable employees.

You should be interested in technology roadmaps for compound semiconductors because:

1. **Lose less money** to competing technologies - examples -
   a) Earlier generations of cell phones had more compound semiconductor content than they do today.
   b) Silicon CMOS has replaced GaAs RF power amplifiers in cell phone base stations. But, the competition between LDMOS and GaAs occurs again for RF amplifiers in base stations for third generation cell phones.

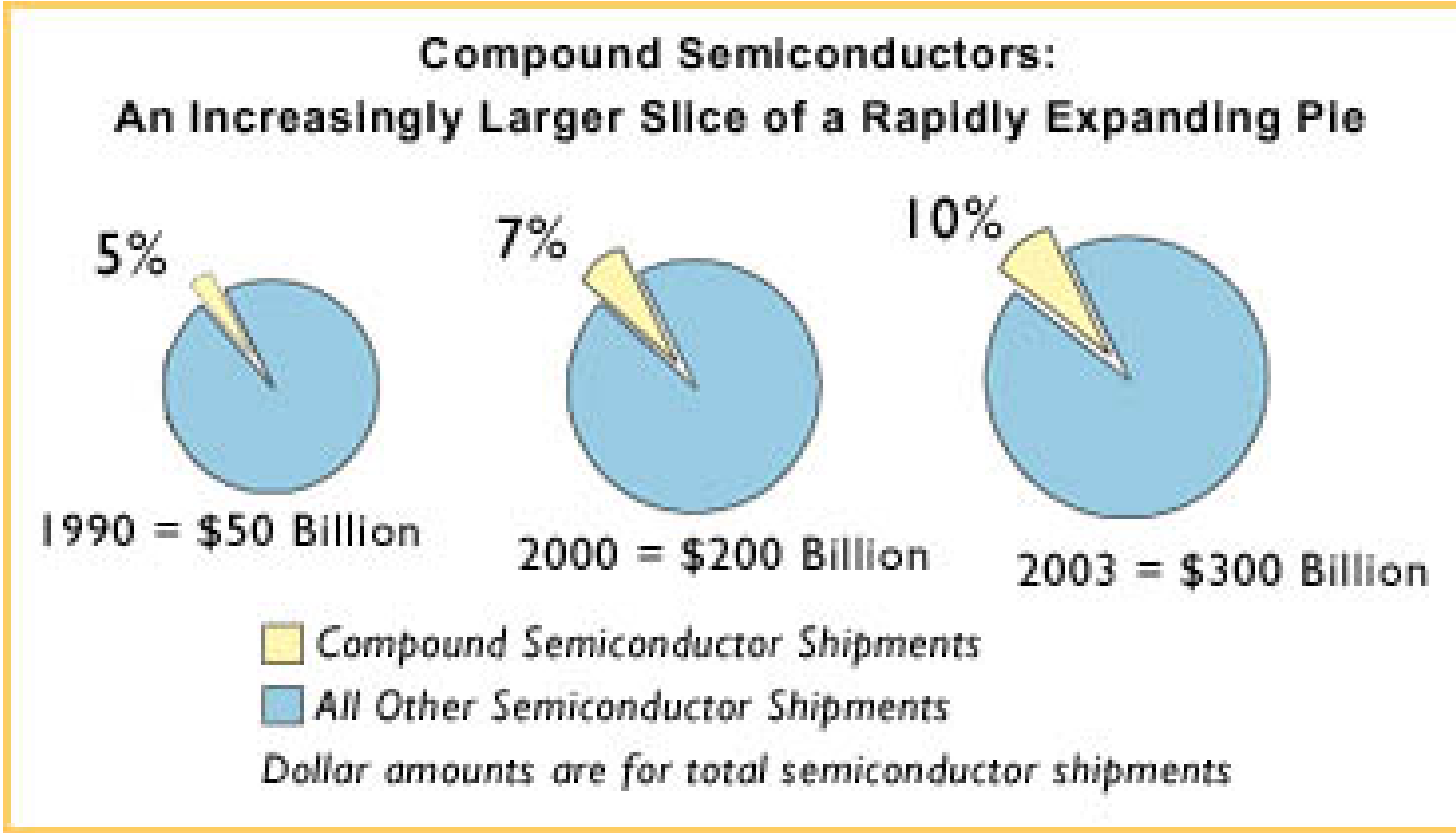
You should be interested … because (continued):

2. Make more money by enabling new technologies - examples -
   a) Advanced analog-to-digital converters for very high data rate wireless communications systems (greater than 200×10^6 samples/s with over 14 bits of resolution).
   b) Optical interconnects for scaled CMOS (co-integration of compound semiconductor lasers and LEDs with CMOS processes below the 65 nanometer node in the ITRS 2001. This is considered to be a way to solve interconnect delays and cross-talk issues with conventional interconnects. [CMOS industry wants to know when lasers could be co-integrated with CMOS, ITRS 2001 Meeting, 18 July, San Francisco]

Allan Alan, Intel and International SEMATECH, told New Technology Week that the ITRS Update for 2002 will include compound semiconductors. The goal … will be

"to develop perspectives for the future of compound semiconductors within integrated circuits and begin tracking their relevance in multi-chip modules,"

From New Technology Week, King Communications Group, Inc., Washington, D.C. , Monday, September 17, 2001.



From Compound Semiconductor Manufacturing Exposition (CS-MAX), Hynes Convention Center, 8 – 11 July 2001, Boston, MA

Trends

- Bigger wafers and smaller devices.
- Increased R & D and production facilities costs are becoming too great for any one company or country.
- Shorter process technology life cycles.
- Emphasis on faster characterization of manufacturing processes.
- All - global participants in the "Si CMOS ecosystem" now collaborate to develop and improve manufacturing technologies; e.g., ITRS and International SEMATECH.

Trends (continued)

- **Competition among Si CMOS manufacturers is shifting from an emphasis on technology and fabrication to a much greater emphasis on product design, architecture, algorithm, and software; i.e., shift from technology-oriented R&D to product-oriented R&D.**

- **Many observers credit consensus-based planning and deliberate roadmapping efforts for the sustained average annual growth rate of 15% for the silicon semiconductor industry over this past decade.**

- **Users interested more in function and price than in process.**

Trends (continued)

- **Communications products to replace computers as key driver of volume manufacturing.**
- **Present and future volume products include:**
  - **cell phones and video phones**
  - **Bluetooth appliances**
  - **optoelectronics**
  - **automotive electronics that add functionality of home and office to cars and trucks.**

History – Where are compounds addressed?

- **NEMI (December 2000 Report)**
  - some material specificity in energy storage, RF components, and optoelectronics
  - numerous market applications
- **ITRS (December 1999)**
  - very material and process specific (limited primarily to crystalline Si CMOS)
  - limited to a few very big market applications (microprocessor-logic, memory, and mixed-signal)
  - simple metrics for determining progress (e.g., line width, and density)
- **OIDA (October 1996 Report)**
  - some material specificity in sensors and detectors
  - numerous market applications

History (continued)

- **MEL-ARI OPTO (June 1998 Report)**
  - **material specificity for optoelectronic interconnects**
  - **drivers and detector/receiver arrays**
  - **numerous market applications**

- **OITDA (August 1998 Report)**
  - **material specificity in light sources, optical modulators and receivers, and ultra-high-speed electronic devices.**
  - **numerous market applications**

- **A common critical issue in both OIDA and NEMI Roadmaps is the lack of predictive computer simulations of processes, devices, and circuits. [e.g., pp. 143, 205, and 208 of NEMI Roadmaps]**

Lessons Learned from Si CMOS Roadmaps

- **Many technology barriers, once thought to be of concern to a few companies, are common through out the industry. Overcoming such barriers offers an appropriate focus for technology roadmaps.**

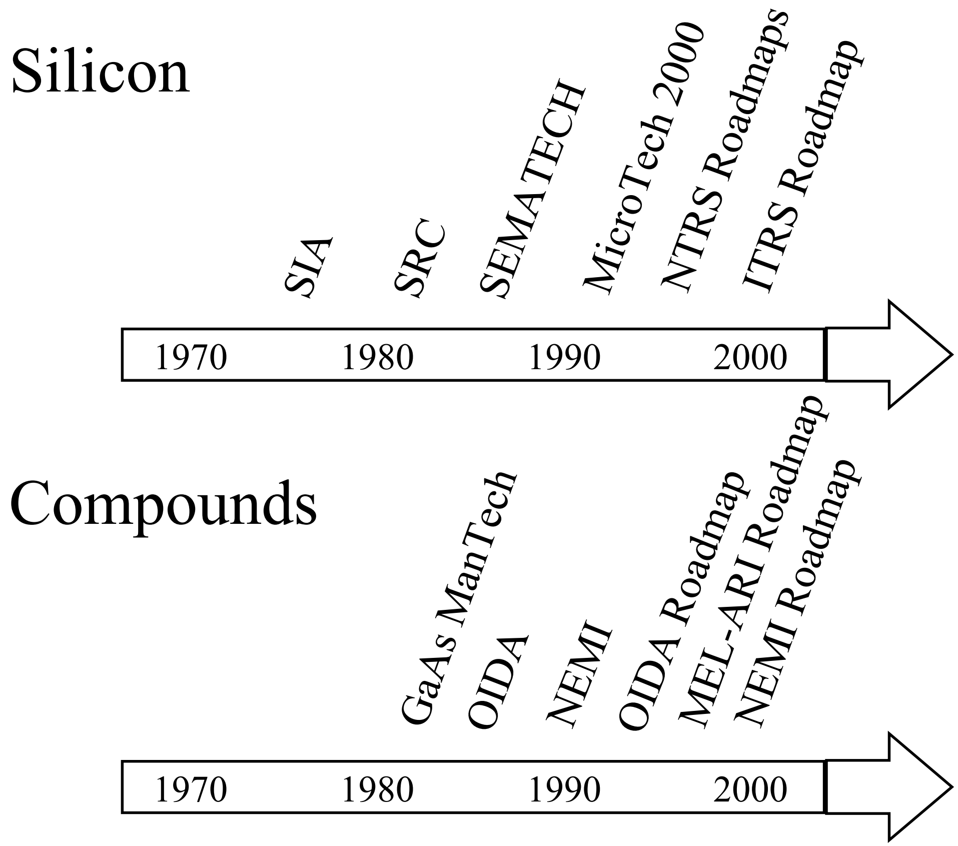
- **Prior to mid 1980's, most Si CMOS companies assumed that over 50% of what they knew was proprietary and not to be part of consensus-based planning and collaborations.**

- **From the late 1980's to today, most Si CMOS companies found that over 50% of what they know is not proprietary and may be shared with other companies for a globally more competitive industry.**

Lessons Learned from NEMI

- Discussions with senior industrial managers for acceptance.
- Worked from a "virtual product" as basis for bringing all stakeholders together.
- Challenge was to have a large enough effort to be effective, but still focussed enough to have measurable progress.
- Everyone has similar problems. Much IP is common to everyone. Industry moves faster when these are recognized and common problems are solved.

Historical Events for Road-Mapping Activities



Industry's Role?

- Industry should lead in compound semiconductor planning
  - Compete with alternative technologies
  - Converge on requirements for base materials to lower costs and increase performance
  - Downsizing requires smarter investments determined in part by consensus-based planning

- But, governments may facilitate compound semiconductor planning.

Academe's Role?

- Invent new and alternative technologies.
- Provide well trained people that industry and government want to hire.
- Provide long-term knowledge base to support future marketable technologies.
- Be partners in addressing research challenges such as fabrication processes and equipment for new high-performance materials and systems.
- Receive industrial and government feedback for development of university programs.

Action Items

Making progress towards a technology roadmap for compound semiconductors includes:

1. **Define needs/applications for technologies to advance.**

2. **Assess which needs/applications are most amenable for developing an ITRCS to support an enhanced global infrastructure.**
3. **Identify which organizations will sponsor the development and maintenance of the proposed ITRCS and speak for that portion of the compound semiconductor industry.**

Action Items (continued)

3. **Perform economic assessments of the benefits and costs associated with developing roadmaps and without developing roadmaps for those few selected applications.**

4. **Convene workshops that identify the key system applications and technical and commercial problem areas (e.g., cost reduction for epi-layer fabrication, millimeter-wave circuits, thermal management, and packaging and mounting of radio frequency devices) and the technology performance gaps between what is or will be available and what the intended market application requires.**

Metrics for Success

Assessing the success of a technology roadmap includes:

1. **Determine whether the compound semiconductor infrastructure permits going from tolerances in processing parameters (e.g., composition, thickness, and doping density) to acceptable costs, yields, reliabilities, and bit error rates in a system.**

2. **Determine whether sufficient knowledge exists to determine how the above examples of tolerances in processing parameters vary with time and with market application.**

Metrics for Success (continued)

3. Assess whether the compound semiconductor market segment growth is greater than that projected today.

4. Measure the investments that commercial companies commit to the roadmap activities.

5. Document the number of roadmap citations by university, industry and government as a function of time.

One Approach

- An international effort involving existing commercial organizations and universities could:
  1. **Coordinate efforts among roadmaps** that are relevant to compound semiconductors and identify additional roadmaps needed for future markets.
  2. **Recommend ways to bridge the technology gaps** between what the market wants and what will be available.
  3. **Recommend strategies** for delivering systems at the cheapest point in the procurement spectrum.
- Participating organizations would be able to develop internal domestic solutions to the above needs and technology gaps as desired.

Technologies for Wireless Applications - Candidates for Roadmapping Efforts

" Today millimeter-wave manufacturing issues are high volume module assembly and development of low cost, high frequency packaging methods and materials ..."

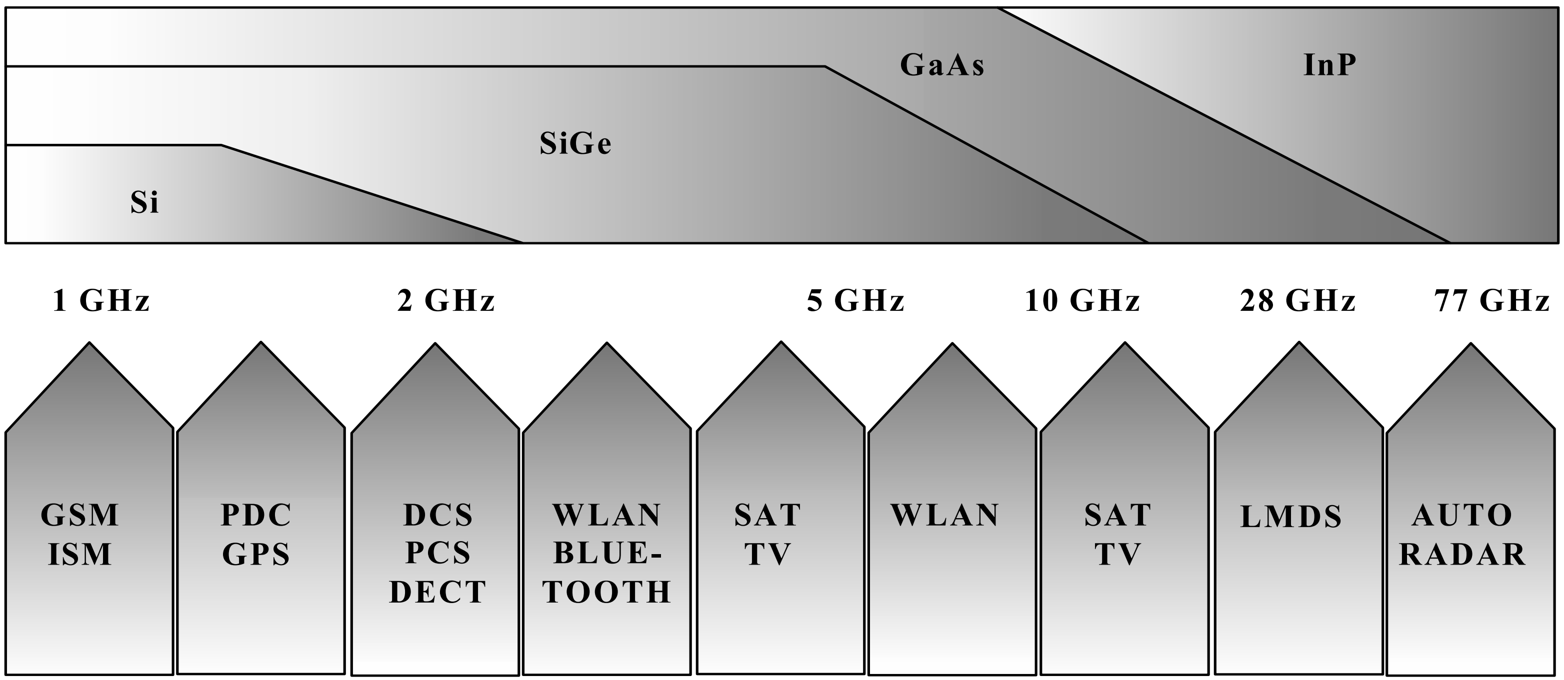
" Wideband CDMA is forcing a detailed understanding of linearity and its relation to device design and process parameters."

" Moore's Law .... will enable the demise of analog functions such as filters and mixers and the growth of "software" handsets ... whose modulation formats and other architectural details are programmable."

----- Peter Staecker, M/A-COM, Inc., guest editorial in Microwave Journal, July 1999, p. 62.

Interplay Among Commercial Applications, Frequency, and RF Device Technology

Today's Technology Options for Designers



What will the technology options be in 2005 or 2010?

Adapted from Fig. 1of the paper by D. Barlas, et. al., page 22, June 1999; printed with permission from the Editor, Microwave Journal.)

Wireless Videophones are Coming

No longer bound to the realm of science fiction, hand-held videophone technology developed at a breakneck pace in late 1999. In Japan, NEC developed a prototype of a small video handset that incorporates a small LCD screen and built-in camera to transmit images and sound simultaneously. And on the other side of the globe, Orange, a UK-based mobile phone firm, has developed a Windows CE-based videophone that receives either Internet-based data or audiovisual information.

The world's first mass-marketed wireless videophone, Kyocera's VisualPhone, broadcasts data at 32Kbps, or about 2 small images per second. Tied closely to the PDA (personal digital assistant) market, handheld internet videophones will become a workable reality in the US only when enough wireless bandwidth becomes available to send and receive a halfway-decent picture—something closer to 400Kbps. NEC's prototype videophone relies on the as-yet undeployed W-CDMA wireless network, which will deliver up to 2000Kbps (2Mbps) when the user is stationary, or about 384Kbps when walking.

Adapted from Videomaker, December 1999, page 13.

One Candidate for a Technology Roadmap

Drivers in Handset Application:

- IF Frequency
  $\Rightarrow$ ADC Sample Rate
- Dynamic Range
  $\Rightarrow$ ADC Resolution or number of bits

Issues

1. Specifications for wireless systems and components may differ substantially throughout the world; e.g., VSB, COFDM, CDMA, and the like.

2. Requirements on SiCMOS ICs for digital video (DV) are greater and more challenging than some of the ITRS performance goals.

3. Similarly, requirements on compound semiconductors for DV are expected to be greater and more challenging than for other applications.

Wireless Digital Video Networks

As an illustrative example, consider compound semiconductors for wireless real-time digital video (WRTDV) communications networks - i.e., very high quality digital data networks. Applications of WRTDV include health care, weather, agriculture, commerce, and consumer products.

Compound semiconductors will be essential for

- **transmitters and receivers**
- **ADCs**
- **OEICs to connect wireless sites to fixed and satellite sites**

Technical Challenges

Transceiver Front Ends:

- Increase power efficiency, reliability (lifetimes), die size, and linearity; manage circuit complexity; decrease feature size, error rates, and costs.

- Determine role of HBTs, MESFETs, and HEMTs to alleviate spectrum crowding.

- Assess operating frequency vs. linewidth above 10 GHz

Technical Challenges (continued)

ADCs:

- **Make digital signal processing more versatile, cheaper, and smaller, and use less power.**

- **Develop strategies to increase ADC resolution and sampling rates.**

- **Develop circuits with large numbers of InP HBTs, HEMTs, and RTDs for ADCs.**

Difficult Challenges – Potential Showstoppers

Analog to Digital Converters - candidates for stopping the show!

- **Performance limits - aperture jitter, device speed, matching scaled components, and thermal management.**
- **Increased dynamic range, sampling rates, and much lower power.**
- **Too slow improvement in performance - about 1.5 bits increase in resolution at constant sampling frequency over the last 8 years.**

Difficult Challenges – Potential Showstoppers (continued)

- **Consequences - not enough “headroom” for encoding/decoding and error correcting, especially for high data rate wireless systems such as (high performance laptop computers, videophones, and HDTV receivers); will not be able to increase functionality (smart receivers).**

Rate of improvement of ADC technology

A "Moore's Law" for ADC Technology

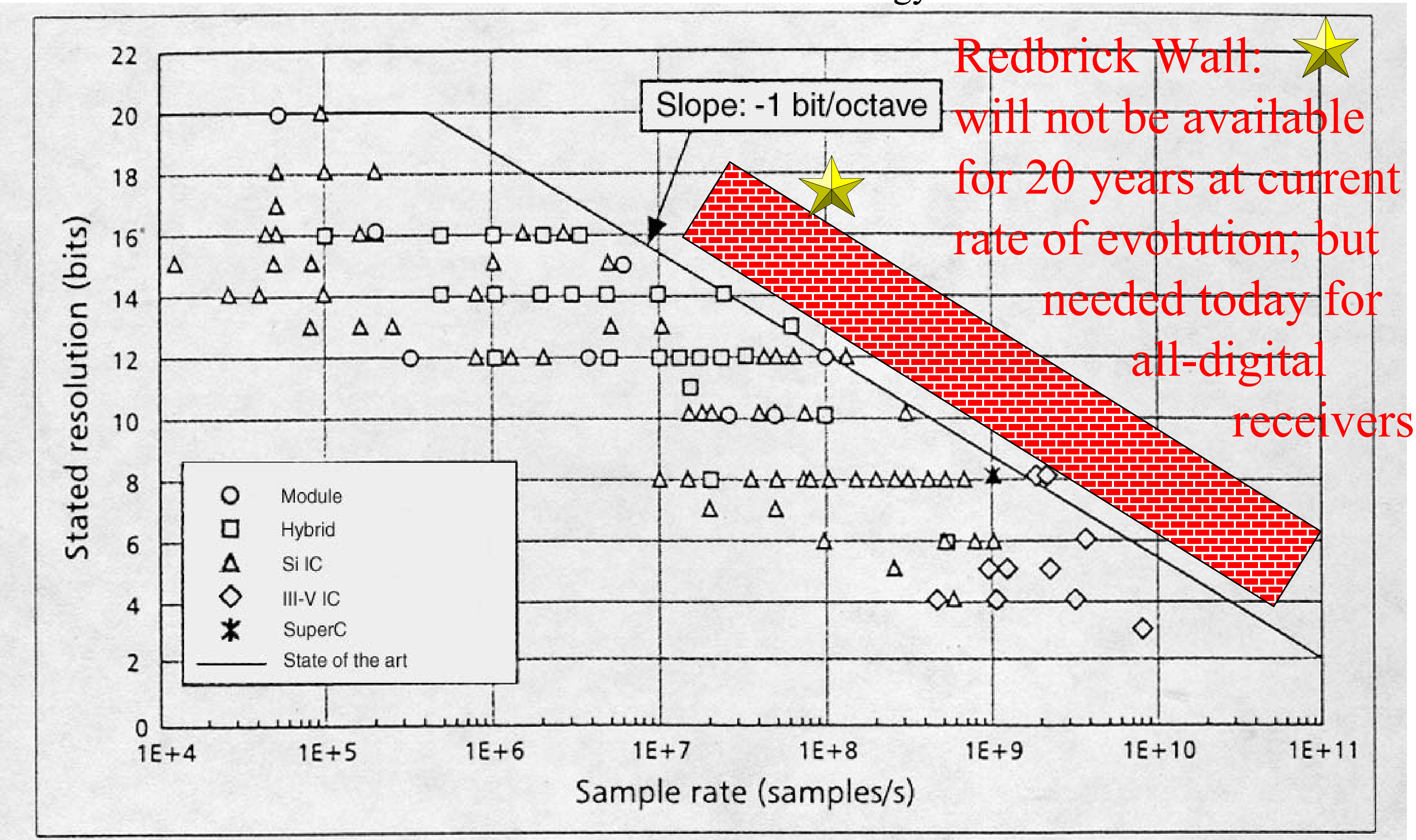


Figure 1. *A survey of analog-to-digital converters.*

Adapted from R. H. Walden, *Performance Trends for Analog-to-Digital Converters*, IEEE Communications Magazine, February 1999, pp. 96 - 101.

Next Steps

- **Economic Assessments:**

    1. **Develop more convincing arguments that the benefits of consensus-based planning for selected compound semiconductors outweigh the costs associated with such planning.**

    2. **Determine economic advantages and disadvantages of future market scenarios.**

Next Steps (continued)

3. **Collect data as a function of time on the ratio of Si CMOS incompatible content to Si CMOS compatible content in product categories. Such data will quantify the extent to which compound semiconductors have lost market share to Si and SiGe based technologies that are compatible with Si CMOS processing.**

4. **Gather market sizes, specifications, acceptance criteria for starting materials (e.g., GaAs wafers), etc.**

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Next Steps (continued)

- **Workshops:**

  1. **Identify key subsystems and technology performance gaps between what is available today and what will be needed; e.g., to make WRTDV a reality.**

Next Steps (continued)

2. **Rank technology gaps according to perceived technical difficulty; illustrative examples may include miniaturization of microwave filters, low power and very linear amplifiers, circuits with large numbers of HBTs and/or RTDs for high speed and high bit resolution ADCs, increasing resolution and reducing timing uncertainties in ADCs, and the like.**

3. **Rank the above technology gaps by market priorities and economic potential.**

4. **Combine items 2 and 3 to guide investments.**

Conclusions

- International consensus-based planning offers a way to determine priorities in investing funds to support additional R & D to remove technology gaps between what is available and what the markets require.

- In order to deliver its full potential, the compound semiconductor industry needs improved industry, university, and government collaborations.

http://www.eeel.nist.gov/812/itrcs.html
http://www.eeel.nist.gov/812/files/slides1.pdf

Technology Roadmaps

"No one is big enough to drive the totality of the infrastructure and pre-competitive investments on their own."

----- Avtar Oberai, formerly from IBM and a founding director of SEMATECH, in *Compound Semiconductor* **5**, 44 (April 1999).