

The International Technology for Semiconductors (ITRS): "Past, Present and Future"

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Introduction

The semiconductor industry has continued to prosper and also to foster the growth of multiple industries since the early 1970s. The main advantage of the semiconductor industry, as compared with other industries, resides in one unique factor that has made the semiconductor industry successful: "Decreases in device feature size have provided improved functionality at a reduced cost." Device linear features have indeed decreased at the rate of about 70% every three years for most of the industry's history. Acceleration to a 2-year cycle has been experienced in the most recent years. Cost per function has simultaneously decreased at an average rate of about 25–30%/year/function. Silicon technology has played and continues to play a major role in sustaining the semiconductor industry growth.

How long will the semiconductor industry be able to sustain this growth?

The past

Since 1992, the Semiconductor Industry Association (SIA) has coordinated the efforts of producing what was originally named the *National Technology Roadmap for Semiconductors* (NTRS). This document of requirements and possible solutions was generated three times: in 1992, 1994, and 1997. The NTRS has provided, during this time, a 15-year outlook on the major trends of the semiconductor industry. As such, it has become a good reference document for all semiconductor manufacturers. Most of all, it has provided useful guidance for suppliers of equipment, materials and software. It has also provided clear targets for researchers in the outer years.

The semiconductor industry has become a global industry in the '90s, as many semiconductor suppliers have established manufacturing or assembly facilities in multiple regions of the world. Similarly, the suppliers to the semiconductor industry have established worldwide operations. Furthermore, alliances, joint ventures, and many forms of cooperation have been established among semiconductor manufactures as well as among equipment, materials, and software suppliers.

The above considerations have led to the realization that a document that provides guidance for the whole industry would benefit from inputs from all regions of the world that have leadership activities in the field of semiconductors.

The present

This realization has led to the creation of the *International Technology Roadmap for Semiconductors* (ITRS). The invitation to cooperate on the ITRS was extended by the SIA at the World Semiconductor Council in April of 1998. The offer was enthusiastically accepted by the trade organizations of Europe (EECA), Korea (KSIA), Japan (EIAJ), and Taiwan (TSIA). The initial collaboration of these five organizations produced the ITRS 1998 Update, which consisted of a comprehensive revision of the 1997 NTRS tables. Last year, the five regions have jointly produced a new edition of the semiconductor industry roadmap document—*The International Technology Roadmap for Semiconductors: 1999*. The 2000 ITRS Update is presently underway.

As reported in the 1999 ITRS, the number and the difficulty of the technical challenges that need to be overcome continue to increase as technology moves forward. The red areas, signifying "No solutions yet", are in most cases shown within a 5-year reach. Traditional scaling, which has been at the basis of the semiconductor industry for the last 30 years, is indeed beginning to show the fundamental limits of the materials constituting the building blocks of the planar CMOS process. However, it is clearly outlined in the 1999 ITRS that new materials can be introduced in the basic CMOS structure to replace and/or augment the existing ones to further extend the device scaling approach. Since the assimilation of these new materials into the modified CMOS process gives the device physicist and the circuit designer improved electrical performance similar to the historical trends, this new regime has been often identified as "Equivalent Scaling." It is expected that these new materials will provide a viable solution to extending the limit of the planar CMOS process for the next 5–10 years.

The future

Despite the use of these new materials, it will be challenging to maintain the historical rate of improvement in electrical performance of about $2\times$ every two years in the high-performance components by relying exclusively on improvements in technology. Innovation in the techniques used in circuit and system design will be essential to maintain the historical trends in performance improvement. To achieve this result it is expected that the integration of multiple silicon technologies on the same chip and a closer integration of package and silicon technology will be necessary. This emerging product category is identified as Performance System-on-a-Chip (P-SoC).

On the other hand, cost-effective solutions will require an assessment of the silicon technology complexity that can be afforded for a given cost. Specifically, given a system cost target, what technology complexity can be afforded? This product category is identified as Cost-effective System-on-a-Chip (C-SoC).

Finally, as the ITRS looks 10–15 years in the future, it becomes evident that most of the

known technological capabilities will be approaching or will have reached their limits by then. In order to continue providing the computer, communication, consumer, and other electronics industries with more efficient building blocks, it becomes necessary to investigate new devices that may provide a more cost-effective alternative to planar CMOS in this timeframe. Adequate preparation for this potential transition must include starting to identify the possible candidates as early as possible and, then, systematically testing their feasibility.

Conclusions

The planar CMOS silicon gate technology resulted from technical investigations initiated in the 1940s. However, these early studies did not lead to the start of the semiconductor industry, as we know it today, until the late 60s. It would be difficult for any single company to support the progressively increasing R&D investments necessary to evolve the technology from Traditional Scaling to Equivalent Scaling, and also provide the resources necessary to investigate and develop a set of new devices usable beyond the limits of CMOS. The contributors to the ITRS agree that much of the R&D activities can be carried on if multiple companies agree to jointly operate in the shared "pre-competitive domain."

It is the purpose of the 1999 ITRS, of the 2000 ITRS Update, and of future ITRS documents, to provide a set of up-to-date reference documents of requirements, potential solutions, and their timing for the semiconductor industry. These documents have already provided a common reference for international forums that have initiated discussions on cooperation among the leading silicon semiconductor manufacturers and the leading suppliers of equipment, materials, and software, as well as researchers from university and government laboratories. It is hoped that in the near future, through cooperative efforts among the various ITRS participants, the challenge of R&D investments will be more effectively and more uniformly shared by the whole semiconductor industry.

In addition, as the integration of multiple functions (e.g., voice, data, video etc) continues as driven by the recent growth of the Internet, it becomes necessary to also integrate multiple hardware and software technologies in order to provide the best cost-performance solutions to the users. Not all of these functions can be realized by simply using silicon technology alone. This has become apparent in the last few years as non-silicon semiconductor devices and also optical devices, for instance, have experienced an unprecedented growth. In an effort to better synchronize the availability of all these technologies and to also further reduce the cost of the overall solutions to the users, it would appear beneficial if silicon and non-silicon semiconductor roadmaps could be more closely aligned.

I would like to take the opportunity of this presentation to encourage the non-silicon semiconductor experts to begin cooperating with the mostly silicon-oriented ITRS committees and working groups to explore the possibility of closer and continuously strengthening cooperation. I believe that both users and producers could benefit from this activity.