SMC 101

Action Plan for Survival - 2010

(Identification of Roadblocks for Success)
Table of Contents

Part 1 - Introduction

Part 2 - EMS Providers

Part 3 - Multinational OEMs (Set Maker)

Part 4 - Mounting Substrate Manufacturers

Part 5 - Global Material and Equipment Suppliers

Part 6 - Electronic Components (Die, Packages, and Discretes)

Part 7 - Academia

Part 8 - Governmental Agencies

Part 9 - Conclusions

Part 10 - Action Items

Annex A - The Surface Mount Council
SMC 101 Action Plan for Survival - 2010
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Part 1 - Introduction

Scope

The first attempt of the Technology Vision 2010 was an analysis of existing industry roadmaps that were developed by a cross-section of technology experts. Industry working teams addressed areas of similarity, gaps, and inconsistencies between the individual roadmaps. These areas of differences were noted in the summary section. Items not common to the roadmaps were noted, but not used in the direct comparison. Other information as well as the expertise of the participants was used to evaluate the analysis and develop the summary and recommendations contained in the individual sections. The goal of this paper is the identification of Roadblocks to Success.

To help identify those "roadblocks" the Surface Mount Council has developed this analysis of the state of the industry. This analysis was begun in January of 2000 and is now being presented to provide an overview of the changes and challenges within our industry. Surface Mount Council members currently active on the National Roadmap Coordinating Committee and the major national electronics roadmaps, e.g., NEMI, provided input for this paper. As with the original Vision 2010 document this paper is not intended to provide a review of the national roadmaps. Rather this is an analysis intended to stress where action needs to be taken. The Surface Mount Council will attempt to act as a catalyst for future action to remove the "roadblocks" our industry faces.

Content Overview

This section will first list the issues identified by the Council in its analysis. This list is not comprehensive, however, it does represent an assessment of the major issues the major industry players will need to address.

Who are these "players"? They consist of groups that make up the "electronic food chain", e.g., EMS providers, OEMs, substrate manufacturers, material and equipment suppliers, component vendors, academia and government. Note that the latter two have been added because of their influence in the realms of R&D and regulation.

Each of these "players" will face the issues described in this paper. Accordingly each "player" has been given a chapter in which council members review how the issues affect this segment of the industry. At the end of this paper summary sections will describe a set of conclusions and actions items that apply to these industry segments. A final section is provided to acquaint the reader with the Surface Mount Council and its activities.

It is our intent that by highlighting the needs of the industry and describing the issues we have in common, action may be taken for the betterment of all. No one segment of the industry, nor academia and government, is able to deal with these issues alone. Only by working together will our progress continue.

Issues
This Vision 2010 report covers a list of major issues identified by the Surface Mount Council. As noted above they are addressed in the individual parts that make up this report. The issues are:

- **Mounting Substrate Manufacturing**
  - Scaling with Silicon
  - Imbalance domestic versus International
  - Cost, Yield, Capital Investment, High Density Interconnect
  - No Value added factor except location for Domestic
  - Environmentally friendly laminate (flame retardant)
  - Buried resistor/capacitors
  - Lack of OEM support for modification (EMS filter)
- **Assembly**
  - Use of no-lead solders
  - Laminate compatibility (@higher temperature)
  - Printed Board Land Surface finishes
  - Fluxes and cleaning
  - Inspection and Test
- **Components**
  - Use of lead-free finishes on leads
  - Lead-free balls for array packages
  - Void acceptance regarding reliability
- **Reliability**
  - Moisture sensitivity
  - Chip mounting material performance requirements (IPC-JEDEC)
- **Recycling (take-back)**
  - Identification of owner of the problem
  - Appropriate incentives (non-negative)
- **R & D (consortia - new paradigm)**
  - Lack of commitment except through consortia
  - Lack of long range R&D vision
- **Standardization (chicken and egg)**
  - When to start effort is a question
  - To many choices for solving the same problem
  - Consensus versus defacto standards
- **System Design and Architecture**
  - Lack of a structure for Design flow from silicon to the electronic assembly
  - Incomplete Data during transfer to manufacturing
  - No rules for system cohesiveness
  - Hardware and process standardization
  - Data e-commerce model Transfer and feed back
Industry Overview

The electronic interconnection food chain consists of three basic links. It begins with the fabrication and assembly of semiconductor packages and its associated contract packaging industry. The next link is the printed board substrate manufacturing industry. The final link is the Original Equipment Manufacturer (OEM). However, in today’s environment there is a paradigm shift in the historical business model: OEMs are outsourcing much of their previous design and assembly activity to the rapidly growing EMS industry. This has resulted in the rapid development of a sophisticated EMS (electronics manufacturing services) industry.

This change in the economic paradigm is also accompanied by a technical challenge arising from the rapid growth of functionality of silicon devices. This challenge now facing the printed board substrate manufacturing industry is scaling with silicon. This challenge comes directly from the International Technology Roadmap for Semiconductors roadmap. Figure 1 illustrates this increasing demand on printed wiring board density.

![Figure 1 Scaling with Silicon](image)
So what's driving the new trend? More I/Os, shorter lead length, smaller packages, finer board features and smaller interconnecting vias. Today's solution to the component-packaging problem is not leads on two sides versus four sides, nor is it gull-wing, versus "J" lead as the I/O of choice. The array package has come into its own, and a sphere or ball has become the lead configuration of choice. Designers are accepting the new package as component manufacturers find cost-effective ways to assemble the die into the array package configuration. Small form factor is the key; thus closer proximity of the balls to each other. Pitches of 1.5, 1.27, and 1.0 mm are common. Higher density packages are using 0.8, 0.75, 0.65 and even in some cases 0.5 mm pitch to gain additional miniaturization.

Note that this trend affects not only the substrate fabricator. This trend places additional burdens on the Global Material Equipment industry, the OEMs, and the EMS industry. Thus, from the advances in technology at the silicon level, change is rolling through the industry. And this change in technology and economic structure, i.e. the changes in OEMs and EMS providers, poses new challenges for not only the electronic industry but also academia and government.

Why might this paradigm shift affect the governmental and academic "players"? As technology speeds up the pace and silicon and substrate try to match capabilities the shift in fortunes between OEM and EMS are affecting the basis for technology development in the U.S. No longer are budgets geared to the R&D support of the past. Thus new sources of technology need to be developed domestically if the U.S. is to maintain any technology leadership. Two potential sources are academia and government.

There are a few universities who do research in interconnect technology, but it is very limited. It appears that Georgia Institute of Technology (Georgia Tech) has the biggest interconnect budget. Others that have some interconnect technology activities include Auburn University, Cornell, Binghamton University, Florida International, Rochester Institute of Technology, and the University of Maryland. NEMI recently published a list of 19 universities doing research in some form of packaging. While academia wrestles with R&D issues the former leading supporter of U.S. R&D, the federal government, is very unclear as to the magnitude of its future support.

In the chapters following we hope you will gain some understanding of the issues. And in the conclusion and action item section you will have a chance to look at proposals for addressing the needs of the U.S. industry. Together the industry can address these issues. To that end we present this summary as a basis for our action together.
Part 2 - EMS Providers

Situation Analysis

Fundamentally, the electronics industry has changed the way “original equipment manufacturer” (OEM) companies assemble and manufacture electronic products. The reason for this change is often prompted by economics and market strategy. Through ‘strategic outsourcing’, OEMs can utilize extensive manufacturing capability, redirect resources toward product development, and improve inventory distribution. Time to market and cost control are two primary concerns for manufacturers attempting to maintain or gain competitive advantage over their adversaries. The companies have grown to rely on outside electronic manufacturing service (EMS) providers for a number of activities. Originally adapted by the OEM companies who needed to move into the market quickly or to supplement in-house resources without excessive economic impact. Off-loading, out-sourcing, farming-out, whatever the term used to describe the use of out-side services for assembly and testing, the EMS provider continues to play a significant role in an ever expanding electronics industry. And, although many OEM companies maintain in-house manufacturing capability, a significant number have downsized that activity, focusing instead on their core capability and managing capital.

Profile of the EMS Industry Though 2010

There are three major changes taking place in the Electronic Manufacturing Services Industry. These are:

- Design and Prototype Shops Near Customer
- Micro-factories: Dedicated production Lines and Facilities
- Global Business Units w/ a Single Worldwide Customer Manager

Capability from EMS Company to EMS Company will vary a great deal. The smaller service providers, for example, may not have the resources and staff available to plan and purchase materials or perform all services required. In this situation, the customer-company will typically furnish a ‘kit’ of parts and materials for a specific quantity of assemblies and supply specialized equipment for unique assembly or testing of the finished product. Both small and medium sized EMS companies, however, can expect to grow and expand. This growth will be primarily through the ability to respond quickly to their customers needs, providing specialized capabilities and by supporting product introduction or furnishing a necessary additional source for sustaining product flow into the market.

The smaller assembly company may continue to off-load some very specialized functions (electrical test, burn-in) to other local service providers. In addition to quick-turn assembly, some of these service companies have set-up specialized or ‘niche’ capability for prototyping, rework repair and/or product upgrading as well as pack-out or shelf ready packaging for direct shipment to distributors. Advantages that the local service-company can offer is a more direct line of communication, ready and skilled workforce and quick response to customer needs.

Local Service Provider

Manufacturing services provided by localized supplier companies have flourished for decades, offering quick response to customers, reasonable costs and flexibility. Many are not expected to
furnish materials, although some will retain an inventory of common materials and components. The primary benefit offered by these service companies is a ready resource of labor and equipment. The local service provider may also offer special skills or capability not available within the customer OEM company or they can supply the labor pool to buffer the highs and lows of the OEM customers product demand.

**Domestic Provider**

The domestic service provider will often have the resources and capability to manage greater responsibility for the OEM customer. They are typically able to offer turnkey services, purchasing and managing materials, often duplicating the OEM’s manufacturing systems and processes to provide parallel capability to their customer. The domestic provider may also set-up satellite facilities near their major customer companies, strengthening their value to the principle organization with better communication and response.

**Global Provider (Virtual OEM)**

A majority of the largest manufacturing service providers have headquarters in North America. They have grown outward, through the years, often from a local service or OEM captive operation. The multinational supplier can offer many advantages that local or domestic suppliers cannot match. They will often have direct access to low cost material sources, and when facilities are located in Latin America or Asian locales, low cost labor as well.

**Continuing Growth Trend in the EMS Industry**

The growth in manufacturing services has occurred in three significant ways. The ‘green-field’ bricks and mortar method, prompted by the visionary entrepreneur or to comply with a specific contractual agreement. Through merger, partnership, acquisition or, what seems to be a prevalent trend, taking over or buying-out the OEM customer assembly operations, many EMS providers are expanding from an organization offering a limited or specialized capability, to a more diversified service provider. Many of the larger EMS providers have become even larger through acquisition. The trend by several of the OEM companies is to sell their existing manufacturing operations to the service provider. Entire in-house manufacturing assets as well as personnel, are transferred to the service company, often with agreement to maintain a level of manufacturing commitment to the OEM. In some cases, companies in the same business will merge to gain the benefits of combining assets and resources, however, many find the union unworkable due to cultural differences, and management styles. Full acquisition is often more efficient because partnerships derived from merging two companies rarely succeed.

**Data Transfer**

With the aid of new and efficient CAD tools, product development takes less time, often far less time than it would require to plan, order equipment and materials and set-up a factory to manufacture the product. Many of the service providers have designed their factories with a number of flexible systems allowing them to configure assembly systems to meet specific and often specialized processes with only minor tooling and set-up changes/fees. Computer hardware and software represents up to ten percent of the EMS companies purchases (based on the percentage of sales). This expenditure is exceeded only by the investment in manufacturing and test equipment, equipment primarily related to surface mount assembly, representing approximately forty-five percent and fifteen percent allocated for automated test systems.
Financial and Material Management

Success and failure within a single company may be largely determined by business efficiencies achieved in purchasing, material management, machine utilization and assembly process controls. According to a recent IPC-ARMC (Assembly Market Research Council) report, the EMS industry provides the fundamental manufacturing services to high-technology companies. The manufacturing service provider may not be classified as a high-tech organization; many of these companies provide highly automated assembly services. Most have extensive expertise and capability such as surface mounting, ball grid array and flip-chip (direct die attachment). Capitalization and investment for the equipment and facilities to accommodate growth is essential to the health of the EMS Company, providing the efficiencies of automation needed for maintaining lower costs for manufacturing.

Material management plays a significant role in controlling manufacturing costs. Although the OEM typically maintains control over the qualification of suppliers of the materials for the product, supply-chain managers rely more and more on the EMS Company for management of these materials. And, although the OEM may have negotiated excellent terms for key components from suppliers, many manufacturing service companies have developed favorable alliances with material suppliers as well. Utilizing both direct and customer negotiated sources for material allows the EMS Company to establish reliable supply channels and better manage inventory level (and cash). Communication, accurate requirement forecasting and up-to-date information access is paramount to maintaining control of all aspects of the manufacturing process.

Customer and Supplier Relations

A strong supplier-customer relationship is important. Continued changes in the relationship between EMS companies and their customers, typical of that noted above, are expected. Once the out-sourcing of assembly was restricted to ‘board-level’ products only, but today the industry has evolved from sub-system assembly to full system integration (the manufacturing of the entire product) as well as distribution (packaging and shipment) and after-market support (repair and service). Where the relationship in the past was more “transaction based”, with the OEM choosing the supplier offering the lowest price, the current trend is moving more toward a partnership, allowing both customer and service provider to achieve strength through profitability. These alliances require a great deal of trust and mutual respect between supplier and customer. There was a time when a purchasing manager felt successful by hammering the price so low that the supplier could not profit from the service provided. These kinds of transactions are not healthy, often forcing the supplier to decline the business altogether. The customer-company then had to expend their energy and resources to qualify a new supplier and rebuild the business relationship.

Strengths and Weaknesses

The Electronic Manufacturing Service industry, prompted by the OEM's strategy to out-source more and more assembly operations, is expected to experience a twenty to twenty-five percent compound growth through 2005, a trend that could easily continue through 2010. This projection is based on the continued proliferation of electronic products, an industry growing three to four times faster than the gross domestic product both in the US and globally. This growth includes current market players, new entrants to the industry as well as acquisitions and mergers. Growth from acquisitions, according to recent IPC-ARMC reports, will be most pronounced in large OEM companies. The electronic manufacturing service provider image has evolved from the bare-bones, low-tech, so called ‘board stuffing’ house, to a very sophisticated, highly skilled network, capable of providing access to the latest in manufacturing technology and methodology.
As witnessed above, many large EMS companies are forming the strategic alliances with OEMs and purchasing existing captive facilities. These decisions by the OEM to increase the out-sourcing of board and system assembly operations can have an immediate impact on the growth of the EMS industry, adding hundreds of millions of dollars of revenue to the market.

OEM and Contract Manufacturing acquisitions and mergers are expected to continue at a high level. The ten largest EMS companies will capture about fifty percent of the world’s requirement for out-sourcing. The global provider will be expected to furnish seamless product introductions and offer transfers to multiple facilities through the world. Most of these companies already furnish ‘paper-less’ electronic commerce, many can take over material planning and purchasing as well as coordinate material distribution within their facility network. The customers will expect to have access to the global suppliers costs of materials and cost of services for each region, thereby accommodating cost-based pricing models, allowing the OEM self-quoting capability.

The OEMs will attempt to ‘commoditize’ the EMS supply market and expect material cost differences to be minimal from one supplier to another. Service capability levels and responsiveness will be the primary EMS differentiation and because of electronic commerce will instantly be able to locate and furnish pricing for any component worldwide, the current value-add procurement and stocking services offered by distributors may diminish. And, although OEMs will often transition into a ‘virtual corporation’ supplier and the EMS provider becomes more OEM-like, the OEM companies will loose a great deal of manufacturing expertise.

Many of the processes and techniques in manufacturing were developed by the OEM companies. Some of the giants in the industry maintained extensive research and development facilities, often inventing unique materials, methodology and solutions for a wide range of products. The OEM, in turn, transferred the special technologies or process techniques to the service provider as needed but retained the primary expertise and skills within the company. As the trend toward out-sourcing manufacturing increases, so to has the expectation that the EMS provider will take on the responsibility for developing the solutions needed for manufacturing excellence.

**Product Quality and Reliability**

The expectation for product quality remains very high for the OEM. With the advent of new component packaging, higher density circuit fabrication and attrition in knowledgeable of in-house personnel, however, companies are beginning to loose a great deal of their former leadership in technology (relying more and more on the EMS supplier to furnish this expertise).

In regard to maintaining a level of quality in goods manufactured, many OEM companies are relying on industry-recognized standards for establishing assembly requirements and assessment. Through uniform education and training, the EMS companies are complying with their OEM customers requirements to improve individual "discrimination" skills and to improve accuracy of discrimination between "acceptable" and "not acceptable" electronic assembly quality. Programs have been developed to teach individuals the reasons for the accept/reject criteria for applicable "class" or "classes" of production. The training intent is to enhance the operators’ efficiency, motivation and ability to consistently and correctly apply the discrimination criteria. Standards and publications typical of the IPC-A610 for example, are designed to serve the public interest through eliminating misunderstandings between manufacturers and purchasers. The documents and standards are intended to facilitate improvement of products, and assist the purchaser in selecting and obtaining, with minimum delay, the proper product for a particular need.
Relying totally on the expertise of the supplier company may not be prudent. Recognizing their vulnerability, OEM companies may actually bolster-up engineering and retain a somewhat limited level of manufacturing capability. In some cases, OEM’s have already begin to regain a level of manufacturing capability and related core competencies through reacquisition of part or all of an EMS company.

**EMS Industry is Growing Stronger**

Each day brings news about the Electronic Manufacturing Services (EMS) Industries alliance with a major OEM or acquisition of an OEMs facility. For example, it was recently announced that one of the top five multinational assembly service providers head-quartered in North America, agreed to take-over a “significant portion” of a major Canadian based communications company. The program will be worth ten billion US dollars over a four-year period, the largest deal of its kind in the contract manufacturing industry. The OEM estimates that it will save up to three hundred million US dollars per year as a result of its out-sourcing to this and other EMS companies. The same company acquired two manufacturing facilities from a customer based in Sweden; one factory was located in Sweden, the other in France.

A leading publication in California’s Silicon Valley stated “the move toward out-sourcing is indicative of the electronics industry’s growing reliance on the contract manufacturers”. It is estimated that fifteen percent of the electronic products manufactured in the world today is out-sourced to an EMS provider. As confidence in the service-company becomes more secure, the deals are becoming somewhat routine and larger in scale. This type of relationship allows the OEM to operate leaner as well as smarter and it provides more flexibility in planning global market strategy.
Part 3 - Multinational OEMs (Set Maker)

Situation Analysis

The Original Equipment Manufacturing (OEM) or "set maker" segment of the electronics industry was for years the basis of manufacturing in both the United States and the rest of the world. The acronym OEM at one time was a well-defined concept evoking images of a large and powerful economic engine that was, to a great extent, self-contained. Today that image is no longer as accurate as it once was. Social and economic changes are slowly but surely changing what defines an OEM. As noted in the Electronic Manufacturing Services (EMS) section (Part 2 above) OEMs are moving away from their traditional structuring of vertical integration and control to a distributed or horizontal structure. This section will address the evolution of the OEM and the impact of those changes.

Vertically Integrated (Design, Build, Market, Distribute)

At one time the acronym OEM was intimately associated with the concept of vertical integration. Manufacturing within such a company was self-contained in the sense that product concept generation, product design, research and development supporting concept and design, product manufacturing, distribution and service of the product were all done within the same economic umbrella of the OEM and its various business and operational units. This integration of functionality was often times so complete that many companies not only did final assembly of a product but also controlled (internally) the manufacture of such pieces of that assembly as printed wiring boards, metal housings, integrated circuits, passive devices, e.g. resistors, and plastic molded parts. Indeed some OEMs were so self-contained that they also handled product end-of-life functions such as recycling and disposal.

This model of a single company doing all functions associated with a particular market was, through most of the 20th century, dominant in many industries. Within the electronics industry notable examples of this model were such giants as IBM, Delco, and the AT&T/Bell System.

Today, few of the formerly vertically integrated companies within the United States operate under their old paradigm. Globally, some European companies and many Japanese companies still hold to the vertical integration model of operation. However, even within those last bastions of vertical integration many companies are "farming out" many parts of the product realization process formerly performed internally to outside vendors. This new approach to product development is a "horizontal" as opposed to a "vertical" model of organizational structure.

Horizontally Organized (Concept, Marketing, Distribution)

In place of the vertical model of organization the horizontal structure for large OEMs began to appear in the late 20th century. Whereas the old model was based on a concept of all functions being controlled within a single economic entity, the new model uses a concept of distributed functionality. At the core of such an organization there may be a concept center focused on a particular market segment. This concept center may also be affiliated with product development, manufacturing, test, distribution, and service centers. However in the new horizontal model this is rarely the case. For beyond that core segment, the functions of design, research, manufacturing, distribution, and service of a product may be spread across multiple independent companies. These independents may function as business partners or as vendors to the "OEM". Their relation to the OEM may thus be one of shared risk or limited to transfer of goods and services for cash.
Within this model, functions such as design, research, and manufacturing are now, to a great extent, outside of the control of the OEM. Indeed, for economic viability, many of the functions formerly a central part of a vertical structure, e.g., research, have been eliminated in many countries in the name of “cost containment”.

The horizontal model allows many companies to operate with less capital investment than the vertical model of integration, i.e. it lowers the “table stakes” for entry into the electronics manufacturing game. No longer does a company need to do everything. Now the functions previously kept internal can be farmed out to willing vendors who make it their business to maintain expertise in a particular area.

For the global market the horizontal out-sourcing model can provide immediate manufacturing entry into an over seas market that requires in country manufacturing as sine qua non for product sales. Such localization allows an OEM a low capital pathway to establishing localized manufacturing, distribution, and service in a new market. It may also be a way to improve margin if the labor costs in this market are low relative to domestic manufacture.

**National OEM Market Percentage and Impact**

At present the year 2000 U.S. market for electronics assembly is on the order of 800 billion dollars per year. The OEMs contribute around 650 billion to this market with the Electronic Manufacturing Services (EMS) contributing the rest. However, the rate of growth in the OEM segment is about 7% while the EMS segment is growing at 25% per year.

In 2005 the U.S. electronics market is projected to be 1.2 trillion dollars. The OEMs are expected to provide only about 66% of this total.

By 2010, for a U.S. market of approximately 2.5 trillion dollars, OEMs and EMS providers are projected to split the total market between them.

**Financial Conditions**

The greatest strength of the horizontal versus vertical integration of model is the lowered threshold of capital investment needed for entry into the "OEM" world. One need not have the cash resources (or people resources!) of one of the old OEM giants. Now a company, through careful partnering and vendor selection, can direct their available capital into the most lucrative areas of return.

It should be noted that this model is very popular with Wall Street. Thus the move towards horizontal integration is often driven by favorable reviews from financial analysts with resulting increases in stock value.

**Customer Relations/ Supplier Relations**

In the old vertical model customers were external and suppliers were, to a larger extent than today, internal. The control exercised over suppliers was greater given that they were an integral part of the product realization team. (This does not imply that all companies were just large, happy
families. But it means that the lines of communication were quite probably more open and leverage from within was always possible through sharing of a common management structure.)

In the horizontal model suppliers are totally external as are customers. Thus the relationship between both must be carefully cultivated if a company is to deliver the right product at the right time for the right price. Note that this need for careful balancing of business relations may take the emphasis of product development off of technological innovation and shift it into a need for better control of deliveries, cash flow, etc. In other words, given that a company can do only so many things well, a horizontally organized business may shift away from leading edge innovation given a lack of internal resources.

An emerging issue that will impact companies operating under either model is the issue of product take-back. For electronics a new era is coming driven by legislation in Europe that makes a manufacturer responsible for a product forever, i.e. from concept through end-of-life product disposal. In the vertical model the concept of product ownership at end-of-life, i.e. who is the manufacturer, is well defined. For a horizontally integrated company where functions such as design, manufacture, and distribution may be contracted out the "ownership" may become somewhat nebulous.

**Strengths and Weaknesses**

The vertical model allowed for a great deal of control. Internalizing all functions in development allowed a company to mesh concept, architecture, design, technology choices, and manufacturing in the product realization process. In addition, given the internal nature of all phases of development the vertically integrated companies tended to give heavy support to research and development. They assumed that technology was always to come from within. And accordingly, to maintain their technology edge, they invested to prepare the way for the products of tomorrow. All of these were achieved at considerable cost in capital investment. Large sums of cash were needed to fuel these vertical juggernauts.

The horizontal model, on the other hand, is a "low level entry model". By "importing" technology or "outsourcing" functions such as design or manufacturing there need not be the same large capital investment as for a vertically integrated company. But this "reduced cost" proposition is only achieved by sacrificing (or eliminating) some of the functions of the vertical system. Today, one of the more notable items to suffer is research and development. This is especially true in the area of basic research. More and more industry looks to government, academia, and consortia of industry partners to provide the forward looking research that used to be within the purview of the old, vertical OEM.
Part 4 - Mounting Substrate Manufacturers

Introduction

Mounting substrates are those substrates that are designed and manufactured to serve as a base for other electronic devices or components and include substrates for direct chip attachment. This would include single chip packaging substrates used to interconnect electronic components to traditional printed circuits and substrates used to interconnect other substrates, for example, backplanes. The manufacturing community for these types of products is somewhat fragmented with different manufacturers specializing in each of the areas with some limited overlap. According to the non-profit industry organization “Interconnect Technology Research Institute” (ITRI) 1999 White Paper on Domestic PWB Technology, the worldwide interconnect market needed to support the electronics industry in the year 2000, will be $35 billion. The US portion of the $35 billion total in this same year is expected to be over $10 billion. If we add in the exploding silicon chip carrier market the $35 billion could grow to over $50–$55 billion.

The economic and strategic security of the U.S. depends on a strong electronics industry, which in turn depends on a strong interconnection industry. Printed wiring boards form the foundation both literally and figuratively for virtually all electronics in the world. Printed circuit boards and electronic assemblies are the basic building blocks in all electronic systems, which in turn, support every other critical technology in the U.S., and drive productivity in almost every industry.

From the same ITRI report, the following paragraph summarizes well, the important issues:

“The PWB is the essential “glue” that molds individual components into today’s advanced electronic systems. Increasingly sophisticated users are demanding light, highly portable systems that offer more functions but still keep the costs low. As a result, electronic manufacturing can no longer be partitioned into discreet market segments such as semiconductors, passive components, and PWBs, which are designed and built independently and assembled into a system by yet another party.

The new systems are requiring more functions per unit area, which drives more complexity into the interconnecting structure or PWB. The PWB itself is becoming an active part of the electronic circuit, as well as the structural support and package of the system. PWB design and manufacturing capability ultimately determines what and how electronic components can be used and the resulting system size and weight.

Reliable portable systems are required in every industry. Consumer demand for hand held items seem insatiable. New markets for PWBs are opening with the rapidly expanding use of organic substrates in semiconductor device packaging components such as Ball Grid Arrays (BGA) and Chip Scale Packages (CSPs).”

Situation Analysis

It is clear that significant challenges lay ahead for the electronic interconnection industry in general and the printed circuit industry in particular. Printed circuit technology is increasingly being tapped to solve the problems that come with demand for ever greater functionality and performance in
ever smaller and lower priced electronics. The solutions lie in an array of newer manufacturing
technologies for printed circuits being developed to meet the demands of higher density electronic
products. These new technologies are broadly labeled as either high-density interconnection (HDI)
or microvia technologies.

While there are presently many printed circuit fabrication technology methodologies, 20–30 by
different accounts, each process is somewhat unique and has some special requirements,
materials or processes. The capital investment required to keep pace with these technologies will
be significant. And, while some of the fabricators existing chemical processes may be compatible
with the newer processes, fabrication equipment and methodology may be very different. For
example, lasers, plasma and photoimaging can all be used to make microvias, their respective
equipment requirements, for example, are quite unique. This means that the choice of a process
employed to make microvias must be made carefully. Moreover and adding to the confusion, there
is the matter of intellectual property ownership relative to the various microvia processes, which is
not yet clear. Licensing fees and royalties, if required, will likely vary from product to product. As a
result many independent manufacturers in the US seem to be reluctant to make the investment
necessary, with only a minority having made the transition to a microvia technology and/or some of
the new co-lamination technologies. As far as HDI, the US printed circuit manufacturing community
has lost ground to their global competitors especially those in Japan.

The lost ground, to a degree, lies with the fact that the merchant supplier of PCBs in North America
have profit margins which are very thin, limiting their ability to make investment for new or more
efficient equipment or research and development of new processes. Design tools, which have
been slow to develop the capability to design PCBs with microvias is also an obstacle.

OEMs have significantly reduced or abandoned manufacturing and now outsource to those
suppliers who can provide the lowest prices. The selection is often made without regards to the
environmental impact of their choices. Printed circuit suppliers from developing countries can afford
to make lower cost product, not only because they have lower labor rates, but also because they
are not held to the same rigorous environmental restrictions as US based manufacturers. Several
conditions presently appear to restrain the US and North American suppliers of PCBs and a
continuing attrition of the US based PCB manufacturing industry is to be expected. Unless, of
course, there is a shared recognition from both supplier and the customer that there is need for
change in attitude and approach to business. Except for the efforts of ITRI to try to rally the printed
circuit industry though shared research, little has been achieved in developing high volume
capability for HDI and microvia fabrication in North America.

**Single Chip Substrates**

Significant opportunities exist for the technologically competent PCB manufacturer, especially in
the area of substrates for the packaging of ICs. Single chip substrates have rapidly been adapted
as the IC packaging technology moves away from peripheral leads to area array. HDI substrates
are ideally suited to the translation and redistribution of the fine pitch bond pads of the IC chip to a
format suitable for conventional board level assembly. Single chip packages range from simple to
complex and employ both rigid and flexible substrates. Most of the early volume for area array
packaging is being produced using one and two layer circuits. These simple substrates will be
suitable for I/O counts up to approximately 200, depending on the I/O pitch.

**Multi Chip (System in a Package) SIP Substrates**
Multichip modules (MCM) were expected to dominate the world of electronic packaging in the early 1990s, however, they were not able to deliver their promise due to several factors. The two most important factors were substrate cost and lack of known good die and very limited reworkability. The concept was not without merit, however, and it is now being revisited in a slightly less ambitious manner. To distance the newer modified concept from the stigma of the old MCM model, the technology has been renamed as a multichip package or as system in a package (SiP). The differences are subtle but important. One of the major differences is that the expectations for rework have been largely abandoned. This means that the assembly is viewed as a unit and if it fails test, it is discarded. What makes this possible is the fact that lower cost substrates are now available from the PCB manufacturing community replacing their expensive predecessors. The other enabler is the fact that chip yields are constantly improving which helps to reduce the risk. This type of product by nature of its role as an integrator of various chips tends to be more complex than the single chip package described above.

**Product Board Substrates**

These substrates are the primary representatives of the printed circuit industry and are the proving ground for new microvia technologies. These typically lower circuit density products are being challenged by the new chip package formats reviewed above. As a result, they too will, in the future, become increasingly more complex while pressure by the OEMs to reduce their cost remains in force.

**Back Plane (Connector Interface) Substrates**

Backplanes have historically been characterized as circuit boards populated with rows of connectors into which other circuit boards can be perpendicularly plugged into and connected. There are two types of backplanes, active or passive. Active backplanes normally contain logic circuitry that performs computing functions in addition to connectors and/or sockets, which populate its surface. In contrast, passive backplanes contain virtually no computing circuitry. Historically, most personal computers have used active backplanes. However, there is presently a trend toward the use of essentially passive backplanes. With passive backplanes, the active components such as the CPU are inserted on additional product cards. An advantage of and potential cause for increased usage of passive backplanes in the future will be the fact that passive backplanes will make it easier to repair faulty components and to upgrade to new components.

Backplanes may see change in the future as area array interconnection concepts proliferate. The perpendicular arrangement of plug-in cards is not optimal, as the distance between communicating components of the system can be rather large, depending on the design layout. Planar interconnection of subassemblies to the motherboard using area array interconnections would support the high-speed busses planned for future systems. Presently new connector families are available that will allow this concept to progress. These new connectors provide area array connection and offer not only greater density but reduced parasitics associated with the shorter connections they offer.

**Flexible Substrates**

Flexible circuits, either alone or integrated with rigid PCBs (i.e. rigid-flex boards), will likely serve an expanding role in the future. The growth rate for flexible circuits is 2-3 times that of rigid boards. Already flexible circuits have carved out a healthy future for themselves as a preferred method for packaging ICs. This is in addition to the three-dimensional electronic constructions flex circuits are
commonly employed to make in many consumer products such as 35mm cameras. Inevitably flexible circuits will make their way into greater numbers of alternative packaging and interconnection schemes as the technology takes root in the minds of circuit designers. Printed circuit manufacturers should make themselves ready for such changes.

Financial

Investment and financial support for the domestic printed circuit manufacturing community has been inadequate. This is because printed circuits have long been viewed as a commodity rather than as the custom product they truly are. Price pressure on the printed circuit industry has intensified since many of the OEMs have abandoned their own printed circuit manufacturing operations. Price pressure, coupled with intense competition from offshore PCB manufacturers and the lack of allegiance of OEMs to domestic suppliers, have contributed to the stagnation of the US printed circuit manufacturing. The problem is compounded by the fact that the independent domestic manufacturer has limited resources for performing the research and development and capital investment required for them to remain competitive.

According to the ITRI report referenced earlier, the US domestic interconnection industry is comprised of over 650 printed wiring board fabricators, 500 of which have sales less than $5 million. Ninety percent of these fabricators are independent companies not affiliated with a specific OEM. This year, it is anticipated that over 97% of the PWBs will be fabricated by independents.

As stated above, printed circuits are indispensable in electronics manufacture. In 1984, the U.S. controlled 40% of the world’s PWB market. By 1990 that market share had dropped to 28% and the U.S. had lost the leadership position in the world. By 1994, the U.S. had regained market leadership again, but with a much smaller market share than before and unfortunately in areas of aging technology. Presently, the U.S. is again facing a loss of market share, especially in the emerging microvia market, for which the US is not well prepared.

U.S. PWB manufacturing can be divided into three sectors by product type: Conventional PWB, HDI (non-microvia), and microvia. Generally, products in the conventional PWB sector are defined as boards with 125-micron lines and spaces or greater. 100% of all PWB manufacturers can build this technology, and a very large percentage (>65%) builds this type of product exclusively. The entire PWB industry is very cost conscious, but this segment focuses singularly on cost with little interest in new technology developments, except if they reduce cost. Because this is the largest PWB manufacturing segment, there is significant competition between U.S. manufacturers. However, this group is also competing directly with offshore manufacturers on a price basis. The U.S. fabricators have been fairly successful in competing in this sector, particularly for small and medium volume orders and when service and turn-time are a premium. This is mainly because significant portions of their customers are from the near regional area, where they have an advantage in service and turn-time. And even though service and turn-time is important, prices on products in this sector continue to be under pressure for cost reduction. For example, prices dropped 3-5% during 1998 and 1999, slightly more than in the previous few years.

To reduce overall product costs, many of the large purchasers of low technology conventional PWBs have been buying boards from suppliers in the Far East. This trend is most noticeable in the desktop personal computer business where the PWBs for all of the top five producers of PCs in the U.S. are bought from Taiwanese suppliers. Consequently, the U.S. has lost market share and there was a strain on domestic fabricators. In the last five years, over 100 U.S. fabricators have gone out of business.
The second sector of manufacturing, HDI (non-microvia) is made up of fabricators that produce PWB's containing 100-micron or smaller lines and spaces, but do not contain microvias. It is estimated that only 10% to 15% of the PCB manufacturers can produce HDI technology. This is also a very cost conscious sector. However, because there are far fewer U.S. fabricators making the HDI product, it is possible for leading edge suppliers to differentiate themselves from their competition. Still, there are lesser numbers of capable suppliers. Domestic producers of high-density technology have succeeded fairly well in maintaining market share, although it has not been easy and they must continuously look for new ways to reduce manufacturing costs if they want to remain competitive.

**Imbalance Domestic versus International**

The PWB industry, like most industries today, is no longer influenced only by local and national issues. The PWB manufacturer not only competes with the shop down the street, but must also compete with PWB manufacturers from all over the world. Electronic product OEMs are able to send designs anywhere for manufacturing, and they are choosing to send more and more of those designs to low cost PWB manufacturing facilities in other countries. Even companies who order prototypes in the U.S. often send the large volume production orders offshore. The OEM does not want a different technology being used for prototype than used for production, or they would have to re-qualify, and in many cases redesign the product. This means that U.S. PWB Manufacturers must either have offshore volume manufacturing capability, must partner with an offshore volume manufacturing company, or risk losing even the prototype orders.

The U.S. PWB strategy from a global viewpoint has been one of incremental change, a slow methodical approach to increasing the customer base. Except for one or two specific cases, technology investment has not been a primary consideration. This approach has served the U.S. industry well, as long as product cycles were long. With the shortening of product cycles, the OEM does not have the luxury of waiting for fabricators to get better yields and install more capacity. They must hit the product window on its leading edge and have full manufacturing capability available. The U.S. strategy is significantly different from our two major competitors, Japan and Taiwan. Taiwan’s strategy is to become the largest manufacturer of PWB’s in the world. The shops in Taiwan are huge and getting bigger. They sell capacity at low prices. An OEM procuring PWBs in Taiwan knows that if his product is successful in the market, there is plenty of manufacturing capacity for supply. Previously the Taiwanese had not invested heavily in technology. They were very satisfied to become the volume supplier in conventional technology. This may be changing. Several Taiwanese PWB manufacturers seem to be making big investments in microvia technology. It is still too early to determine if this is an industry trend or just a few speculators.

The Japanese strategy is different from either the U.S. or Taiwan. The Japanese OEMs have always been the leaders in announcing new revolutionary products. The Japanese PWB manufacturers follow suit and strive to improve their technological capabilities rapidly and continuously so that PWB manufacturers in other countries cannot keep pace. The Japanese sell technology. This is consistent with their leadership in fine line technology over the past few years, along with their leadership in having the best yields in the industry.

Faced with these two challenges, the U.S. PWB industry cannot afford to continue along the same path it has followed for the past few years. If we are to maintain or recover market share, the industry must adopt a strategy that will make us the world leaders in at least one competitive aspect of PWB manufacturing. The choices are limited. One must compete on cost, service,
quality, turn-time, or technology. Each of these competitive differentiators has a business component: the investments, corporate culture, etc., and a technical component: the manufacturing methods, equipment, and materials, necessary to be successful. The current U.S. business climate is such that we can never expect to be the world leaders in low cost PWB manufacturing. However, there is no overwhelming business obstacle to our becoming world leaders in any or all of the remaining areas. The challenge there is a technical one. Can we as an industry adopt a strategy that will provide us the manufacturing technology advantage necessary to be world leaders in PWB service, quality, turn-time, and technology at a competitive cost?

**Research and Development**

Research and Development in the U.S. has changed significantly over the past 10 years. New paradigms for R&D have begun to emerge in the public as well as the private sector. Previously the leading supporter of U.S. R&D, the federal government, is very unclear as to the magnitude of its future support.

International economics, balanced budgets, and a call to end corporate welfare all affect the congressional R&D policy. Federal support for R&D has been an on-again off-again matter. In the past, the portion of federal R&D support that has been devoted to interconnect technology has been very small. Complacency or resignation to this position is a losing position for the industry, but we can change the status quo. Efforts by ITRI, the IPC, and the member companies resulted in a focused Interconnect Technology area within the Advanced Technology Program (ATP), and the funding of PMTEC. We, the interconnect industry, must continue to lobby for federal R&D. We must develop our relationships with the academic R&D world, and, most of all, we must have a documented plan that addresses the interconnect industries position today and provides a clear path to tomorrow. This plan should be developed through the industry roadmap activities, and will guide our future efforts for Government R&D support.

**University Role**

The PWB industry has not been extremely successful to date in tapping into the university research base. There are a few universities who do research in PWB technology, but it is very limited. It appears that Georgia Institute of Technology (Georgia Tech) has the biggest interconnect budget. Others that have some interconnect technology activities include Auburn University, Cornell, Binghamton University, Florida International, Rochester Institute of Technology, and Univ. of Maryland. NEMI recently published a list of 19 universities doing research in some form of packaging.

The industry needs to form a PWB Interconnect Research Council, which includes members of University and Government Research organizations. This group should meet at least once a year to listen to current activity reports and to strategize together where the PWB research dollar should be spent. To make this large-scale activity successful and ongoing, the IPC, NEMI and ITRI should jointly sponsor this activity.

The IPC sponsors two annual events for PWB and PWA manufacturers, the IPC Printed Circuits EXPO and the IPC/SMEMA APEX Conference. University representatives have always been a part of these conferences, but they have been spread throughout the conference agenda generally discussing the university’s role in an existing activity. One new suggestion is to have specific sessions on far reaching university research giving the universities a chance to showcase their research activities. The session leader should be a recognized university or government lab researcher.
Supplier Relations

A healthy printed circuit industry is heavily dependent on a good relation with its suppliers. Presently, the suppliers to the printed circuit industry have been pressed into service as the research and development arm of the printed circuit industry. This presumes that the suppliers have surveyed the printed circuit manufacturing community as to their needs and that they have looked into what is being asked of the printed circuit industry by its customers.

The historical approach for the supplier has been to provide equipment. Such equipment may or may not provide a viable or valuable solution. A more coherent strategy will be required for the industry to pave a trustworthy road into the future. This means that the printed circuit manufacturers must become more proactive in determining their collective futures and work more cooperatively with the suppliers helping them to specify and produce the next generation materials and equipment that will be required.

Strengths and Weaknesses of the U.S. PWB Industry

The U.S. PWB industry has many strengths, but it is also plagued by several significant weaknesses. In this section, we endeavor to identify these so that we may emphasize the strengths and work to reduce or eliminate the weaknesses.

U.S. Fabricator Strengths

The following are some of the U.S. Fabricator strengths.

- The ability to deliver conventional or commodity products in volume. There are over 600 fabricators capable of delivering this type of product.
- The U.S. PWB industry has complete self-sufficiency. The supply chain of materials, chemicals, equipment and process support allows the U.S. industry to operate completely independent of any foreign influence if it so desired.
- There is a very strong laminate materials technology industry. Besides standard laminates there are several world-class manufacturers of specialty materials.
- The industry has full technical diversity; it is capable of manufacturing conventional, HDI, microvia, military high reliability and other products.
- Strong domestic electronics industry. The U.S. continues to be a world leader in electronics manufacturing, especially in advanced product design. U.S. PWB manufacturers have the advantage of close proximity to many of the leading electronics manufacturers.
- There is an abundance of niche product manufacturers and manufacturers that specialize in generally difficult to make products.

U.S. Fabricator Weaknesses

There are also some weaknesses that need to be addressed. They include:
US manufacturers appear to be satisfied with less than six-sigma quality. Yield loss and the waste associated with such a complacent attitude are areas that need attention. On the material side, the quality of U.S. is satisfactory, but not six sigma.

The U.S. capital equipment industry is still selling tools, not solutions. This is very similar to the semiconductor industry prior to Sematech. Now the semiconductor capital-toolingsuppliers are solution focused. The U.S. PWB capital-tooling suppliers would do well to study this history.

Selling prices are marginally satisfactory. There is little foreseeable opportunity for seeing improvement in selling prices except in higher technology areas. Automation is weak or non existent

Fabricators are relatively small companies that do not have the resources to do the R&D on their own.

There is limited data on cost metrics associated with becoming a global industry. As one moves from a regional industry to a national industry to an international or global industry, the amount and type of cost information needed increases.

The PCB purchasing community does not have a consistently good understanding of the products they purchase and their cost accounting methods apparently do not have a value metric. Price alone, it seems, is all-important.

The printed circuit has been relegated to commodity status in spite of the fact that each PCB is unique. As a result, pricing based on the metric of price per layer unit area is firmly entrenched in the mind of the purchasing community.

The industry does not have a conscious value item that it sells to buyers. Value items are things like price, quality, delivery, or technology. The U.S. tries to be satisfactory in all of them, and is not selling one or two of them as best in the world.

There is a reluctance to cooperate with each other, even when there is no proprietary or confidential items on the agenda, and even when the real competition is offshore.

There are three models evolving for cost reduction. The first is where the largest PCB fabricators can and do use economies of scale as a cost reduction mechanism. The second is the pseudo vertical approach, where all phases of technology are in one large group. (i.e. Design, Chip Manufacturing, Packaging, PWB, and Assembly) The third method for achieving cost reduction is simple improvement of manufacturing efficiency and waste reduction such as can be accomplished by increasing yield.

Industry accepted cost metrics for defining the value of a PWB in relation to increasing density is required. Understanding the cost of the pipeline when OEMs purchase offshore is needed so PWB manufacturers can present a case for OEMs doing business domestically. The PWB manufacturers need to understand the cost drivers of the EMSI industry and develop industry wide plans to help the growing EMSI companies lower their costs. Many of our fabricators are still using regional cost information in a global world.

Table 1 shows the assessment made by the management council of the Interconnection Technology Research Institute. The information identifies those areas where cooperative research is essential. ITRI is seeking to provide industry participants with a coherent strategy for improvement and growth in printed circuit technology. The table outlines some of the important concerns that must be addressed for each of the identified families of printed circuit product.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional PWB Fabricators</td>
<td>HDI Non Microvia Fabricators</td>
<td>Microvia</td>
<td></td>
</tr>
<tr>
<td>(125µm L/S min)</td>
<td>(100-75µm L/S)</td>
<td>(Vias less than 150µm)</td>
<td></td>
</tr>
<tr>
<td>Cost focus</td>
<td>Cost and technology balance</td>
<td>Technology Focus</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface Finishes</td>
<td>Fine Pitch Electrical Test</td>
<td>Fine Pitch Electrical Test</td>
<td></td>
</tr>
<tr>
<td>HASL Replacement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct Plating to reduce process steps</td>
<td>Fine Line Photo Processes</td>
<td>Improve Material Mechanical and Thermal Stability</td>
<td></td>
</tr>
<tr>
<td>Cost of Test Fixtures</td>
<td>Improve Registration for Fine Features</td>
<td>Fine Line Photo Processes</td>
<td>Improve Material Parameters and Stability</td>
</tr>
<tr>
<td>Oxide Replacement</td>
<td>Improve Material Mechanical and Thermal Stability</td>
<td>Improve Uniformity of Copper plating and etching</td>
<td></td>
</tr>
<tr>
<td>Improve Registration for yield</td>
<td>Improve Uniformity of Plating / Etching</td>
<td>Improve Registration for Fine Features</td>
<td>Specifications (JEDEC / IPC)</td>
</tr>
<tr>
<td>More accurate Scaling Factors for yield</td>
<td>Low Cost Imbedded Passives</td>
<td>A.O.I. for fine Line</td>
<td></td>
</tr>
<tr>
<td>Improve Plating of Blind Vias</td>
<td>Improve Laminate Quality</td>
<td>Cad for microvia</td>
<td></td>
</tr>
<tr>
<td>Improve Via Reliability</td>
<td>Reduce Warpage / Improve Flatness</td>
<td>Very thin Copper foils</td>
<td></td>
</tr>
<tr>
<td>Other Concerns</td>
<td>Other Concerns</td>
<td>Other Concerns</td>
<td>Other Concerns</td>
</tr>
<tr>
<td>Better Material properties</td>
<td>Low Cost Embedded Passives</td>
<td>Improve Yield of Features Below 25 µm</td>
<td></td>
</tr>
<tr>
<td>Reduce the cost of making holes</td>
<td>Improve yield of Features below 25 µm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Part 5 - Global Material and Equipment Suppliers

Situation Analysis

The supply chain algorithm is very complex and embraces a variety of scenarios. Partnerships, liaisons and contractual commitment provide the stepping-stones to success in proposing electronic products and thus mirror an equivalent image for those who make up the electronic interconnection industry supply chain.

Preparedness is key in being ready for the years ahead. One can develop all forms of technology, but until the technology reaches the manufacturing infrastructure all the charts and percentages are only a misty vision. That is why it is very difficult to be there with the latest material, process or equipment intended to provide solutions to vague or assumed future requirements. The cost of development must be shared among and between the customers and/or partners working the details in a concurrent manner.

The industry calls it a “supply chain”, and worries about supply chain management. The focus is correct in that with the increase in outsourcing, someone needs to manage the relationships between the supply chain and the participants. Supply chain management represents a pyramid whose base consists of supplier member companies; the management of the technology demands for new and improved materials, equipment, and processes are over shadowed by the desire of some members of the customer community to micro manage the suppliers businesses. Companies that make up the lower tiers of the pyramid supply chain shown in figure 2 are fierce competitors, but in reality need to work together in order to support the electronic equipment-manufacturing infrastructure.

![Infrastructure Pyramid](image-url)
The industry has a long history of developing great ideas and great methods in the laboratory, in the university, and in the research consortia. The difficulty lies in moving these methods and technologies into the mainstream, and this requires a champion. The champions of our industry are the suppliers of the design tools, manufacturing automation tools, substrate materials, fabrication processes for printed boards and interconnection structure products, and the developers of the assembly and attachment techniques used by the electronics interconnection industry infrastructure.

**Substrate Materials**

Key material attributes of rigid board laminates are listed in Table 2. In particular, the status of conventional, leading edge, and state-of-the-art technologies are differentiated. Conventional technology refers to the high volume and high yield products with matured fabrication processing. Leading edge technology is used to manufacture smaller volume products and the technology is still in the learning curve. State-of-the-art technology reflects the current manufacturing limits, and very small amount of products are produced in this category. In general, leading edge and state-of-the-art technologies point in the direction that conventional technology will move.

**TABLE 2  KEY MATERIAL ATTRIBUTES**

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Conventional/ Threshold Technology</th>
<th>Leading-edge Technology</th>
<th>State-of-art Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impregnation Resin</td>
<td>Standard FR-4 T&lt;sub&gt;g&lt;/sub&gt; 130-180°C</td>
<td>BT Epoxy/PI/IPN</td>
<td>High T&lt;sub&gt;g&lt;/sub&gt; resin Low D&lt;sub&gt;k&lt;/sub&gt;, D&lt;sub&gt;f&lt;/sub&gt; Special resin for chip packaging</td>
</tr>
<tr>
<td>Impregnation Fabrics</td>
<td>E glass 106,1080, 2116, 7628</td>
<td>Engineered E-glass weaves, 6060, 3070 quartz, Kevlar</td>
<td>Non-fiber glass, nonwoven materials such as aramid etc.</td>
</tr>
<tr>
<td>Impregnation Process</td>
<td>Treater technology capable Resin uniformity 2-3%</td>
<td>Resin content uniformity 1-1.5%</td>
<td>Uniformity 1-1.5%</td>
</tr>
<tr>
<td>Cu Foil</td>
<td>18 µm foil Low profile High THE</td>
<td>12 µm Reverse treated foil Very low profile</td>
<td>9 µm Very low profile</td>
</tr>
<tr>
<td>Mass Lamination Process</td>
<td>4-6 layer board</td>
<td>4-8 layer board</td>
<td>4-10 layer board</td>
</tr>
<tr>
<td>Unreinforced laminates</td>
<td>Special polyester/polyimide</td>
<td>Polyimide</td>
<td>Polyimide</td>
</tr>
<tr>
<td>polyester/polyimide</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The trend toward thinner and higher performance resin is evident. Thinner copper and reinforcement (or no reinforcement) enables smoother surface, finer line/space features, and thinner boards. Higher T<sub>g</sub> resin makes the laminate more thermally resistant, less overall thermal expansion, and a greater capability to withstand the soldering temperatures if and when the use of
lead-free solder becomes mandatory. In addition to improved technology requirements is the need to provide halogen-free resin. Many companies that recycle printed boards used burning techniques. Releasing toxic resin into the atmosphere is not an image with which the industry wants to be associated. The characteristics of the new resin systems are still in the evaluation stage.

**Assembly Materials**

Assembly materials deal primarily with the solders, under fill materials used for direct chip mounting and cleaning/coating materials. The current status is shown in table 3.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Current Technology Status</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Solders:</strong></td>
<td></td>
</tr>
<tr>
<td>Eutectic</td>
<td>Lead tin still preferred</td>
</tr>
<tr>
<td>Lead Free</td>
<td>Considered environmentally friendly, Use is marketing driven with major impetus from Europe and Japan. The technology is being widely investigated but may require a major transformation in the industry infrastructure.</td>
</tr>
<tr>
<td>High Temp Solders</td>
<td>Driven by under the hood harsh environment application (automotive). Increasing in popularity. High temperature solders support double pass reflow High temperature solders also provide standoff for reliability of attachment in ceramic BGAs at the component level.</td>
</tr>
<tr>
<td>Preform</td>
<td>Specialty applications with a small market</td>
</tr>
<tr>
<td><strong>Solder Paste &amp; Fluxes:</strong></td>
<td></td>
</tr>
<tr>
<td>Rosin Base</td>
<td>Mature technology still in some use</td>
</tr>
<tr>
<td>Water Soluble</td>
<td>Common use, needs good cleaning</td>
</tr>
<tr>
<td>No Clean</td>
<td>Widely used, environmentally friendly, may require inert atmosphere for certain applications</td>
</tr>
<tr>
<td><strong>Solder Alternatives:</strong></td>
<td></td>
</tr>
<tr>
<td>Epoxies</td>
<td>Solder alternative for certain type of applications .Number of issues with them, niche application</td>
</tr>
<tr>
<td>Z-axis</td>
<td>Niche application</td>
</tr>
<tr>
<td><strong>Underfills and Encapsulants:</strong></td>
<td></td>
</tr>
<tr>
<td>Conformal Coating</td>
<td>Military/Automotive/High Reliability applications. Use diminishing</td>
</tr>
<tr>
<td>Underfills</td>
<td>Most widely used for flip chip.</td>
</tr>
<tr>
<td>Encapsulants</td>
<td>Protection for DCA</td>
</tr>
<tr>
<td><strong>Alternatives Finishes:</strong></td>
<td></td>
</tr>
<tr>
<td>OSPs</td>
<td>Maturing. Popular in high volume application with tight coplanarity requirements Environmentally Friendly (avoids HASL). May require inert atmosphere</td>
</tr>
<tr>
<td>Nickel/Gold Flash</td>
<td>Maturing in tight coplanarity requirement Higher cost, less handling concerns as compared to OSPs</td>
</tr>
<tr>
<td>Immersion Tin</td>
<td>Emerging technology. Not commonly available.</td>
</tr>
<tr>
<td>Immersion Silver</td>
<td>Emerging technology. Not commonly available.</td>
</tr>
<tr>
<td>Palladium</td>
<td>Still an emerging technology. Limited use</td>
</tr>
<tr>
<td><strong>Cleaning Materials:</strong></td>
<td></td>
</tr>
<tr>
<td>Aqueous</td>
<td>Saponifiers followed by DI water rinsing most commonly used with rosin fluxes. Water only cleaning common for water-soluble fluxes. Water recycling common.</td>
</tr>
<tr>
<td>Semi- aqueous</td>
<td>Water miscible solvent followed by water rinsing. Environmentally friendly process, (easy to remove solvent from water). Not as widely used as full aqueous system</td>
</tr>
</tbody>
</table>
**Substrate Manufacturing Equipment**

Substrate manufacturing equipment includes the circuit imaging equipment, the plating and etching systems that produce the circuitry, the hole producing equipment (mechanical, chemical, and laser ablated), automated optical inspection, lamination presses and electrical bare board test. There are many other pieces of equipment that play a part in the yield and reliability of the final product. Some of these include surface preparation systems, hole smear removal, rinses and drying ovens, soldermask material application, contact plating, routing/scoring, various cleaning operations, and organic surface protection application equipment.

The manufacturing of printed boards is a complex process that includes many process steps. Each step uses a specific piece of equipment. Each step contributes to the end product meeting the desired results. It is also possible that the equipment, if not properly maintained, can contribute to non-conforming products or reduced yield from the manufacturing panel. As printed boards become more complex with smaller holes, finer conductors and conductor spacing, and all with more layers, the board manufacturer continues to press equipment manufacturers for greater machine efficiency and greater machine control/accuracy.

The US government puts an extra burden on the purchaser of these substrate manufacturing equipment by having the amount of years over which they must be amortized be excessively higher than is imposed in any other country that produces printed boards. The IPC has been working to have a bill approved in congress to shorten the process to one that is more reasonable and is commensurate with the changes in the technology that force the board fabricator to look for improved equipment on a yearly basis.

**Assembly and Test Equipment**

Assembly equipment encompasses several types and characterizations. In addition to the assembly machines that position the components on the assembly several types of equipment are used in both the pre inspection and post inspection processes. Pick and placement machines have in general kept up with the demand for speed and precision. The traditional “Chip Shooters” are now being tested to place the very small chip resistors and capacitors (0201). IC package placement machines are capable of placing the large ICs with sufficient accuracy especially if fiducials are available for the equipment vision systems to improve positioning accuracy.

The Incoming Test and Inspection process have equipment for qualification for components that assess moisture sensitivity, compatibility of devices with reflow, flux, etc. In addition, some of this equipment guarantees quality levels for devices both packaged and unpackaged e.g., known good die, KGD.

There is equipment used to facilitate process control by providing cost effective feedback loops that allow process monitoring at all critical assembly points. The data collection/analysis for feedback starts with the design analysis, and helps in the Design For Assembly development process. The monitoring and analysis systems are also used for operator training and use the human factor as an advantage in diagnosis of assembly problems.
Electrical testing consists of in circuit and functional testing. This type of test equipment is used by all EMS companies to meet the demands of their customers. In recent years combinations of various other test equipment has been employed. These new processes have become necessary due to the emergence of BGA parts becoming part of the assembly process. Thus Automated Optical Inspection (AOI) and Automatic X-ray Inspection (AXI), have joined In Circuit Test (ICT).

Using combinations of AOI, AXI and ICT assessment can be made of the solder joints for insufficient solder, excess solder, bridging, cold or marginal solder joints; of components for orientation, polarity, inverted, tomb stoned, missing, misalignment, wrong, or extra part; of electrical requirements for opens, shorts, bad part, lifted leads, bypass capacitor needs. Other tests relate to the component electrical performance in the attached position and include procedures such as device level built-in self-testing, and boundary scan component evaluations. Both of these require special equipment.

Last but far from least is the fact that many customers want board assembly burn-in while the unit is under field operating conditions. To determine long-term reliability, additional testing is occasionally required and referred to as Highly Accelerated Stress Testing (HAST). Both burn-in and HAST require special test equipment that provides temperature and humidity controlled conditions. If conformal coating of the assembly is required it may be accomplished before or after burn-in. Most customers want their assemblies in the configuration that the assembly will see in service, thus the coating is applied prior to this HAST or burn-in test. The coating application and curing ovens needed to polymerize the coating also add to the list of equipment needed by the assembler.

**Financial Conditions**

Global competitive pressures have caused the supplier community to shrink in size based on the type of product, equipment or service offered to the industry. Mergers and acquisitions continue on a yearly basis and the names of companies that existed in the last decade are no longer recognizable. It is not that the facilities have closed; it is mainly to take advantage of the economy of scale for managing similar business. When too many competitors exist providing the same product a natural attrition takes place. The strong survive. Sometimes it is because they have better or more aggressive management; sometimes it is because they offer a better product.

In general the supplier community is financially healthy. They continually assess the needs of the manufacturers, and try to meet those needs in a timely fashion. Unlike the printed board industry they truly serve their global customers. Thus one would find that assembly facilities throughout the world have equipment that bear the labels of companies that are located, or have their corporate headquarters, in any hemisphere. It is a usual situation to have at least “three of a kind” exist in each of the commodities needed. Having a little competition is healthy; too much competition is not good for anyone.

An example, of the trend is the original offerings of materials used to produce the outer layers of HDI products. As the technology evolved every supplier of material needed to have some solution to the manufacturing demand. After several years the material needs settled down to several different groupings, depending on the method of producing the very small microvia holes. The technology affected both the material and the equipment needed to produce microvias, and the processes to achieve good plating characteristics. The evolutionary conditions have kept the financial condition of the supplier community at a reasonable level. It also appears that the
financial support that the supplier community receives from the banking industry is more robust than that provided to the board fabricators.

**Customer Relations**

The customers of the suppliers tend to stay with those that have provided excellent service over the years. Service is based on high quality and on-time delivery. During times of company acquisition the trend is to stay with those survivors who promise to continue the same level of service offered in the past. It does not mean that customers deal only with one company; they normally like to have an alternative. Thus equipment from Europe stands next to that from the US, equipment from Asia stands side by side with that from the other hemispheres. Choice is based on performance, price, and industry hype. If laser technology is being tried a board manufacturer will evaluate equipment based on his customer needs. This relates to the type of product being designed, the hole configuration, the cost of entry into the technology, and the perception of the customers’ customer.

The philosophy of making supplier assessments is consistent throughout the supply chain. The products might be components, laminate materials, assembly materials or equipment used for fabrication and test. Differentiation is offered through new and demanded features, however it is not too long before the competitors, in a particular segment, offer similar performance or something that exceeds the last offering.

**Data Transfer**

The supply community will become some of the first to use the Internet as the communication channel between the supplier and their customers. The idea of eCommerce has grown to the point where if one is not envisioning business to business (B2B) transactions they are already behind the curve. It starts with the ordering of suppliers products, and continues until the equipment will communicate back to the operator, engineer, or manager as to its’ state. All of this communication is over the Internet at WEB speed using the latest format known as XML. The format is a text based, data description meta language, designed to be used on the Internet. Thus, the eXtensible Markup Language, a streamlined version subset of SGML, will become the mechanism used for the future data transfer transactions.

The IPC-2540 series of standards define the requirements for the XML encoding scheme, which enables a detailed definition of electronics equipment messages to be exchanged at a level appropriate to facilitate the plug-and-play characteristics in the factory/shop-floor integration process. The IPC-2541 details the generic requirements. That document is used together with other sectional standards of the IPC-2540 series. The sectional standards (IPC-2542 through IPC-2549) define the set of messages and key attributes of each equipment class used in the electronics manufacturing area.

There are several utilities that can be accomplished by using the 2540 XML messages. These include data collection, charting and reporting. The Physical side of the model includes line, equipment, resources, materials, product, and orders. The objective of the equipment model used in the standardization effort is to capture important machine status information that can be used to track machine utilization and availability. Figure 3 shows the elements related to equipment monitoring and equipment control.
Figure 3 Elements Related to Equipment Monitor and Control

It is useful to monitor and control resources in an automated surface mount (SMT) line. A processing station in the SMT line processes raw materials to produce finished or semi-finished products, as shown in Figure 3. The other objectives and constraints considered in the development of the IPC-2540 series CAMX equipment model include:

- Support of the Semiconductor Equipment and Materials International (SEMI) E-10 standard in the interim and provide upward compatibility.
- Minimize the number of states. Each state must have significance for process monitor and control.
- Define states so that no variations in the basic states are allowed in implementations.

The equipment model consists of several components: e.g., the state diagram, and the state transition table. The transitions are defined with alarms, operator or host inputs, or material conditions. These three components are presented in Figure 4. Table 4 represents the various state transitions.
Figure 4. State Diagram

Table 4. State Transition Table for Equipment State Model

<table>
<thead>
<tr>
<th>Current State</th>
<th>Typical Trigger</th>
<th>New State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off</td>
<td>Power on (default entry of state Setup)</td>
<td>Setup</td>
</tr>
<tr>
<td>Setup</td>
<td></td>
<td>Ready (Idle)</td>
</tr>
<tr>
<td>Ready</td>
<td></td>
<td>Setup</td>
</tr>
<tr>
<td>Ready (Idle)</td>
<td>Material in, and authorized command of start</td>
<td>Ready (Processing)</td>
</tr>
<tr>
<td>Ready (Processing)</td>
<td>Material out or command of stop or abort</td>
<td>Ready (Idle)</td>
</tr>
<tr>
<td>Down</td>
<td>Complete repair or maintenance</td>
<td>Ready</td>
</tr>
<tr>
<td>Ready</td>
<td>Upon major errors, or run out of supplies</td>
<td>Down</td>
</tr>
<tr>
<td>Setup</td>
<td>Upon major errors</td>
<td>Down</td>
</tr>
<tr>
<td>Down</td>
<td>Start error correction procedure</td>
<td>Setup</td>
</tr>
</tbody>
</table>
The objective of the equipment model used in the standardization effort is to capture important machine status information that can be used to track machine utilization and availability. These conditions will provide the means of communication. Equipment manufacturers are building the capability into the equipment controllers to respond to the queries, given either by human intervention or by a request coming from another equipment that needs the information.

**Strengths and weaknesses**

There are many strengths offered by members of the supply chain. The main one is the responsiveness to customer needs. Making decisions as to what technology to support becomes the ever-changing evaluation that a supplier must make. The suppliers as a group perform the research needed in the domain that they serve. Customers who provide input help focus the research in the direction of their future needs. Thus, it is a good business practice to listen, evaluate and advise the customer base as to what is possible and what is impracticable from a technical or business point of view.

There are still additional needs that keep coming up, especially related to testing and test equipment. Included in these needs are:

**In Circuit Test (ICT):**

- Shorter, more effective test vector generation.
- Flexible probe/non-contact probe systems that reduce requirements for the number/size of test pads.
- Improved compatibility of test probe systems with no-clean solder processes.
- Development of a non-contact electrical test to eliminate all physical probing.
- Better utilization of non-destructive test methods that identify process defects. (Possible examples of such test methods are thermal imaging, x-ray, acoustic imaging, etc).

**Functional/System Level Test:**

- Improved test generation tied to CAD and simulation tools
- Reduced test time/increased test coverage

**Device level: Built-in Self Test (BIST):**

- Standardized test structures (libraries)
- Reduced overhead, i.e. less silicon area needed to support BIST

**Board Level: Boundary Scan (BS)**

- Standardized test structures (libraries)
- Reduced overhead, i.e. less silicon area needed to support BS

**Environmental Stress Testing/Environmental Stress Screening (EST/ESS):**
Direct tie between EST/ESS results and CAD tools: Design for Reliability
Feedback to suppliers: rapid identification of incoming quality issues.

Final Manufactured Assembly (FMA) end of life cycle testing needs to provide feedback to design and materials and components suppliers. FMA is generally a low priority with most manufacturers. The value of FMA to design, components, materials, and test development needs to be recognized.

Conclusions

The suppliers to the industry do a good job in servicing their customer base. They are responsive and many times are asked to perform what appears to be an insurmountable task. Their business success is based on being there when needed, and having the material, equipment and processes available for the next generation of products.

The best suppliers are those that have a close relationship with their customers. The term “preferred supplier” must be earned and once achieved is guarded by supplier management in order to maintain that status. It is difficult to break into a relationship that has been built up over years of trust and meeting commitments on both the customer and supplier side.
The condition of the Semiconductor Industry can best be summarized by the details shown in the SIA forecast. The chart shown in Figure 5 clearly shows growth in all of the world sectors, however those companies located in the Asia Pacific region increase their potential at a much greater rate than other world segments.
Semiconductor Component Manufacturers:

The Semiconductor industry is in its third year of extremely high growth and is predicted to continue well into the middle of the decade. The continued break throughs of shrinking die geometries and lower packaging costs are creating increasing strong pressures for the packaging communities to follow the trends. The requirements to remove Pb, Sb, and Br out of the packaging materials is going to increase prices by at least 10 to 15% above present cost estimates. The major issue is meeting the new requirement of higher reflow temperatures for lead free materials at the present cost goals.

The growth of the market is occurring in all major package areas such as Single Chip Packaging, Systems in a Package (SiP), and Systems on a Chip (SoC) Packaging. At the same time the new package developments must accommodate new electrical and thermal requirements to meet the higher speeds and heat dissipation requirements. The newer package families must also be smaller, thinner, lighter, and cheaper. The packages are moving from the conventional leaded varieties to the new ball or land array styles. The new business models show that the majority of IC Merchant Semiconductor manufacturers continue their push to out source all the package design, assembly, and test. This business model change is allowing the IC Merchant Semiconductor manufactures to refocus their limited R & D and capital resources in the areas of IC design and wafer fabrication. This new focus is creating extreme pressures on the Semiconductor Packaging Manufacturers and their vendors to pick up the full cost of R & D and capitalization for all present and future advanced package families.

Discrete Component Manufacturers.

The Discrete Semiconductor industry like the rest of the Semiconductor industry is in its third year of extremely high growth and this is predicted to continue well into middle of the decade. The continued break throughs of shrinking die geometries does not create the same pressures that are in the rest of the Semiconductor Device Industry. However, the discrete industry will have to address the same issues of removing Pb, Sb, and Br out of the packaging materials and meeting the new requirements including higher reflow temperatures for lead free materials at the present cost goals.

The growth of the market is in Single Chip Packaging and Systems in a Package (SiP). The Systems on a Chip (SoC) Packaging can occur when the discrete function is added to the Semiconductor design. At the same time, the new discrete package developments are focused only in the heat dissipation requirements. The newer package families must also be smaller, thinner, lighter, and cheaper. The packages are moving from the conventional leaded varieties to the new leadless land styles. The discrete business models shows that the majority of Discrete Component manufacturers are not pursuing the outsourcing model of all the package design, assembly, and test being done outside. Figure 6 shows some of these trends.
The Semiconductor Packaging Manufacturer’s are growing at 2-3 times the normal Semiconductor Market rate because of the accelerated outsourcing from the IC Merchant Semiconductor manufacturers. The new burden of doing all of the R & D and capitalization for new packaging, materials, and processes is taxing the financial resources of the Packaging manufacturers. Only the very large manufacturers have the human and financial resources to do the R & D development. The manufacturing center of gravity for packaging manufacturers is changing from conventional leaded packages to the new ball or land style package families. Most of these new families carry higher raw material costs therefore are more expensive to build but the market will only accept them at the older technology pricing structure or less. The die interconnect technology being used is moving from wire bonding to direct flip chip attach. The supply of substrates that match the shrinking technology is limiting the progress to meet the customer’s needs in a cost effective and timely manner. See Table 5.

Table 5 Assembly & Packaging Technology Requirements
Source: The International Technology Roadmap for Semiconductors: 1999

<table>
<thead>
<tr>
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<tbody>
<tr>
<td></td>
<td>Cost (Cents/Pin) (A)</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Low cost</td>
<td>0.40–0.90</td>
<td>0.38–0.86</td>
<td>0.36–0.81</td>
<td>0.34–0.77</td>
<td>0.33–0.73</td>
<td>0.31–0.70</td>
<td>0.29–0.66</td>
<td>0.25–0.57</td>
<td>0.22–0.49</td>
<td>0.19–0.42</td>
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<tr>
<td>Hand-held</td>
<td>0.50–1.30</td>
<td>0.48–1.24</td>
<td>0.45–1.17</td>
<td>0.43–1.11</td>
<td>0.41–1.06</td>
<td>0.39–1.01</td>
<td>0.37–0.96</td>
<td>0.32–0.82</td>
<td>0.27–0.70</td>
<td>0.23–0.60</td>
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<tr>
<td>Cost-performance</td>
<td>0.90–1.90</td>
<td>0.86–1.81</td>
<td>0.81–1.71</td>
<td>0.77–1.63</td>
<td>0.73–1.55</td>
<td>0.70–1.47</td>
<td>0.66–1.40</td>
<td>0.57–1.29</td>
<td>0.49–1.03</td>
<td>0.42–0.88</td>
<td></td>
</tr>
<tr>
<td>High-performance</td>
<td>3.10</td>
<td>2.95</td>
<td>2.80</td>
<td>2.66</td>
<td>2.52</td>
<td>2.40</td>
<td>2.28</td>
<td>1.95</td>
<td>1.68</td>
<td>1.44</td>
<td></td>
</tr>
<tr>
<td>Harsh</td>
<td>0.50–1.00</td>
<td>0.48–0.95</td>
<td>0.45–0.90</td>
<td>0.43–0.86</td>
<td>0.41–0.81</td>
<td>0.39–0.77</td>
<td>0.37–0.74</td>
<td>0.32–0.63</td>
<td>0.27–0.54</td>
<td>0.23–0.46</td>
<td></td>
</tr>
<tr>
<td>Memory</td>
<td>0.40–1.90</td>
<td>0.38–1.71</td>
<td>0.36–1.54</td>
<td>0.34–1.39</td>
<td>0.33–1.25</td>
<td>0.31–1.12</td>
<td>0.29–1.01</td>
<td>0.25–0.74</td>
<td>0.22–0.54</td>
<td>0.19–0.39</td>
<td></td>
</tr>
</tbody>
</table>
**Financial Conditions**

Financial pressures on the Semiconductor Packaging Manufacturer’s community have been relentless. This is because packages have long been viewed as a commodity rather than as the custom product they truly have become. Price pressure on the packages has intensified since the over capacity environment of 1996-1998 drove prices down by as much as 30-40 % in a short time. Many of the IC Merchant Semiconductor manufacturers have abandoned their own Semiconductor Packaging Manufacturing Operations and have forgotten the real cost of being in the packaging design, assembly, and test business. Pricing pressures, coupled with intense competition from other Semiconductor Packaging Manufacturers and the lack of allegiance of IC Merchant Semiconductor manufacturers to their suppliers have conspired to eviscerate Semiconductor Packaging Manufacturing. The problem is aggravated by the fact that the independent manufacturers have limited resources for performing the research and development and capital investment required for them to remain competitive. The trend to take all the “Pb” (Lead), Bromines (Flame Retardants), and Halogens out of the final assembled package is creating additional cost penalties. In addition the present leaded package materials are going up for the first time in 3-4 years. The major issue is meeting the new requirements including higher reflow temperatures for lead free materials at the present cost goals.

**Customer Relations**

The Semiconductor Packaging Manufacturer is dependent on customer long-term loyalty and partnering. Unfortunately, with the globalization of corporations and demand for higher profits from investors, extreme pricing pressure is being placed on the Semiconductor Packaging Manufacturer’s. High quality and reliability requirements are demanded of the Semiconductor Packaging Manufacturers and the package purchasers seems willing to forego such requirements in favor of lower cost from a Semiconductor Packaging Manufacturer’s. Customers are too willing to abandon their present vendors or partners at a drop of a hat in favor of their own pursuit of saving pennies per unit. They are trading their futures partnerships for the savings today.

**Data transfer**

The Semiconductor Packaging Manufacturers are having data problems at every turn. They are not getting the proper readable formats from the Semiconductor Device Manufacturers and the entire die / wafer information must be inputted by hand. The Package Design function is beginning to replace Gerber files with GenCam files so that all vendor programs can universally use the same set of data. Presently this is not the case and all new package designs have to be re-inputted by the vendor to make the new package. This takes time and a lot of extra work driving up the final package cost. The internet is being used as the electronic delivery system for new designs and depending where the design comes from the new package could be worked on from many different times zones in a 24 hour period.

**Supplier Relations**

A healthy packaging industry is heavily dependent on a good relation with its suppliers. Presently, the suppliers to the packaging industry have been pressed into service as the research and development arm of the packaging industry. This presumes that the suppliers have surveyed the package manufacturing community as to their needs and that they have looked into what is being asked of the packaging manufacturers by their customers.
A more coherent strategy will be required for the industry to pave a trustworthy road into the future. This means that the package manufacturers must become more proactive in determining their collective futures and work more cooperatively with their suppliers helping them to specify and produce the next generation materials and equipment that will be required.

The major problem is the fact that the supplier must give the packaging manufacturers lower prices so that they can meet their price goals while minimizing their profitability. They put limitations on what they can do in R & D for the future.

**Strengths and Weaknesses**

There are many strong points but the industry is also is plagued by significant weaknesses.

**Semiconductor Packaging Manufacturer’s Strengths**

- The ability to deliver conventional or commodity products in volume.
- There is a very strong Semiconductor Packaging technology industry. Besides standard packages there are several world-class manufacturers of specialty packages.
- The industry has full technical diversity; it is capable of manufacturing Leadless Packages, BGAs, CGAs, CSPs, Military high reliability and other products like Sips (Modules)
- Semiconductor Packaging Manufacturer’s have the advantage of close proximity to many of the leading global Electronic and Semiconductor manufacturers.
- There is an abundance of niche product manufacturers and manufacturers that specialize in generally difficult to make package families.
- Continue to produce low cost solutions to meet customers needs

**Semiconductor Packaging Manufacturer’s Weaknesses**

- Selling prices are marginally satisfactory. There is little foreseeable opportunity for seeing improvement in selling prices. There are the following three models evolving for cost reduction:
  - 1. The largest package manufacturers can and do use economies of scale as cost reduction mechanisms (i.e., Materials, Equipment, and Factories).
  - 2. The pseudo vertical approach, where all phases of technology are in one large group. (i.e., Design, Chip Manufacturing, Packaging, PWB, and Assembly)
  - 3. The third method for achieving cost reduction is simple improvements of manufacturing efficiency, equipment utilization and increasing yields to reduce waste.
- One of the major difficulties with the packaging manufacturers is their seeming satisfaction with less than six-sigma quality. Yield loss and the wastes associated with such a complacent attitude are areas that need attention.
- The capital equipment industry is still selling tools, not solutions. It would do well to study their own history.
- Semiconductor Packaging Manufacturer’s are relatively small companies when compared to IC Merchant Semiconductor manufacturers and do not have the financial and human resources to do all of the R&D all on their own.
• The Packaging Manufacturer’s reluctance to cooperate with each other, even when there are no proprietary or confidential items on the agenda. Global standardization is becoming increasingly difficult.

• Customer loyalty is creating problems with long-term commitments and developments of new packages, materials, and processes.
Part 7 - Academia

Situation Analysis

The North American PWB industry has not had significant success utilizing the university based research and development process to enhance the industry.

There are a few universities that do have some efforts focused around PWB needs. Georgia Tech and Auburn University are two that immediately come to mind.

In comparison the semiconductor industry has had significant success utilizing this resource. In fact the semiconductor industry has a formed a consortia (SRC) to coordinate the academic R & D efforts.

The PWB industry in this country has gone through a massive restructuring over the past few years and the restructuring continues today. In 1979, captive fabricators within the major U.S. electronics companies accounted for 60% of the market revenue with significant R&D budgets and central research laboratories. Today, small, independent manufacturers with small revenues and no ability to fund R&D serve over 94% of the market. This restructuring has had a major impact on R&D expenditures in the domestic PWB industry.

In the 60’s, 70’s and even into the early 80’s the OEM’s shouldered the majority of PWB R&D activities. Companies like IBM, AT&T, and DEC each had significant R&D laboratories specifically focused on interconnect technology. These three companies alone spent over $100 million a year on PWB research activities. The industry benefited greatly from their activity. Many of today’s specifications and processes can be directly traced back to an OEM R&D project.

Financial

Current OEM research and development investment in the United States lags behind other countries and the OEM’s overall R&D commitment continues to decline. For the past several years R&D investment, as a percentage of sales in the PWB industry, has been less than one percent. We can compare this to a 3 –5% investment by Japanese PWB manufacturers and a greater than 10% investment by semiconductor industry manufacturers. None of the small independent PWB manufacturers have the resources by themselves to replace the R&D investments formerly made by the large U.S. OEMs.

The OEMs and EMS providers have reduced R&D spending to cut costs. Within the academic community this means little or no financial support from these organizations.

University Role: Customer Relations

The customers of academia can vary from society as a whole, for technically trained graduates, to specific companies who contract R&D for specific development items.
There is considerable debate in the U.S. regarding how well the higher educational system is doing in providing U.S. industry with technically trained students. Arguments both defending and attacking the current system of training science and engineering students have been put forth. It is not the purpose of this paper to enter into that debate.

What is more important given the trends in the OEM and EMS segments of the U.S. electronic industry is what role academia is playing in R&D for the U.S. The authors believe that the industry needs to form a PWB Interconnect Research Council, which includes members of University and Government Research organizations. This group should meet at least once a year to listen to current activity reports and to strategize together where the PWB research dollar should be spent. To make this large-scale activity successful and ongoing, the IPC, NEMI and ITRI should jointly sponsor the activity.

The IPC sponsors two annual events for PWB and PWA manufacturers, the IPC Printed Circuits Expo and the IPC/SMEMA APEX Conference. University representatives have always been a part of these conferences, but they have been spread throughout the conference agenda generally discussing the university’s role in an existing activity. One new suggestion is to have specific session on far reaching university research giving the universities a chance to showcase their research activities. The session leader should be a recognized university or government lab researcher.
Situation Analysis

Governmental interactions with the domestic electronics industry can be divided into three broad categories:

Regulation Activities (OSHA, EPA, etc.)

Regulation is the most obvious and possibly the most onerous (to the industry) of all government-industry interactions. At the top of the list of adversarial interactions are the relations of industry with the U.S.EPA and OSHA. Too often these agencies are viewed as government bodies whose decisions are divorced from any understanding of industry's problems. Instead of working together government and industry more often litigate than cooperate.

Part of the difficulty in these relations is the disconnect between the legislative and enforcement functions. While the legislatures are charged with legislating laws that cover the environment and worker safety the U.S.EPA and OSHA are charged with interpretation and enforcement. Thus feedback that citizens in industry provide to influence environmental regulation and enforcement must be directed to both legislative and enforcement bodies.

Research Support (NIST, DARPA, DoD)

Whereas the relations between industry and OSHA and the U.S.EPA are often rocky the relations between industry and many of the research bodies supported by the government are usually better. With the decline of industry-supported research, especially long-term research, the role of government-supported research is growing in importance.

Based on budgetary status within the government agencies such as NIST have the funding to support long term R&D that can be of use to industry. The nature of these projects is also amenable to some shaping and direction by industry.

Declining Government Investment in R&D

However, the United States government role in research and development is also changing. In the late eighties and early nineties, the U.S. government spent millions of dollars funding technology research and development projects in industry. In the year 1994, The federal government funded $155 million of interconnect related R&D (see Table 1). This funding came primarily from DARPA (Defense Advanced Research Projects Agency), NIST (National Institutes of Standards and Technology), and DOE (Department of Energy). About three-quarters of this money went directly to the U.S. industry through contracts, grants, and other agreements.
### Legislative Economic Incentives (Depreciation)

Economic incentives provided by the legislature are a third form of industry-government interaction. Tax relief in the form of write-offs for depreciation and R&D investment can be a support for modernization. This constant upgrading is important within the electronics industry where technology changes are rapid.

### Financial Conditions

Financially the three types of government interactions are, at present, negatively impacting on industry for regulation, positively impacting for research, and indefinite for many legislative activities.

The long-term intent is to make all interactions positive (or as positive as possible). The general proposal for this would be:

1. Better industry-government cooperation on environmental and safety issues. A method of achieving this in the environmental area is to apply more economically positive impacting initiatives through a focus on the disciplines of "green manufacturing" and "industrial ecology". As opposed to end-of-the-pipe regulation these disciplines improve environmental performance while also economically benefiting industry. An especially critical issue emerging in the environmental area is “product take-back.” There is general agreement that recycling is a good thing environmentally. However, the financial impact on industry may be either negative or positive depending on yet-to-be-developed government policy.

2. Closer ties between government sponsored R&D and industry goals.

3. More sensitivity within the legislature to the impact on industry of:
   - Environmental regulation
   - Tax support of research and development
   - Depreciation to support capital investment in new technology.

### Customer Relations/ Supplier Relations

A clear distinction between customer and supplier in the relation between government and industry is not possible. In some instances government acts as the supplier by providing support for industry through research initiatives. In some instances it is industry through taxes that suppliers...
the government with financial support. This mixed set of linkages means that there is little to be gained by adversarial relations between the two groups. Each has a set of goals. But, given the social structure of the U.S. these goals are really, in the long run, indistinguishable if both partners are acting for the country’s greater good.

**Strengths and weaknesses**

Based on U.S. economic growth and strength the relations between industry and government cannot be considered to be fatally flawed. Indeed, they may be at times strained, but on the whole they are relatively sound. Government has provided industry with a stable environment for growth. Industry has responded by providing goods and services to support the government through taxation etc.

The weaknesses come in the changing paradigms of environmental discipline and research and development. Shifting the emphasis of environmental legislation from politically driven regulation to science based evaluation of real risks within the discipline of industrial ecology will do much to improve both the environment and the bottom line of industry. The first step would be a government realization that the paradigm of industry R&D is changing with the demise of the old vertically integrated OEM. Suggested second steps would be increased government funding for basic R&D and increased tax write-offs for R&D by industry.

**Conclusions**

The relation between industry and government within the U.S. is sometimes tense but still remains basically healthy. Basic improvements in the methodology used by the government to direct environmental legislation are in need of more basic science with an emphasis on industrial ecology. Support for research continues to be a priority for both industry and government. Tax incentives to support this research and investments in new technology are also needed.
Part 9 – Conclusions

OEMs and EMS Providers

The balance of power between OEMs and EMS providers is changing. No longer is the OEM the vertically integrated monolith of the past. Driven by financial pressures and operating under the current paradigm for manufacturing OEMs are divesting themselves of manufacturing and flattening their infrastructure. Even as the OEMs "horizontally integrate" the new vendors of manufacturing services, the EMS providers, are making every indication that they will "vertically integrate".

As much of this shift in power and structure is market and paradigm driven it is unclear how far any trend, either horizontal or vertical structuring, will proceed before the pendulum swings back. However, based on a linear extrapolation (not always the best procedure for predicting the future) manufacturing will be equally split between OEMS and EMS houses before 2010.

Independent of prediction accuracy it is obvious that one of the early casualties of this trend is R&D. This is especially true in the area of substrate R&D. Neither the OEMs nor the EMS have the resources, given the demands of Wall Street, for long-term investment in what many consider to be "low tech."

Semiconductor Packaging Companies

Very much like the OEMs and EMS Providers, the balance of power for package design, assembly, and testing is changing from the merchant semiconductor companies to the semiconductor packaging companies. The merchant semiconductor companies are being driven by the new business models that continues to push to out sourcing all package design, assembly, and test to minimize overall cost. This is the same business model that has been so successful in the semiconductor start-ups. Many of these start-ups are now becoming as large or larger than the full service merchant semiconductor companies. The merchant semiconductor companies must change rapidly to this business model to compete. This business model change is allowing the merchant semiconductor manufacturers to refocus their limited R & D and capital resources in the areas of IC design and wafer fabrication.

This new focus is creating extreme pressures on the semiconductor packaging manufacturers and their vendors to pick up the full cost of R & D and capitalization for all present and future advanced package families. The information in this paper shows the outsourcing occurring presently at a rate of 28% in 1999 and moving to 31% in 2004. With the speed of change in this industry it would not be unusual to see this come much faster than presently predicted. The faster to conversion the greater strain on the small semiconductor packaging companies. The required development in new packages may not occur in time for the advancing semiconductors due to limited or non-existence resources. This area must be monitored very closely to be sure that this does not happen.

Substrate Providers

With the silicon moving steadily along the path of Moore's Law the interconnection density being demanded of substrates is constantly increasing. It is the challenge of "scaling with silicon" that is
pushing the U.S. industry. However, as noted above, the R&D sources previously based in the
OEMs are disappearing. Although EMS providers are providing some R&D the overall amount of
U.S. R&D lags far behind the investment of the Asian countries.

The stakes for the domestic substrate industry are significant. In order to be a player in the world
of High Density Interconnect (HDI) one needs to understand the role of electronic packaging
design and the dilemma that engineers face trying to meet the requirements of increased
functionality in an ever decreasing envelope and form factor. More I/Os, shorter lead length,
smaller packages, finer board features and smaller interconnecting vias are all needed to meet the
new form factors resulting from the increased functionality of ICs. Today’s solution to the
component-packaging problem is not leads on two sides versus four sides, nor is it gull-wing,
versus "J" lead as the I/O of choice. The array package has come into its own, and a sphere or
ball has become the lead configuration of choice.

In order to efficiently interconnect array packages with high I/Os HDI technology is needed.
Surface layer microvias produced using lasers individually, or chemical/plasma etching in mass are
replacing the old drilling methods. Microvias make it possible to achieve the "escapes" from
component ball patterns that are at the center of the array component. The layering technique
used in sequential multilayer manufacturing provides the additional routing room needed when one
layer of circuitry is insufficient. Printed board manufacturers provide the mounting structure used
inside the plastic ball grid array. This requires smaller form factors, smaller panel sizes, thinner
materials with a higher Tg, finer circuit features, and smaller holes. Those who build standard
boards being identified as the "mother board" used to mount many components are also receiving
the challenge. Here the form factors are large. Only now are the characteristics becoming the
same as the Single Chip or Multichip component boards. i.e. finer features, thinner materials,
smaller holes etc.

Substrate manufacturers must prepare to meet this growing market. US based printed circuit
manufacturing success is often dependent on customer loyalty. With the globalization of
corporations and demand for higher profits from US investors, extreme pricing pressure is being
placed on the domestic printed circuit manufacturer. While high quality and reliability requirements
are demanded of US manufacturers, many PCB purchasers seem willing to forego such
requirements in favor of lower cost from a non-domestic provider.

The Electronic Manufacturing Service vendors (EMS) are also impacting the domestic PCB
industry. EMS has grown rapidly over the last decade as the U.S. OEMs began selling off or
closing down some of their captive assembly capability and outsourcing that work to independent
assembly companies. In many cases, the independent assembly company has become the
customer of the PWB manufacturer, rather than the OEM, as in the past. This puts another link in
the already fragile communications chain. Because the EMS companies have little interest in
funding research and development of advanced printed circuit manufacturing methods, PWB
manufacturers must either go it alone or find other ways to get the future OEM requirements
necessary to properly focus their R&D.

**Global Equipment and Material Suppliers**

The pace of change affecting OEMs, EMS vendors, substrate manufacturers and component
suppliers is also having an effect on the equipment and material suppliers. As the technologies in
products become more sophisticated so too do the demands on suppliers. Complicating the picture
is the proliferation of links in the "electronic food chain."
In the past a supplier may have needed only one contact with an OEM to play a part in product realization. Now the links of the chain are no longer self-contained within a vertically integrated OEM. Being a supplier means being able to cross company boundaries. It also means taking a larger role in what is being done in the design, data transfer, manufacturing, and test process that now stretch across multiple financial entities.

The suppliers to the industry do a good job in servicing their customer base. They are responsive. However, many times they are asked to perform what appear to be insurmountable tasks. Their business success is based on being there when needed, and having the material, equipment and processes available for the next generation of products.

The best suppliers are those that have a close relationship with their customers. The term “preferred supplier” must be earned and once achieved is guarded by supplier management in order to maintain that status. It is difficult to break into a relationship that has been built up over years of trust and meeting commitments on both the customer and supplier side.

**Government and Academia**

The reader may have noted a common theme in the above summaries for each of the industry segments. That theme is squeezing costs cuts R&D.” Given this trend in the various segments of the U.S. electronic industry what role is government and academia playing in R&D for the U.S.?

The PWB industry has not been extremely successful to date in tapping into the university research base. There are a few universities who do research in PWB technology, but it is very limited. It appears that Georgia Institute of Technology (Georgia Tech) has the biggest interconnect budget. Others that have some interconnect technology activities include Auburn University, Cornell, Binghamton University, Florida International, R.I.T., and Univ. of Maryland. NEMI recently published a list of 19 universities doing research in some form of packaging.

The industry has a need to for a PWB Interconnect Research Council, which includes members of University and Government Research organizations. This group should set the strategy as to where the PWB research dollar should be spent. To make this large-scale activity successful and ongoing, the major industry organizational players, e.g. IPC, NEMI and ITRI, should jointly sponsor the activity.

It is also important for there to be more cross fertilization between existing research programs in government and academia and industry. Given the variety of industry forums and conferences there appears to be a multitude of opportunities for the government and academia to showcase their research activities. Possible ways of doing this are to encourage more academic and government research leaders to act as leaders, technical consultants, and session chairs for the industry conferences.

Industry for its part needs to understand that consortia can work. Establishment of consortia can leverage declining R&D dollars across an industry. This requires levels of trust to be developed. It also requires all parties to fully understand what they must bring to the table and what they can take away from the shared results.
Part 10 - Action Items

The previous sections were intended to be informative in nature. Each was to provide an overview of a particular segment of the industry. The conclusion section was to briefly summarize the description previously provided. This section deals with what the Surface Mount Council feels are the action items of each of the industry segments. As such it delineates what the Council feels are the responsibilities of the industry segments.

Descriptions and analyses are easy to do. Determining courses of action are more difficult. And carrying out a course of action such that a concrete and desired result is obtained is the most difficult of all.

Below are listed specific suggestions for each industry segment. The Surface Mount Council (SMC) feels that these are the areas of importance. And only by acting in these areas will the U.S. industry advance beyond the difficulties noted in the descriptive sections above.

EMS Providers and OEMs

It will be difficult if not impossible for the trend from vertical to horizontal integration in the OEMs to be reversed. The most likely scenario is a move by the electronic manufacturing services (EMS) to vertical integration by acquisition of contract design and/or manufacturing-less OEMs. In either scenario it is important for all involved to remember that there is no substitute for investment.

Accordingly the SMC feels that:

1. Investment in long term R&D should be stated as a priority for the U.S. electronics industry.
2. To support this end the major players in the U.S. industry, e.g. IPC, NEMI, need to develop a public policy statement that encourages and supports R&D investment especially in the substrate interconnect area.

Substrate Manufacturers

It is the challenge of "scaling with silicon" that is pushing the U.S. industry. With the R&D sources of the OEMs disappearing and the EMS companies providing only limited R&D the overall amount of U.S. R&D lags far behind the investment of the Asian countries. PWB manufacturers must find ways to get the future OEM and EMS requirements necessary to properly focus their R&D. With the current extreme price pressure few options are available. The Surface Mount Council's suggestions for addressing this are:

1. As with the OEMs and EMS companies long term R&D needs to be a stated priority.
2. Existing industry organizations, e.g. the IPC, need to help U.S. PWB manufacturers focus on the most productive areas of R&D.
3. Positive interactions between industry members, i.e. consortia, academia, and government need to be fostered in support of increased R&D investment.
4. Increased support for standards development is critical as substrate manufacturers now deal with an increasing mix of OEMs and EMS companies. Standardized design data transfer processes increases productivity and helps to smooth across-company transfers of information.

**Semiconductor Packaging Companies**

Like the trend in the EMS companies, the packaging, assembly, and test are not likely to go back into the merchant semiconductor companies. It is likely that larger packaging companies will absorb either small semiconductor packaging companies or they will go out of business. There may be a major shortage of resources if the merchant semiconductor companies in the semiconductor packaging companies do not make the investments. The OEM may even have to invest to be sure that they will have the components needed for their final products. The Surface Mount Council feels the following must happened in this area:

1. Investment in short and long term R & D should be stated as a priority for the US Semiconductor Industry. This commitment is for global investments because the merchant semiconductor and OEM companies are all global in their customer base.
2. The Universities and Industry Associations (SIA, IPC, JEDEC, NEMI, etc.) must take active roles in creating standards, policies, and consortiums that will bring the industry the new advances.

A longer-term approach must be taken by the industry on profits to create the needed revenue to make the long-term investments.

**Global Material and Equipment Suppliers**

The pace of change affecting OEMs, EMS vendors, substrate manufacturers and component suppliers also impacts equipment and material suppliers. Demands on suppliers become greater as the number of links in the "electronic food chain" increases. With the links of the chain no longer self-contained within a vertically integrated OEM a supplier must be able to cross company boundaries and take a larger role in what is being done in the design, data transfer, manufacturing, and test process that now stretch across multiple financial entities.

To that end the Surface Mount Council recommends that suppliers:

1. Continue to support standardization of material requirements, design, and data transfer.
2. Actively help to address the U.S. shortfall in R&D investment. For many suppliers their participation could be a windfall area in which new market opportunities open up.

**Academia**

The SMC believe that the industry needs to form a PWB Interconnect Research Council, which includes members of University and Government Research organizations. This group should meet at least once a year to listen to current activity reports and to strategize together where the PWB research dollar should be spent. To make this large-scale activity successful and ongoing, the IPC, NEMI and ITRI should jointly sponsor the activity.
The IPC sponsors two annual events for PWB and PWA manufacturers, the IPC Printed Circuits Expo and the IPC/SMEMA APEX Conference. University representatives have always been a part of these conferences, but they have been spread throughout the conference agenda generally discussing the university’s role in an existing activity. Establishing a specific session in each of these major conferences that is devoted to far reaching university research gives the universities a chance to showcase their research activities. The session leader should be a recognized university or government lab researcher.

**Governmental Agencies**

The following are suggested actions for government bodies. These suggestions can also be a call to action for the electronics industry to lobby for a change in government direction.

1. Move the current legislative and regulatory thrust from politically directed end-of-pipe regulations to science based industrial ecology.

2. Increase government support for research. The cooperation between industry and government and industry in the direction of this research must increase to improve the pay back on investment. This pay back emphasis must not be at the expense of long-term basic research.

3. Government support for tax incentives that increase industry investment in research and capital investment in new technology is needed.

4. Strive to increase the linkages that span across the boundaries between industry, academia, and government.
Annex A Surface Mount Council

The Surface Mount Council is made up of key industry representatives dedicated to promoting the use of surface mount and advanced electronic packaging technology in the design and production of electronic assemblies. The IPC (Association Connecting Electronics Industries), EIA (Electronic Industries Alliance ECA Division) and SMTA (Surface Mount Technology Association) jointly sponsor the Council.

The mission of the Surface Mount Council is to facilitate, coordinate and promote the orderly implementation of surface mount technology and advanced electronic packaging technology through standardization, the development of technical documents, and other means.

Roadmap Listing

The following are the published roadmaps that were used in Technology Vision Analysis 2010. A brief description of the roadmap is provided for reference. The current chair of the roadmap activity is also listed.

The 1997 National Technology Roadmap for Semiconductors. It is published by the SIA (Semiconductors Industries Association), but receives considerable support from Sematech, and SRC. This roadmap is a 15-year projection of CMOS integrated circuit technology. It identifies research needs and provides some potential solutions. The chairman of this roadmap is Paolo Gargini from Intel.

The 1996 National Electronics Manufacturing Roadmap. This roadmap takes a system view, utilizing five product emulators as its basis. The chairman of the NEMI (National Electronic Manufacturing Initiative) roadmap is Irwin Asher of Lucent Technologies. Leo Feinstein of NEMI is the co-chair.

The 1997 National Technology for Electronic Interconnections. The IPC roadmap is based on 18 product emulators and covers the areas of printed wiring board assembly, device packaging, board assembly, and environmental issues. The chairman is Jack Fisher, from ITRI.

The 1996 Electronic Design Automation Roadmap. This roadmap is a cooperation between EDAC (Electronic Design Automation Companies), CFI and Sematech. John Teets from Silicon Integrated Initiatives, is chairman.

The 1996 Optoelectronics Technology Roadmap Series Conclusions & Recommendations Sensors, Multimedia, Parallel Optical Interconnects, and Military and Aerospace Since 1992, OIDA has conducted both market and technology-oriented workshops, which serve to identify critical issues for suppliers and users, develop statistical estimates, and provide recommendations to industry and government. In addition to assistance from the Defense Advanced Research Projects Agency (DARPA), OIDA's workshops are supported by the active participation of the National Institute of Standards and Technology (NIST) and the
National Science Foundation (NSF) which provide valuable expertise and insight to the process.

**History and Benefits of Roadmapping**

Roadmapping in the United States is a recent activity. It is believed to have gotten its start from the auto industry in the late 80’s. At that time the big auto companies were calling in their suppliers and asking them for their roadmaps of future products. Today there are several national roadmaps in the auto industry, the electronics industry, the steel making industry and others. What is unique about the electronics industry is that it is the only industry where the separate roadmaps are being refined and meshed together to provide an integrated picture. These roadmapping activities have a clear benefit. They require industry leaders to think about their future needs in quantitative terms.

Roadmaps are not intended to provide technical solutions. Roadmaps define trends in an industry and the needs of the industry that results for the predicted progression of those trends. A user of a roadmap should be able to assess where the industry is now, where that industry will be in a given number of years, and what he or she would need at that time in the future if current directions continue. The user of a roadmap should be able to assess any gaps between the predicted direction and expected needs.

**Tomorrow is Here - Get Ready**

The electronics industry is alive with rhetoric about new materials, new components, new high density interconnecting structures, new assembly techniques, and new performance requirements for complex electronic modules and assemblies. Are the design tools able to provide the best arrangement of components and conductor positioning? Will the materials hold up when exposed to the stress conditions of some equipment types? Is the industry infrastructure ready to serve the customer? Will the standards and test methods needed to define the requirements within reasonable and reliable boundaries be ready in time to be effective for the first orders?