Low Expansion Alloys

The Printed Circuit Board Industry and Innovations for the 1990s

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INTRODUCTION

Dramatic changes occurring in the printed circuit board market will lead to exciting business opportunities for both suppliers and end users. These changes, among others, involve the provision of smaller, lighter and more reliable interconnections and will contribute to an average annual growth rate of 11% over a five-year period, with shipments rising from $4.6 billion in 1987 to an estimated $7.8 billion in 1992.

Until recently, the manufacture of printed circuit boards remained little changed from the procedures set in place 30 years ago: hand-designed artwork; the use of a copper-clad reinforced substrate in two dimensions; drilled and plated-through holes; and manual inspection. However, the competitive pressures to accommodate the performance demands of very-large-scale integrated circuits with high lead counts on tightly spaced centers, as well as surface mounted assemblies demanding fine lines and vias, have generated research and development in the areas of new manufacturing processes and materials.

The printed circuit board industry has recently keyed into high technology to meet the new demands of miniaturization and increased component density, which are the driving forces of circuit design, interconnection and packaging.

BACKGROUND

Printed circuit boards are the basic building blocks of the electronics industry, acting as the "command modules" for thousands of electronics products, such as computers, telecommunications equipment, automotive and appliance controls, radios and TVs, as well as aerospace equipment. The boards are used to mount and interconnect integrated circuits and descrete components.

The printed circuit boards consist of metallic patterns which conduct electrical current and which are on or bonded within insulated material. The boards are the foundation for and the interconnection between semiconductors, integrated circuits and other electronic components.

Today's printed circuit board substrates are primarily made from thermoset plastics, which have copper foil bonded on to them to make single-sided, double-sided, or multilayer circuits. However, printed circuit boards are also made from thermoplastics for certain specialized electrical applications such as microwave systems. Other substrates, such as ceramics or insulated metals, are also used for special performance requirements like surface-mounting components.

Printed circuit technology is being driven by the needs and developments of packaging the integrated circuits into the total electrical system. The integrated circuits are the prime components that combine the functions of many electronic components in a single substrate, which is usually silicon. The circuit elements formed on a small silicon chip are then encapsulated in plastic, ceramic or metal packages having metal lead wires for connection to the printed circuit board. The advent of semiconductors reduced the size and weight of components so that today's circuit boards have surfaces ranging from a few square feet down to a few square inches.

Rapid strides in the semiconductor industry have incorporated very large functions into a single component package, which, in turn, has put a larger number of functions onto the printed circuit board. Additionally, improvements in integrated circuit processing have dramatically increased circuit speeds, producing very-high-speed integrated circuits.

Currently, there are three different, but compatible, technologies that are pushing the innovations in the printed circuit board industry for the 1990s—surface mounting, additive circuitry and injection molding.

Surface Mounting Technology

The driving force behind the development of surface-mount technology is the need to provide smaller, lighter, more reliable packages beyond the capabilities of traditional dual-in-line packaging (DIP). As printed circuit density increases, physical limits have started to curb existing technologies as shrinking line/space width comes at a price of increasing heat build-up. Surface-mounted component leads are soldered to the top level conductors of the circuit board rather than into the circuit board itself.

The attachment of electronic parts to the top side of the circuit board eliminates the need to make electrical connections with pins inserted through holes in the boards. Avoidance of this assembly requirement permits a higher density of electronic components on board substrates. However, the end result is heat build-up and exposure to temperature of up to 420°F using vapor phase soldering.

The main attraction of surface-mounted components is that they allow for a reduction in the printed circuit board size by 50-70%. The primary function of surface mount packages is the increase of package and circuit board density. However, cost savings resulting from the adoption of surface-mount technology depend on the specific applications of the technology and the production volumes involved.

Manufacturers report up to a 70% reduction in board size when surface mounting is utilized. One vendor cites a reduction in manufacturing costs as much as 50%, and the board size was reduced by as much as 58% for the same density while providing increased circuit reliability. Additional benefits cited for surface-mounted component assembly include increased suitability for automated assembly and testing, lower noise and improved frequency response resulting from shorter circuit paths, and less electromagnetic interference (EMI) shielding and filtering to meet Federal Communications Commission standards for EMI generation.

Additive Circuitry

The additive process allows conductive lines to be formed by an electroless deposition of copper onto the board. The additive process differs from the subtractive in that no etching is required because the circuit pattern is defined at the same time the through-hole connection is made. Currently, over 90% of all printed circuits produced in the U.S. are manufactured using the subtractive method. Disad-

Rigid Circuits

Rigid circuits comprised of single-sided, double-sided and multilayer rigid substrates are expected to continue healthy growth levels once the electronics industry recovers from its recent recession. Total rigid circuitry will increase in dollar volume from $4.37 billion in 1987 to $6.98 billion in 1992, a 9.8% increase over five years.

Double-sided printed circuit boards represent the largest segment of the printed circuit market. In 1987, these boards accounted for 52.7% of all printed circuits, valued at $2.4 billion.

Although the double-sided printed circuit board segment will demonstrate healthy growth between 1987 and 1992, its share of the total market value will fall, primarily because of the explosive growth in the multilayer segment.

Multilayer printed circuits will exhibit the most dramatic growth in this category, with average annual growth of 14.1%. Multilayer printed circuit boards continue to be the most dynamic and fastest-growing segment of the printed circuit market because the trend in electronics is toward increasing the component density and, therefore, toward a greater demand for high-density, multilayer printed circuits. Computers, communications equipment and defense account for over 90% of all multilayer printed circuit usage.

Multilayer growth will be driven by the expansion in the production of electronic equipment, particularly in the data processing, telecommunications and industrial categories. Overall, the demand for more sophisticated, more powerful and smaller electronic products incorporating surface mounted components will propel the multilayer market.

In 1987, 35.7% of all circuit boards were multilayer, valued at $1.5 billion. By 1992, shipments are forecast to be valued at $3 billion.

Others

Overall, "other" printed circuits, consisting of injection-molded and rigid-flex circuits will enjoy the greatest growth through 1992, with average annual growth of 56%. By 1992, this should translate into 6% of the total printed circuit market.

THE PRINTED CIRCUIT BOARD MARKET

Business Communications Company estimates that 25% of printed circuit board production is used for surface-mount applications, valued at $1,150 million in 1987. By 1992, 45% of U.S. printed circuit board production, valued at $1.5 billion, will be used for surface-mount applications.

Table II. U.S. Electronic Equipment Market

Market	1987*	Percent of Total
Data Processing Equipment	82.0	42.0
Test & Measurement	7.3	3.7
Analytical/Medical	4.8	2.5
Communications	32.5	16.6
Consumer	22.2	11.4
Industrial	6.5	3.3
Federal Government	40.0	20.5
Total	195.3	100.0

*In billions of dollars.

The demand for printed circuits is a function of the demand for electronics equipment. Each major electronic application segment varies in its need to achieve higher density as well as its willingness to invest in capital equipment for surface-mount technology, new printed circuit board technology and interconnection products.

U.S. Electronic Equipment Market

The U.S. market for electronic equipment is enormous (accounting for nearly 60% of the free world's total consumption) and is still growing, despite the decline in rate of growth to 9.9% during 1985.

As shown in Table II, U.S. shipments of electronic equipment were estimated at $195 billion in 1987, and growth in the electronic equipment market was triggered by the upswing in the semiconductor industry. The U.S. consumed $13 billion worth of semiconductors in 1987, 17% more than the previous year.

Data processing equipment now comprises the largest electronic equipment segment. Shipments of data processing equipment equaled $82 billion, or 42% of all electronic equipment sold. Shipments of data processing equipment are forecast to grow 11.5% annually between 1987 and 1992, with total shipments of $141.3 billion in 1992. Percentage wise, this translates into a 16.7% share of the total in 1992.

After data processing equipment, the U.S. government is the second largest market segment for electronic equipment. Shipments to the government, primarily for military applications, are expected to equal $10 billion in 1987, or roughly 20% of total electronic shipments. Reductions in military spending, partly as a result of the U.S. budget deficit, will translate into an average annual growth rate of 5% through 1992.

Other major markets for printed circuit boards include industrial and instrument applications, led by demand for machine and process controls, including semiconductor production equipment in response to renewed component demand. This market sector should grow at an average annual rate of 11% to $10.9 billion through 1992.

Additionally, consumer electronics equipment, with a value of shipments in 1987 estimated at $22 billion, constitutes 11.4% of the total electronic equipment market.

It is projected that growth in the consumer electronics sector will slow to 5.2% annually due to saturation in the video segment. However, increases are expected in the automotive and home sectors, as advanced technologies utilizing multilayer printed circuits create new consumer products for the home through 1992.

CONCLUSIONS

The science of plastic materials for printed circuit boards is constantly improving to meet the demand for better electrical and mechanical performance of electrical systems. Epoxy resins will continue to dominate the printed circuit market through 1992. However, thermoplastics will make inroads due to their superior mechanical, thermal and electrical properties and compatibility with the surface-mount process.

Through 1992, it is expected that laminates will resume a positive growth, but with most of the increase in value of printed circuit boards coming from increased circuit density on smaller surface volumes.

During the 1990s, the function of the printed circuit board will change. The long-term role is for the circuit board to become part of the circuit. In some cases, the printed circuit board will provide not the second level of interconnection but the third level as future customization will move the circuit board function to silicon.

New technologies will change the nature of printed circuit boards and the way firms in the industry do business. Board fabricators and consumers who prepare to adopt these technologies will benefit from exciting business opportunities.

If you want more information on this subject, please circle reader service card number 53.

vantages of the subtractive process include an increase in production steps and material handling, limited substrate selection, and photocircuit design constraints. Additive circuitry produces finer conductors and smaller and deeper holes.

In the world market, the Japanese printed circuit board industry primarily employs the additive process.

Injection-Molded Circuitry

Another technology, spurred on by surface mounting is injection-molded (three-dimensional or 3-D) circuit board fabrication. More circuits can be printed directly on injection-molded plastic than on conventional rigid or flexible substrates, if projected cost savings can be realized. The printed circuit is constructed out of layers of polymer thick film (PTF) applied by the additive process. High-volume applications will be best served by injection-molded plastics.

Injection-molded printed circuits are made from a new generation of high-heat thermoplastic substrates. One industry view is that better substrate materials will lead to a long-term switch of some major electronic applications from thermosets to thermoplastics, particularly in high-volume uses.

All claims regarding cost savings would come after the high capital investment necessary for the retooling needed to fabricate injection-molded printed circuits. The costs of the molds range from $15,000 to $40,000 compared to high-end tooling costs of $2,000 for traditional thermoset epoxy FR-4 boards.

At the present time, injection-molded boards command less than 1% of the U.S. printed circuit board market. As this process is a break with traditional extruded sheet subtractive fabrication processes, this may be looked upon as a drawback by an industry that views 3-D as experimental and exotic. However, a major feature of molded printed circuits is that all mechanical features such as through-holes, connector housings and mounting surfaces are molded. This eliminates machining such as drilling and routing. Other benefits include the elimination of production steps, and waste reduction.

All told, the combination of surface mounting, additive circuit fabrication, and injection molding is advancing the development of new printed circuit boards for the 1990s.

TYPES OF PRINTED CIRCUITS

There are two basic types of printed circuits: flexible and rigid. Additionally, two other categories currently exist which are expected to make an impact on the market through the 1990s. They are injection-molded circuits and rigid-flexible hybrid circuits.

Flexible printed circuits are made from a flexible base material and have the ability to conform to almost any pattern or shape. Flexible printed circuits are used to interconnect components assembled in the non-planar arrangement, such as folding around corners or bends. Electronic applications include aerospace and military, as well as computers and telecommunications.

Rigid printed circuits are usually made from a rigid thermoset plastic substrate, commonly referred to as a printed circuit board. Rigid printed circuits are used whenever a rigid plane or configuration is desired for interconnection.

Although the term "injection-molded" refers to a fabrication process rather than a specific type of circuit, 3-D or injection-molded printed circuits are a departure from rigid and flexible printed circuits, yet have characteristics of both.

Hybrid circuits refer to the fabrication of a complete circuit through a combination of active and passive devices on a common metal-patterned insulating substrate. Passive components and interconnections are screened or deposited onto a substrate, generally ceramic, by thick- or thin-film technology, followed by the attachment of the devices/integrated circuits and lead bonding. These efficient, high-density hybrids are used as functional modules on printed circuit boards to support flexibility of design.

Another category of printed board is the hybrid which combines flexible and rigid board elements. Current applications for "rigid-flex" circuits are mostly in the military. However, the growth of surface-mount technology will spur hybrid board usage in commercial markets. In the electronic interconnection industry "hybrid" has many meanings.

Rigid-flex hybrid circuits encompass two varieties: rigidized "Kapton" flexible circuits and rigidized "Mylar" flexible circuits. In a rigidized flexible circuit, a flexible circuit is bonded to a rigid membrane. This type of circuit is universally used in "static" applications (e.g., a military application where electronic gear is folded over on itself in an aircraft fuselage). This is in contrast to a flexible circuit such as a printer, where the circuitry is in motion for the product's lifetime.

Printed circuits, whether rigid or flexible, are further classified by one of three basic classes of structure: single-sided, double-sided and multilayer. Single-sided circuits have conductors on only one surface of a dielectric substrate base. Holes for components may or may not be present. Double-sided circuits have conductors on both sides of a dielectric base that are usually interconnected by plated-through or otherwise reinforced holes. Multilayer circuits have three or more (up to thirty) conductor layers separated by dielectric material and usually interconnected by plated-through interlayer holes.

Both rigid and flexible printed circuits, as well as injection-molded and hybrid printed circuits may be of single-sided, double-sided or multilayer construction.

MARKET SEGMENTATION

As shown in Table I, the U.S. printed circuit market is segmented both by circuit type (rigid and flexible) and structure (single-sided, double-sided and multilayer).

Flexible Printed Circuits

Flexible printed circuits represent the smallest traditional segment of the printed circuit market, accounting for 5% of total circuit production. Flexible circuits are more expensive than rigid boards, but provide greater freedom for designers. Flexible circuits, used primarily in communications and military equipment, will grow in value from $230 million in 1987 to $387 million in 1992. The ability of flexible circuits to conform to almost any shape makes them ideally suited for audio and video equipment, automobile dashboard clusters, telephone receivers, and mobile radios. Flexible printed circuits are expected to grow at 11% annually through 1992.

Over the next five years, growth in flexible circuits will be driven by surface-mount technology, polymer thick films, multilayer circuitry, and the use of rigid-flex hybrids.

Table I. U.S. Shipments of Printed Circuit Boards by Type

Type	1987*	Percent of Total	1992*	Percent of Total	AAGR (%)† 1987-1992
Rigid	4,370.0	94.0	6,983.0	89.0	9.8
Single-sided	362.0	7.8	427.0	5.4	3.3
Double-sided	2,450.0	52.7	3,542.0	45.2	7.7
Multilayer	1,558.0	33.5	3,014.0	38.4	14.1
Flexible	230.0	5.0	387.5	5.0	11.0
Other‡	50.0	1.0	465.0	6.0	56.2
Totals	4,650.0	100.0	7,835.5	100.0	11.0

*In millions of dollars.
†Average annual growth rate.
‡Includes injection-molded and rigid-flex circuits.