# Flexible Printed Boards

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This paper describes flexible printed circuit boards, used as "Product Boards" or "Interposers", chip mounting structures. Traditionally, flexible circuit boards are made with polyimide dielectric cores. These are made either by lamination processes of a foil with adhesive, or the build-up of the copper from an "adhesiveless" process

**Current Technology Status for Flexible PCB's**

There are many benefits of using flexible circuits to build product boards. These benefits include:

- Flexural endurance (for dynamic flex)
- Flex for 3-dimensional installation (for flex/bend to install)
- Light weight
- Thinness
  - Thin (25µm) adhesiveless flexible layers in all-flex constructions or as flex layers in rigid boards reduce inductance and reduce EMI (electromagnetic interference)
  - Unfilled and ceramic filled thin flex layers are suitable as planar decoupling capacitance layers.
  - Thin flex layers, notably ceramic filled layers are effective heat dissipation layers.
- Low dielectric constant
- Low dissipation factor
- Low coefficient of thermal expansion (CTE)
- Availability of very thin copper cladding
- High break-down voltage
- CAF (conductive anodic filament) resistance, "zero CAF" in adhesiveless polyimide flex layers
- Roll-to-roll processing
- Appropriate for high density applications: laser-drills well and thin copper allows fine lines and spaces.

Flexible printed boards (FPBs) find application where interconnect structures have to survive severe flexural life cycles and torque (e.g. hard disk drives, printers), or where shock and vibration absorption are required (e.g. military applications). Most flexible printed boards are not subjected to dynamic flex requirements but need to flex to be installed in 3-dimensional static shapes, a feature that assists miniaturization in hand-held electronic equipment and certain medical applications. Specialty applications also include membrane switches (key pads) and single-layer structures serving as superior alternatives for wire harnesses.

The disadvantages of these products are closely related to their flexibility advantage: dimensional instability, unique tooling requirements, uniqueness of applications that add engineering costs. High Tg flex substrates, suitable for soldering (typically polyimide), are more expensive than comparable rigid substrates.

Using the convention of earlier technology roadmaps, the current flexible printed board technology status can be described by distinguishing between conventional, leading edge, and state-of-the-art sectors, color coded green, yellow, and red. The green color is meant to signal technical feasibility and economic viability across a broad range of fabricators, yellow signals a higher degree of difficulty, mastered only by a limited number of fabricators, and red suggests considerable barriers against wide use due to the degree of technical difficulty, high cost, or both (see Table 1).

Organic flexible interconnecting structures are among the most demanding products in terms of what is required of the manufacturing process. Very fine lines and spaces (sub 100µm) and small holes (sub 125µm) are hallmark features of this type of product. As a result, they represent the leading edge of flexible circuit technology. Note that the high layer count boards may not be all-flex structures but mixed dielectric lay-ups containing e.g. ceramic, PTFE, polyimide. Table 2, below, provides the characteristics of the design features used for flexible interconnection interposer substrates..

**Table 1 - Product Board Design Feature Characteristics**

| Design features | Conventional | Leading Edge | State-of-the-Art |
|---|---|---|---|
| Lines & Spaces (µm) | 100-250 | 50-100 | 25-50 |
| Via Diameter (µm; as drilled) | ≥275 | 100-250 | 50 |
| (Conductive) Layer Count | 1-2 | 2-12 | >12 |
| Dielectric Thickness (µm) | 25-100 | 12-25 | 12 |
| Conductor Thickness (µm) | 18-36 | 9 | 3-5 |
| Adhesive | Yes | adhesiveless | adhesiveless |
| Controlled Impedance | No | Yes | Yes |
| Minimum Annular Ring =(pad diameter-hole diameter)x1/2 (µm) | 250 | 50 | None (landless via) |

**Table 2- Design Feature Characteristics for Interposers**

| Design Feature | Conventional | Leading Edge | State-of-the-Art |
|---|---|---|---|
| Lines & Spaces (µm) | 100-250 | 50-100 | =25 |
| Via Diameter (µm; as drilled) | ≥250 | 100-200 | 50 |
| (Conductive) Layer Count | 1-2 | 2-20 | >20 |
| Dielectric Thickness (µm) | 25-100 | 12-25 | 12 |
| Conductor Thickness (µm) | 18-36 | 10-17 | 8-9 |
| Adhesive | Yes | adhesiveless | adhesiveless |
| Minimum Annular Ring (µm) =(Land diameter-hole diameter)x1/2 | 200 | 50 | None (landless via) |

***Market Overview***

The global market for rigid and flexible printed boards is estimated at about $34 billion for 2003, $4.4 to $5.2 billion of which, depending on the data source, are flex circuits. See Figures 1.

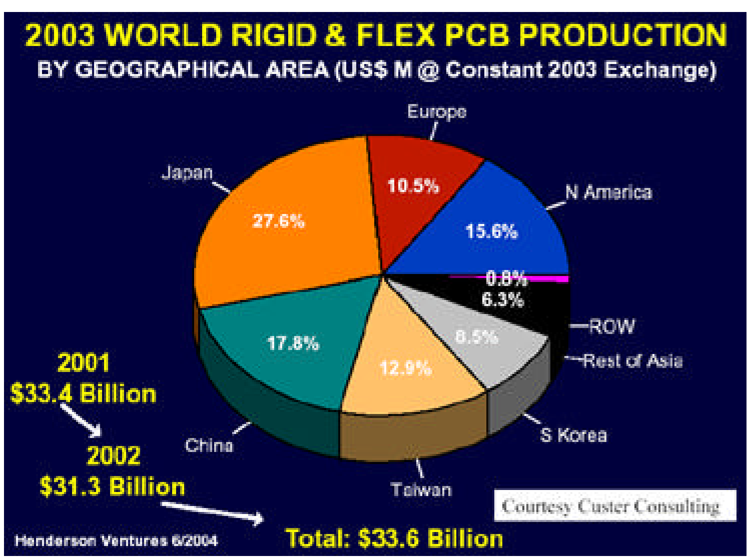


**Figure 1 World Flex Production**

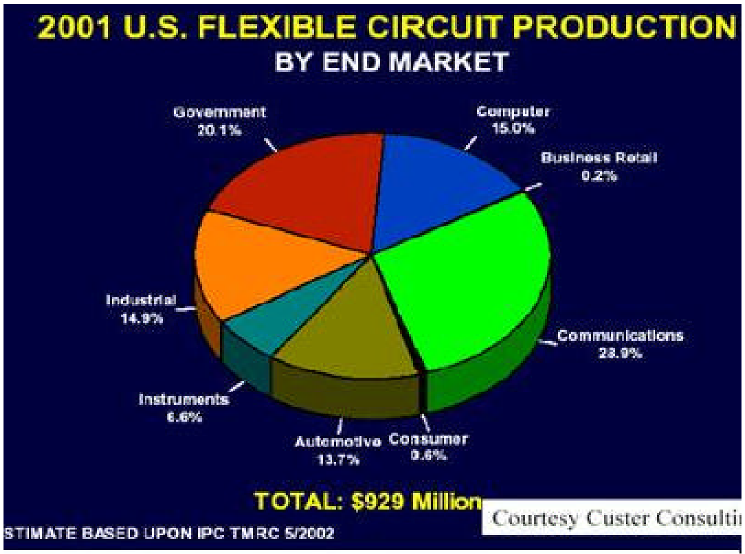


**Figure 2 Growth of Flexible Printed Board Production**

At a projected growth rate of 12.4%, flex circuits are expected to grow faster than any other PWB market segment (Figure E-2-6). This growth stems from a number of different end-uses (Table 3), the most significant being cell phones, in particular camera cell phones

**Table 3 - Global PCB Production Forecast**

| Technology | 2003 | | 2008 | | % Yr CAAGR |
|---|---|---|---|---|---|
| | Value ($M) | Share | Value ($M) | Share | |
| **Single and Double sided PCB"S** | **7428** | **22.6%** | **7933** | **18.2%** | **1.3%** |
| **Four and Six Layer PCB's** | **9305** | **28.3%** | **10515** | **24.2%** | **2.5%** |
| **Complex conventional PCB's** | **5424** | **16.5%** | **7196** | **16.5%** | **5.8%** |
| **Microvia MLB's and silicon platforms** | **5971** | **18.1%** | **9234** | **21.2%** | **9.1%** |
| **Flexible PCB's** | **4803** | **14.6%** | **8607** | **19.8%** | **12.4%** |
| **Total** | **32931** | **100%** | **43484** | **100%** | **5.7%** |

**Curtesy: Prismark**

Cell phone flex applications include:

- Rigid-flex, where the flex circuit connects the rigid mother board and the LCD rigid portions of the rigid-flex.
- Display driver circuit, typically a double-sided flex assembled with driver IC and passive components attached to the color LCD with anisotropic conductive film (ACF). Color screen with monochrome caller ID might require two driver display flex circuits
- Multi-layer flex cable, typically a 4-layer flex, bonded at the ends and terminated with connectors. The center of the circuit is not bonded, consequently these are sometimes referred to as air gap circuits. Flex endurance along with signal integrity are key design considerations.
- Camera flex, generally a single sided flex. The bend here is circular in nature to accommodate turning of the CCD camera.

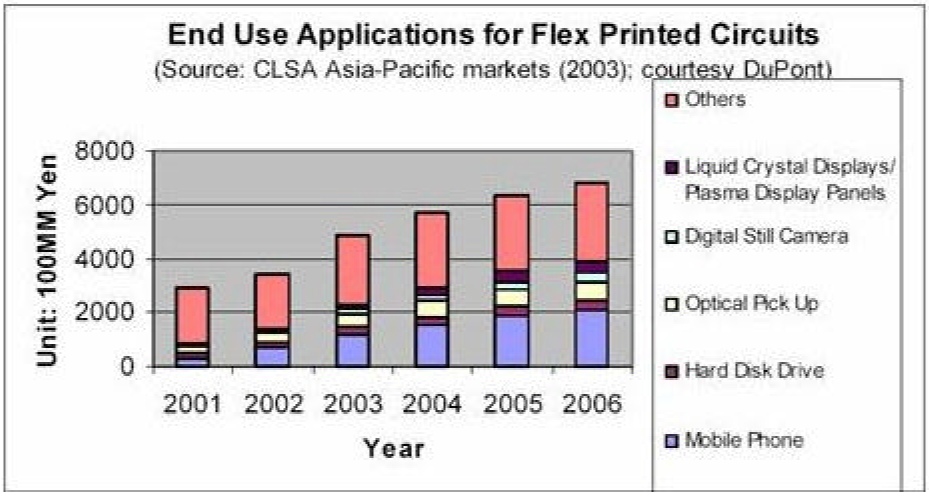


**Figure 3 - End Use applications for Flex Printed Circuits**

**Flex Circuit Constructions, Materials, and Applications**

Depending on the market segment's needs, various layering constructions are in use:

- Single-sided flex consists of a single layer of conductive patterns, supported by a flexible substrate, with or without a protective coverlayer. Electronic components are mounted and accessible only on one side. A classic example of a single-sided flex structure with a coverlayer is a flex circuit with parallel tracks, serving as a wire harness.
- Double access (or "back bared") flex circuits are single layer circuits with access to the circuit from both sides created by partial removal of flex substrate. An example is the Tape Automated Bonding (TAB) package, with cantilevered conductors extending over the access hole.
- Double-sided flex consists of a flexible substrate sandwiched between two layers of conductive patterns. Components can be mounted on both sides.
- Double-sided plated through-hole flex circuits are more common than double-sided flex circuits without metallized through-hole connections.
- Multilayer flexible printed boards feature more than two conductive layers that are interconnected with plated through-holes. It is common to not laminate all layers together, except in regions of plated through-holes, to maintain maximum flexibility.
- Rigid-flex circuits are hybrids with sections of flex and rigid circuitry laminated together and interconnected with plated through-holes. Typical applications include military use and lap top computers. The most rapidly growing application in the last few years has been the use in cell phones where the flex circuit connects the rigid mother board and the LCD rigid portions of the rigid-flex.

***Choice of Interconnect Structures and Materials***

The choice of flexible printed board structures and materials is dictated by their electronic function and the need for component interconnectivity. Wire harness function requires simple single-sided flex with coverlayer protection. Double-sided plated through-hole and multilayer flexible boards are needed for higher wiring density. Microvias and (update: 50micron?) conductors and spaces are found in area array chip scale packaging technologies shown in D-2. Dimensional stability and heat resistance requirements may dictate the use of adhesiveless polyimide dielectric film for this particular application. Typical adhesiveless polyimide fabrication technologies are shown in Figure 4.

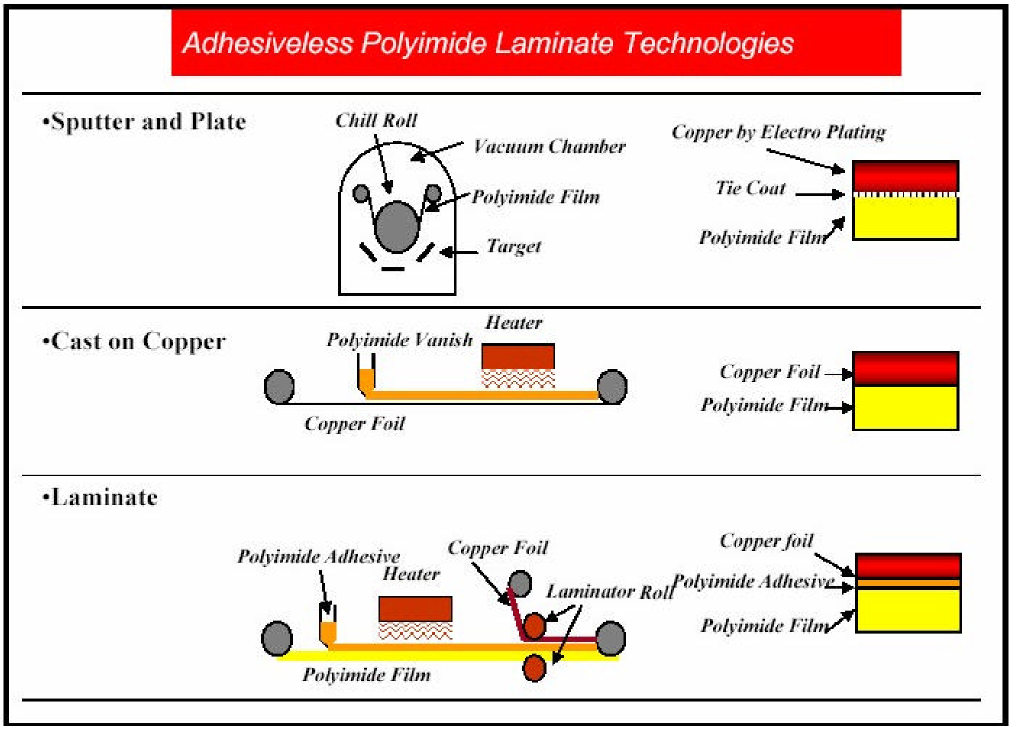


**Figure 4 - Adhesiveless Fabrication Process**

Circuitry layout and design, e.g. co-planar conductors vs. micro strip vs. stripline is largely dictated by shielding and cross-talk avoidance considerations. Other structural choices are related to flexible printed board package integrity and fabrication process requirements. To minimize post-etch shrinkage, large non-functional copper areas may be part of the design. To avoid tearing of the dielectric film, corners of the flexible product are "radiused", slits end in relief holes, and windows feature tear stops at the corners as shown in Figure 5. Conductors on double-sided flexible boards are inter-digitized (offset to each other) for better flexibility. Bend lines are designed as far away as possible from mechanically fixed areas of the assembled package. Conductors are positioned at the neutral axis of the flex line wherever possible for best flexural endurance. The coverlayer often serves to "balance" the structure for that purpose. Dielectric, conductor, and adhesive layers are kept as thin as practical for improved long term flexibility.

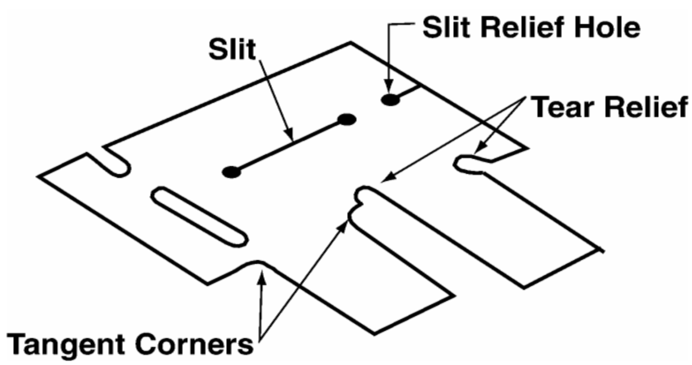


**Figure 5 - Flexible Circuit Tear Stop Configurations**

**Market Overview and Trends**

Figure 6, shows the polyimide flex circuit market by market segments to illustrate major first and second level packaging applications.

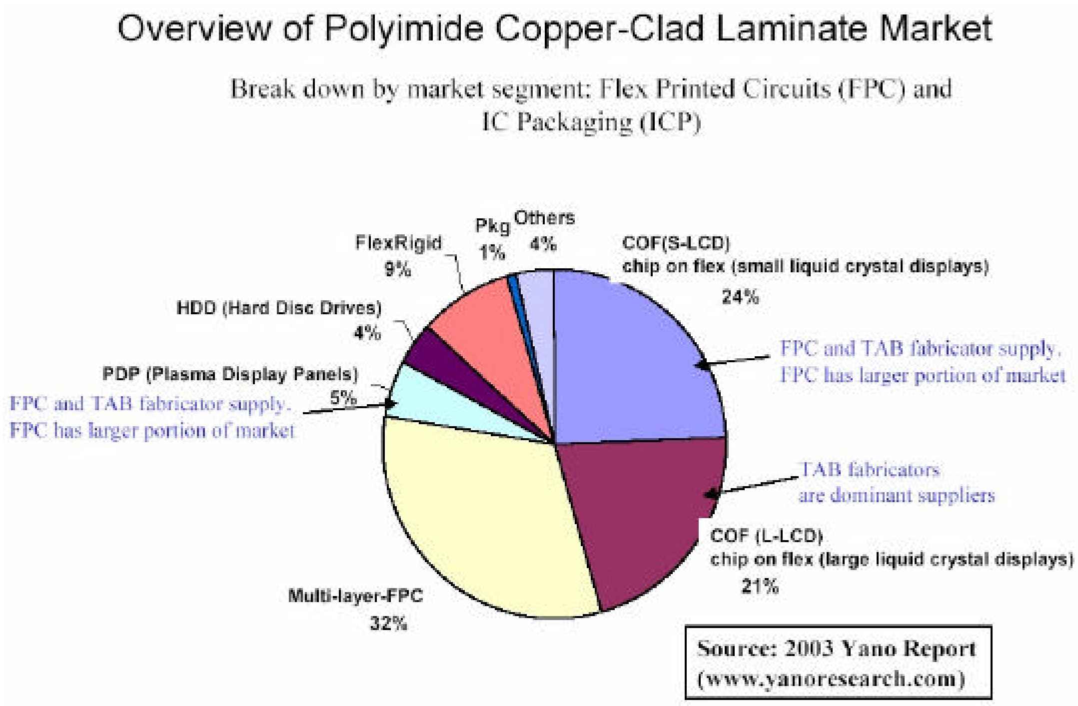


**Figure 6 - Flex (Polyimide) Market Overview**

Figure 7 indicates expected growth trends by market segment. While the relative share of L-LCP (large liquid crystal displays) is expect to decline, S-LCDs (small liquid crystal displays), PDPs (plasma display panels), T-BGAs (tape-ball grid arrays), and FS-CSPs (fold stack chip scale packages) are expected to gain share. The total volume for all segments is expected to grow from 2.7MM $m^2$ in 2002 to 5MM $m^2$ in 2005.

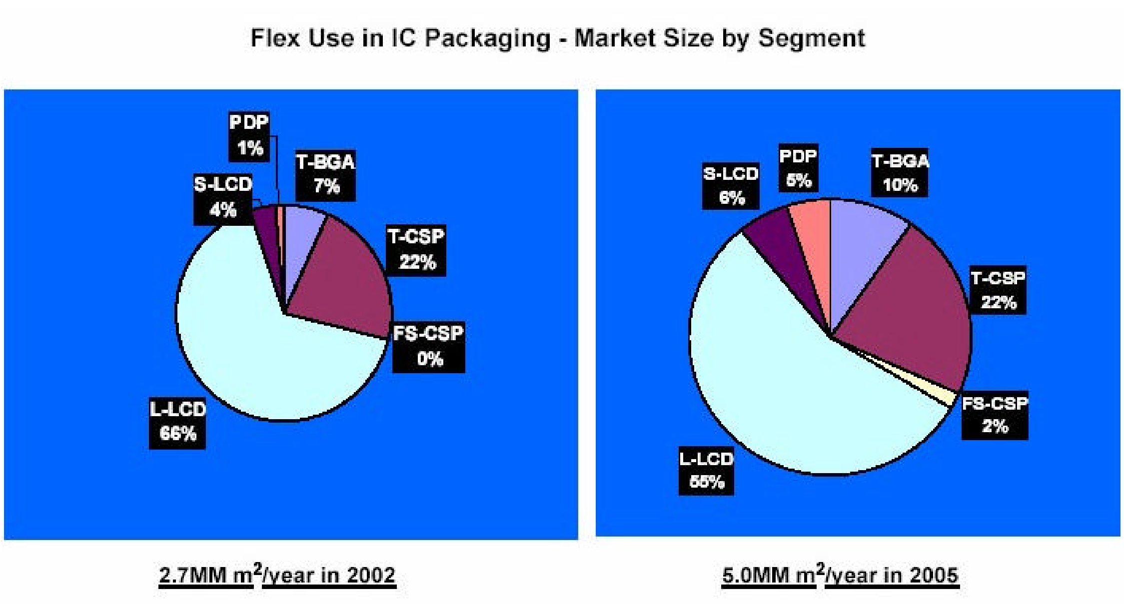


**Figure 7 - Flex Interposers Market Share**

Table 4 shows technology roadmaps and design rule shifts for the 2002 to 2010 time span for TCPs (tape carrier packages).

**Table 4 - Design Rules Trends for TCP/COF**

| Design Rules for TCP/COF (Source: Misuzu Industries Co., 9th Annual KGD Workshop, Napa, Ca, Sept 2002; courtesy:Tech Search International, Inc.) | | | | |
|---|---|---|---|---|
| | 2002 | 2003 | 2005 | 2010 |
| Gold Bump Design (same for TCP and COF) | | | | |
| Bonding Pitch (µm) | 50 | 40 | 35 | 30 |
| Bump Size (µm) | 40x80 | 30x80 | 25x100 | 20x100 |
| Bump Height (µm) | 15 (+/-3) | 15 (+/-3) | 15 (+/-3) | 15 (+/-3) |
| Tape Design | | | | |
| Bonding Pitch (µm) | 50 | 40 | 35 | 30 |
| Inner Lead Width (Top) (µm) | TCP/COF 25/17 | TCP/COF 20/14 | TCP/COF X/13 | TCP/COF X/11 |
| Copper Thickness (µm) | 18/12 | 15/9 | X/6 | X/6 |

Portable and wireless electronics represent the most aggressive growth area for high-density package technology. In both circuit board fabrication and IC packaging, the technology for compressing even the most sophisticated electronic functions into a smaller and lighter finished product continues to evolve.

Portable or hand-held electronics are a natural target. Digital cameras and camcorders, for example, must consider ease of use, lighter weight and performance. Cellular phones, pagers, personal communicators, palm top computers, industrial and automotive electronics, personal GPS, medical and diagnostic products, are all viable candidates for more efficient device miniaturization.

**Flexible Circuit Technology Needs**

The following needs have been identified for flexible printed boards. They include the technology and market drivers that are shared with other electronic packaging sectors.

- The growing demand for "portability" fuels the demand for flexible printed boards in notebook computers, cellular phones, pagers, etc.
- Narrower spacing between conductors and thinner dielectric layers require dielectrics with higher break-down voltage and CAF (conductive anodic filament) resistance.
- The growing demand for flex circuits in high frequency, controlled impedance circuits, particularly for telecom switching stations.
- Demand for higher bandwidth drives the need for dielectrics suitable for high-speed digital and RF applications with low Dk, low loss, and tight thickness tolerances.
- The need for size and weight reduction drives the use of transformer coils for DC/DC and low voltage AC/DC conversion formed from thick copper on flex, capped with a second flex layer and mounted to the surface of rigid boards.
- Growth in displays is driving the use of flex connections from the display panel to the display driver.
- The need for embedded passive components will drive the use of thin flex planar capacitance layers.
- The military market consolidation forces a shift to commercial applications. They, in turn, become the technology drivers, and military applications borough from standard, high volume commercial designs.
- Reduced product lifecycles demand shorter lead times and quick ramp-up and ramp-down.
- The highest volume growth is in Asia (outside Japan), and value-added assembly drives in-house assembly options and partnerships

To meet the demands, it is likely that processing equipment more dedicated to the needs of flex circuit type products will be required. Roll-to-roll processing provides the manufacturer with a very cost effective method for circuit production. The method is also ideal for establishing and controlling the processes using in manufacturing as process steps can and must be very accurately controlled as parts are indexed from process to process. Two metal layer flexible base films with thickness on the order of 25µm will be required to meet the needs of certain next generation products, especially folded flexible packages.

**Directional Changes**

Focused effort should be spent to make a dramatic difference in the world of flex circuitry. The concepts are intended to be realistic and can set the stage for future research. The following paradigm shift opportunities are:

- A step change in assembly technology for flex circuits which would allow assembly of flex circuits with the same ease and efficiency as rigid boards, to substantially cut flex circuit assembly cost.
- A fully dynamic, photoimageable, all-polyimide coverlay to complete the all-polyimide package for very fine pitch and for improved mechanical reliability.
- A substantially lower cost polyimide substrate or equivalent thereof as a prerequisite to expand flex circuitry into the domain of lower cost rigid boards.
- A low cost, low Dk, process-friendly dielectric for high speed applications

**Conclusions**

Flexible printed boards are the most versatile type of wiring interconnect structure that exists within the industry today. The products' inherent advantages make it an ideal candidate for surface mount technology, chip scale packaging, microvia formation, wafer scale packaging, lap top computers and "hand held sector" applications. Flexible printed board markets are growing faster than those for rigid boards and have shifted from the military sector to consumer electronics where large volumes and standardization hold promise for cost reduction in materials, tooling, and process flow.