Manufacturing Flexible Printed Circuits

Understanding and Managing the Issues Associated with Conventional versus Roll-to-Roll Processing

Background

The worldwide flexible printed circuit (FPC) market was estimated to be approximately US$5.9 billion in 2005, and is expected to grow at an average annual growth rate (AAGR) of 13.5% to reach US$11.2 billion in 2010. Although Thomas Friedman believes the world is flat, this market is anything but!

![Worldwide Flex Circuit Market, 2002-2005 and 2010 (US$ Billion)](image)

**Worldwide Flex Circuit Market, 2002-2005 and 2010 (US$ Billion)**
Source: electronics.ca (NE Asia Online)

FPC technology is an enabling vehicle for several important applications in various industries such as telecommunications, computer applications, automotive, medical, and aerospace. The demand for FPCs has grown rapidly. At the same time, there is performance pressure to reduce the size, weight, assembly time, and costs of FPCs – and a continuing need to enhance their functionality. The growth market will be primarily driven by a strong demand for higher density and smaller-sized devices, which will lead to the rise in demand for FPCs in the digital electronics industry. Moreover, the demand for various electronic products such as cell phones, PDAs, and camcorders is expected to increase over the next five years, particularly in emerging markets such as India and China. There is also a rapidly increasing demand for flexible circuits in the automotive, industrial, and white goods markets where unique packaging requires three-dimensional circuitry. A less defined but emerging market is electronic identification, which includes RFID and smart cards. All told, the FPC industry is expected to grow at an impressive rate.
FPC Technology

FPCs use various base materials/substrates, such as polyimide and polyester. As polyimide provides high performance properties to the rigid-circuit world, polyimide film-based FPCs will dominate the total FPC market. Approximately 90% of the FPCs being produced in the world use polyimide as a substrate. Polyester-based FPCs are the second most popular substrate in the industry. In the future, it is expected that alternative materials including PEN, PEI, and thin FR-4 will be widely used.

For the purposes of this discussion, FPCs will be classified on the basis of layer count; which include single-sided (Tier I), double-sided (Tier II), and multi-layered (Tier III). Tiers I and II dominate the market driven by a technology trend in the industry to produce lighter and higher density interconnects (HDI). It is also important to note that the demand for Tier III FPCs is expected to continue to grow due to 21st century applications in the high-technology electronic marketplace. Advancements in handheld products such as cell phones and PDAs continue to suppress and replace existing tabletop electronic hardware and will demand the integration of thinner FPC substrates driving increased performance, with less real estate, all at a more affordable price. As the Wal-Mart motto and mission statement reads, "to give ordinary folk the chance to buy the same things as rich people," so goes the electronic world.

FPC Market Drivers

The impressive growth of the Tier I and Tier II FPC market has given shape to a new outsourcing opportunity for industry OEMs and a burgeoning breed of job-shop vendors. This new breed of vendors currently does not manufacture FPCs in roll-to-roll form but continues to utilize the more difficult rigid-panel/sheet processing techniques. The implications of this method of processing ultimately limit the quality, capacity, and overall yield of panel processing suppliers. Thin dielectric films, used for the fabrication of FPCs, are commonly in the 12-micron to 75-micron thickness range and cannot be handled effectively with conventional rigid-panel protocol. Unfortunately, this dilemma has adversely affected not only the capability of FPC manufacturers but also has projected an unfavorable image to the OEMs that they are supplying.

Historically, only the premier FPC fabricators, through innovation and technology, have been able to optimize their production by integrating roll-to-roll methods for FPC fabrication. Companies such as Nitto Denko, Nippon Mektron, and Fujikura have, over the past several years, developed, utilized, and protected roll-to-roll process and equipment IP. As such, they have dominated the FPC fine pitch and HDI market segment.

However, a new class of equipment supplier, capable of providing a turnkey approach to fabricating FPCs in roll-to-roll form has emerged in the marketplace. Roll-to-roll equipment requirements including, but not limited to, thin film wind and unwind stations, thin film transport systems, advanced OSP equipment, roll-to-roll electro-less copper/direct metallization lines, vertical web electrolytic plating lines, and thin film transport DES lines are now available from M.E Baker Company (Baker).

On February 6, 2006, Baker purchased MacDermid Equipment, a center of excellence in engineering and equipment design for MacDermid, Incorporated. Through this acquisition, Baker has initiated a comprehensive “Technology Roadmap” that will lead to the formation of several strategic alliances with prominent chemical and equipment manufacturers. These alliances will support a commitment to develop and support industry needs for future circuit fabrication for both thin film panel and roll-to-roll applications.
Strategic Alliances

Imaging Partner

This alliance will focus on high-speed roll-to-roll systems utilizing existing high stability glass artwork technology; it will also advance conventional and HDI technology. Adjunct, this segment of the technology roadmap will support thin film panel processing in FPC operations where roll-to-roll fabrication is not practical. Only through this partnership, and the implementation and integration of novel/unique equipment, will process advancements in the thin film and HDI market be realized.

Electro-less and/or Plated Through Hole (PTH) Partner

Key considerations in this alliance are the environment (green technology) and low cost manufacturing. Strategic partners will focus on efficient methods and processes that will integrate easily into Baker’s equipment and produce reliable solutions for PTH products. Direct metallization will be utilized, where applicable, and will focus on high-speed transport systems for PTH metallization and subsequent electroplating. Electrolytic processing will utilize vertical roll-to-roll equipment with unique handling and fluid delivery techniques that will dramatically improve manufacturing yields and overall product quality.

There are basically two primary competing technologies for the generation of a PTH in the fabrication of PCBs. The techniques commonly applied are a) electro-less copper, and b) direct metallization. While vacuum metallization and sputtering are used for producing thin copper seed layers on flexible substrates (polyimide film) these technologies have not been successful in metallizing a hole. Adhesive-less substrates produced through dry methods continue to require the use of electro-less copper or direct metallization for PTH applications.

Electro-less Copper: Electro-less copper has been the conventional and dominating technology for manufacturing double-sided and multi-layer PCBs. Based on aqueous formulations and the chemical reduction of copper, processing is typically conducted in batch-type regimes that utilize semi-automatic equipment and a multiple vertical rack system. While electro-less copper dominates the rigid and rigid-flex market, in all aspects of printed circuit panel fabrication, FPC manufacturers continue to search for improved processing methods and technology.

Direct Metallization (DM): Various techniques and IP can be found in the science of producing an electrically conductive layer for subsequent electrolytic deposition for PTH application. Four technologies dominate this market: a) graphite-based colloids (Rockwood’s Shadow and Rohm & Haas’ Graphite 2000); b) carbon-based colloids (MacDermid’s Blackhole); c) palladium-based systems (Atotech’s Neopact); and d) various conductive polymers. All have their advantages and idiosyncrasies. One major advantage in DM is that it has less environmental impact and is commonly applied through the use of high-speed horizontal processing equipment. Most modern FPC roll-to-roll fabricators utilize DM techniques.

Metal Sputtering / Vacuum Metallization: Sputtering is a process based on the physical collision of atomized copper released from a target and the implantation of that metal onto a substrate. Vacuum metallization is simply an evaporation and phase change, producing the same result, and is also used extensively for metallized film production. These processes have only recently been accepted within the FPC fabrication community as a source of metallized base material. Companies such as Molex, Flextronics, M-Flex, 3M, and Parlex will continue to advance and drive this segment of the FPC market.

The equipment and processes that are needed for the 21st century will require suppliers with a fundamental understanding of the sciences and commitment to an intelligent investment in capital equipment. The technological challenges are: a) handling thin and ultra-thin dielectrics; b) controlling DIMSTAB - dimensional stability; c) matching CTE (elimination of adhesive-based di-
electrics); d) improving substrate thermal conductivity; e) producing ultra-thin copper layers on dielectric substrates and the subsequent ED copper seeding (6 to 12 micron copper thickness); and f) utilizing high speed roll-to-roll fabrication to improve capacity and yield.

**Equipment Considerations & Results**

At the very core of the manufacturing trend towards producing thinner, lighter and higher density circuits, the demands are now shifted to fabrication equipment technologies and the effective handling and processing of thin core material. Roll-to-roll processing equipment will need to focus on the smooth, yet firm, transport of films through various wet processes. These systems will ultimately need to handle FPCs in a horizontal or vertical plane and will require “next generation” spray- or immersion-type technologies. An illustrative example of this is in the field of wet processes: FPC capacity and capability requirements demand high speed plating, improved etching uniformity, intelligent material handling, as well as proper fluid delivery and dynamics. FPC fabrication using batch processing and antiquated rigid-panel protocol was the failure of the 20th century and will be superseded in the 21st century by roll-to-roll technology.

**Steady State Systems - Transport Technology**

Baker:

Utilizes specially developed horizontal conveyors that drive both top and bottom rollers that nip the web in key locations to ensure uniform transport of the film, avoiding drag while minimizing the physical distortion (stretching) of the substrate. Top rollers, other than nip style, were developed to be light and resistant, eliminating film and circuit scratching/abrading, while providing unequaled transport stability, with film thickness capability down to 33 micron.

Baker:

Integrates serpentine transport systems providing a highly efficient web-to-machine “footprint” where maximum process exposure is realized in a short linear distance. A field proven multi-drive technology - that reduces drag on the web while maintaining high transport speed - is especially effective in additive technology where delicate coatings on a substrate can be easily abraded by roller drag.

**Steady State Systems - Fluid Delivery**

Baker:

Maintains an engineering philosophy where all fluid delivery systems are designed to be process specific. Unique fan sprays for High Performance (HP) fluid delivery are used in all processing and rinsing stations. The HP system was developed to provide maximum uniformity and proper fluid dynamics across the entire web width, providing unequalled etching capability for conventional and HDI substrates. Via-head is a technology that provides chemistry uniformity across the web through utilization of a low pressure, high volume flow regime. This has proven to be an extremely effective concept in processing blind micro-via and through-hole micro-via technology, effective in both roll-to-roll web or rigid-panel constructions.

**Six Sigma**

Six Sigma is a common statistical methodology for quality control and improvement and is used worldwide to manage all critical processes at all levels of manufacturing. Reducing and controlling variation eliminates defects. Customer responsiveness is improved and internal efforts are strategically aligned. Baker’s MEI Division has used the statistical analysis protocol of Six Sigma in the manufacture of its equipment since 1995, reducing defects while improving delivery time and quality! Baker’s deployment of Six Sigma has led to improved performance and will continue
to allow them to supply unequalled quality and highly reliable equipment, designed to support tomorrow’s needs.

Customer Yields

Baker’s FPC customers include many of the world’s largest suppliers of adhesiveless flex circuits for the hard disk drive, medical, IC packaging, printer, display, optoelectronics, and mobile electronics. Utilizing M.E. Baker equipment, customers have manufactured HDI circuits with a 30 micron pitch, chemical milled via-arrays with diameters down to 100 µm, produced wire bond chip-scale packaging (CSP) with FPCs utilizing 50 µm wire bond pads, all with thin film polyimide and LSP substrates. The introduction of roll-to-roll equipment, with M.E. Baker’s unique engineering approach, has increased fabrication yields from less than 75% to as high as 99%.

Conclusion

There is no question that Thomas Friedman’s brief history of the twenty-first century is accurate, if not revolutionary.

Here I was in Bangalore – more than five hundred years after Columbus sailed over the horizon, using the rudimentary navigational technologies of his day, and returned safely to prove definitively that the world was round.

When I set sail, so to speak, I too assumed that the world was round, but what I encountered...profoundly shook my faith in that notion. Columbus accidentally ran into America but thought he had discovered part of India. I actually found India and thought many of the people I met there were Americans.

The world is flat. “As flat as the forty digital screens put together on which Infosys CEO Nandan Nilekani can host a meeting of his whole global supply chain. I am convinced that the flattening of the world will be seen in time as one of those fundamental shifts or inflection points, like Gutenberg’s invention of the printing press, the rise of the nation-state, or the Industrial Revolution.”

Flexible printed circuits, it turns out, are also flat. And though Mr. Friedman does not reveal the manufacturer of Mr. Nilekani’s LCD display modules, it is highly possible, if not probable, that they use an optical film manufactured by an M.E. Baker customer.

We are clearly at an inflection point in the technology of manufacturing FPCs. As commoditization drives the margins out, the only way to recover lost profit is to increase yields. FPC fabricators using batch processing and antiquated rigid-panel protocol have finally reached the yield threshold, a tipping point at which there is no turning back. They simply must innovate their wet processes to survive.

FPC capacity and capability requirements will demand high speed plating, improved etching uniformity, intelligent material handling, as well as proper fluid delivery and dynamics. All these requirements can be achieved with production-proven roll-to-roll equipment from M.E. Baker Company. Perhaps most importantly, production-proven technology from Baker allows the FPC fabricator to benefit from development work already achieved, resulting in standard roll-to-roll equipment that is both cost-effective and fast to market.
Bibliography and references


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