The strong growth of the flexible circuit market is expected to continue, driven particularly by ever-increasing demand for the miniaturisation and further function integration of handheld devices like cell phones and digital cameras. Since flexible materials are difficult to handle in manufacturing, conventional singulation techniques like punching or routing have in some cases already reached their limits with regard to accuracy, burr formation and reliability. Laser cutting has already proven to be a suitable technology for complementing conventional cutting technologies in prototyping, pre-series and low-volume production. By reducing product changeover time, increasing accuracy and eliminating tooling costs, laser systems are designed to produce a better product at a lower cost.

Today’s electronic devices - in particular handheld devices such as cell phones, PDAs, and cameras - require higher density electronics and tighter tolerances due to the ever-increasing demand for miniaturisation and function integration. Flex and rigid-flex printed circuit board technology offers the possibility of solving three-dimensional structural issues and achieving high-density electrical interconnections, outperforming standard PCB technology based on rigid boards, cables and connectors. Not surprisingly, the flex and rigid-flex printed circuit board market is exhibiting a strong growth.

The drawback to flexible materials is that they are difficult to handle in the manufacturing process. Mechanical stress placed on the materials by standard mechanical routing or punching equipment is detrimental in terms of accuracy, burr formation and reliability.

Lasers, on the other hand, are non-contact tools and offer advantages due to their flexibility and versatility. Their high-intensity light can be focused to very small focal points, thus providing a very high precision tool. The ability to cut complex shapes with a stress-free process in combination with an extremely small tool diameter allows more circuits to be placed on a single panel, significantly increasing the net usable area. Reducing burr formation is another important factor for the sophisticated products of the future and helps to considerably improve the yield of high-end flexible printed circuit manufacturing. Based on today’s achievable throughput, and taking into account the investment costs of a laser-based cutting system, laser cutting has already proven to be a technology well-suited to complementing conventional cutting technologies in prototyping, pre-series and low-volume production.

In 2004 flexible circuitry production grew at 4 times the rate of rigid boards. BPA Consulting expects the production of flexible printed circuit boards to double by 2010. Today the rapidly growing handheld device market (mobile phones and digital cameras) accounts for 33% of the flex and rigid flex PCB production and this figure is expected to increase to 40% by 2010. DKN Research has conducted an intensive investigation into the future of the flex industry, covering business segments that currently use flex and those applications that will require flex in the future due to packaging constraints, weight considerations or cost goals. According to their investigations, the demand in square metres will have more than doubled by 2010 (Figure 1), with a 12.6% annual growth in volume and a 10.9% increase in revenue.
The driving force behind this strong market forecast for FPCs is the miniaturisation and increased functionality of mobile phones and digital cameras. System intelligence equal to that of a small pocket PC, larger high-resolution displays to view pictures taken with an integrated high-resolution camera, and mobile TV are already integral features of many of today’s mobile phones. FPC interconnects with thinner materials and finer lines and spaces will contribute to enable more components to be integrated and the size of the mobile phone to be reduced at the same time.

The key to success with FPC manufacturing is in the control of production techniques. Techniques that are quite simple in theory, including the separation (i.e. the cutting) of single circuits within a panel, may prove very difficult in practice. Integrating new and innovative manufacturing techniques and automation can contribute to an increase in quality and yield as well as helping to keep pace with product requirements. Time-to-market is also one of the most important issues for FPC manufacturers. Being able to react quickly to layout changes during prototyping and pilot production runs can be a further key to success. For this reason, laser technology, generally used as a tool for drilling the smallest micro vias in advanced IC packages, flexible circuits and high-density circuits (HDI boards), is nowadays used more and more for cutting FPCs. Expensive tooling and extensive time-consuming manufacturing steps, particularly in prototyping and pre-series production, can be eliminated, guaranteeing excellent quality and yield at the same time.

Conventional tool-based technology vs. laser technology

This comparison of laser cutting and conventional cutting techniques focuses on the following two process steps within the prototyping and pre-series production of FPCs: overlay cutting for prototyping and pre-series, and body cutting for prototyping, pre-series, and low-volume series.

Overlay is one of the major differences between flexible and rigid circuit boards. Overlay is the mechanical protector for the fragile conductors on flex circuits and determines the solder coating areas (apertures) for component assembly. Usually, the same films are used as base material of overlay and substrates. The major problem in manufacturing the overlay films for FPCs is dimensional distortion during the lamination process, which makes automation difficult and increases costs. Apertures are usually introduced into the overlay films prior to lamination. Overlay films usually comprise polyimide with a thickness of either 12.5µm or 25µm coated on one side with adhesive attached to release paper.

Body cutting refers to the singulation of flexible circuits from their panel. Usually this comprises the cutting of arbitrary shapes into a combination of polyimide layers with adhesives (single or double side, double access, multi-layer). Connectors, Copper layers and stiffeners (e.g. FR4 or Polyimide) have to be cut out as well.

Conventional tool-based technologies to cut overlay, flex and flex-rigid circuits comprise punching and routing. Punching involves cutting dies with either hard or soft tools. Hard tools are produced from hardened steel and are made to precise tolerances achieving up to 50µm accuracy in cutting. Soft tools such as steel rule-dies (SRDs) are made of plywood, into which are embedded semi-hardened steel blades; achievable accuracy is limited to approximately 100µm. Routing, on the other hand, is a dynamic, vector-based cutting method characterised by a computer programme moving the flex circuit relative to the cutting tool. Because a router is software controlled on the basis of CAD data, waiting for tooling is not necessary, flexibility is high, and the achievable accuracy is relatively low, approximately
100µm. All conventional technologies are accompanied with significant burr formation.

Laser cutting, being a vector-based technology, offers the same advantages as any other vector-based technology. Furthermore, as a non-contact tool, the laser completely eliminates mechanical stress on the material. Burr formation and micro-cracking in solder resist are also avoided. Due to the small beam diameter (approximately 20µm), only a small volume of material is removed. The nature of the laser ablation process, i.e. evaporation of material, significantly reduces deposits on the circuits. The ability to cut complex shapes without stress and with an extremely small tool diameter allows for more circuits on a single panel, increasing the net usable area. The achievable accuracy of laser cutting rigid-flex boards is significantly better than that of any other conventional technology.

Laser cutting also offers economic advantages. Tooling costs are inexist-ent. Hard and soft tools, on the other hand, are expensive with prices ranging from $50 to $100 for soft tools and from $700 to $900 for hard tools. Due to the complex nature of manufacturing hard tools, lead times are generally from two to four weeks. Soft tools can be made in a few days. Laser-based production can start on the same day based directly on the customer’s data, with no delays for tooling (cutting die or routing adapter). The manufacturer can instantly react to layout changes.

With market requirements regarding precision, burr formation and lead times in prototyping and pre-series production getting tighter, conven-tional technologies are no longer the best choice.

**Laser cutting: process description**

The processing speed and the resulting quality depend on both the characteristics of the material being processed and the nature of the laser emission (wavelength, fluence, peak power, pulse width, and pulse rate). It is important to know the absorption characteristics of the material to be cut. Most insulators, and thus poly-imides, absorb radiation in the UV and far IR region (Figure 6). Q-Switch frequency-tripled diode-pumped Nd: YAG lasers (UV-DPSS) emitting a wavelength of 355nm are the correct choice in the UV region, producing short optical laser pulses in the range of a few tens of nanoseconds in length, with a peak power in the range of a few kilowatts.

In the far IR region, the laser radiation of CO$_2$ lasers with wavelengths of, for example, 10.6 µm is strongly absorbed. However, IR lasers remove material by intense local heating leaving carbonisation and residue that must be cleaned during post-processing. Furthermore, far-IR radiation is completely reflected by Copper. As a result CO$_2$ lasers are not suitable for cutting flex or flex-rigid circuits.

Material ablation in the UV region is based on a different process. Incident photons are absorbed in a thin layer of the material up to the optical penetration depth. This is the depth at which the intensity of the absorbed radiation

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**Figure 9 - Effective cutting speed of polyimide sheets as a function of material thickness**

**Figure 10 - Coverlay cutting: 12.5µm PI + 25µm adhesive (right and left); 25µm PI + 25µm adhesive (centre)**

**Figure 11 - Flex rigid cutting: transition area between flex and rigid part (left and right); rigid part of PCB (centre)**
has decreased by a factor of 1/e. The energy released is transformed into heat and transferred to the molecule chains. When the evaporation temperature of the material is exceeded, the material explosively evaporates and leaves the cutting kerf. The heat diffuses from the surface layer into the material. The thermal diffusion depth is a function of the material's diffusion coefficient as well as the laser-beam pulse length.

In any case, an improved cutting quality can be achieved by reducing the thermal influence on the material, i.e. by keeping the heat-affected zone and charring/carbonisation to a minimum. The optical and thermal penetration depth parameters provide a good estimate of how much thermal influence is involved in the cutting process: the smaller the parameters and the smaller the thermal penetration depth compared to the optical penetration depth, the more the energy is confined to a small volume, increasing the thermal gradient and thus the cutting quality.

Polyimide is used for flex circuits due to its high thermal and chemical stability. It does not have a melting point when cut with a laser but is directly evaporated. Based on its relatively low evaporation temperature of 750°C, a relatively low laser power is needed to achieve high cutting speeds. A small optical penetration depth (277nm for 355nm wavelength radiation) reduces the volume of material in which the energy is absorbed. The wavelength’s thermal penetration depth is also small (178nm) due to the short laser pulses used. The result is a well-defined material removal area and excellent cutting quality with a minimum of carbonisation.

**Laser cutting tools**

Beam guiding system used for cutting are based on a scanner: two galvanometer-mounted mirrors are used in a vector-scanning configuration to direct the focused laser beam across the work surface in a cut pattern created by CAD/CAM software. As such, being nearly inertia-free, extremely high acceleration and high moving speeds are possible.

The MicroLine 350D laser system from LPKF is especially designed to cut standard format coverlay films, flex and flex-rigid circuits. It comprises a scanner providing precise, high speed beam movement as well as a fast and dynamic x-y table (Table size 460mm x 310mm) that moves the sheets and panels into the working area of the scanner. Accurate x-y-theta alignment of the laser focal spot is achieved through a CCD camera-based vision registration system. Vision registration and high position accuracy of the x-y-table coupled with a focused spot size of approximately 16µm enable this system to achieve levels of accuracy as high as +/-20µm. Automatic calibration by means of a special sensor removes the effects of thermally induced drift of the scanner and eliminates laser power variations. LPKF uses advanced dust and particle extraction and filtering to prevent any contamination of the workpiece or the environment. The CircuitMaster software supplied with MicroLine Series laser systems provides flexible and intuitive system control. The software controls all process parameters so new materials and processing techniques can be accommodated. The system is also available in a sealed housing that can be integrated into an existing production line.

**Cutting results and examples**

To evaluate the performance of the laser system, a good benchmark is to cut straight lines into polyimide sheets of different material thicknesses. During testing at LPKF, the cutting quality was taken into account, with the objective of maximising speed while minimising carbonisation at the same time. As such the numbers in Figure 9 do not represent the maximum achievable cutting speed, but realistic figures with regard to what is accepted by customers in terms of cutting quality. The cutting speed in flex and flex-rigid circuits will be lower since such circuits comprise numerous polyimide sheets bonded with adhesives and even stiffeners (e.g. FR4) and Copper layers have to be cut around connectors.

As can be seen from Figure 9 the maximum effective cutting speed possible for high-quality cuts in 25µm material is approximately 350mm/s. Even for thick materials the achievable cutting speed is high with 42mm/s. Aside from optimising parameters like pulse repetition rate, average power, pulse overlap and so on, the cutting strategy applied (single-pass or multi-pass) is a vital parameter for achieving a good quality cut. The real challenge is to find an optimum parameter set. The MicroLine 350D’s control software supports the user by supplying predefined parameter sets, which are based on the substantiated process knowledge of LPKF’s application engineers. Figures 10-12 show various application examples with covering overlay as well as flex and flex-rigid circuits. All results show an excellent cutting precision, no burr and little to no carbonisation.

![Figure 12 - Flex cutting: FPC connector (left); FPC with embedded Copper track (centre); single layer FPC (right)](image-url)