ABSTRACT
Polymer Thick Film (PTF) technology provides the lowest cost, cleanest and most efficient manufacturing method for producing flexible circuits. PTF is a 100% additive process capable of applying conductors, resistors and dielectrics directly to a substrate. SMD components can be assembled using low temperature process conductive adhesives making the PTF system compatible with the most temperature-limited flexible films and components. Millions of SMT assemblies are built with PTF flexible circuits every year.

Non-contact radio frequency (RF) Smart Cards and related information transaction devices, such as RFID tags, appear to be a good fit for PTF-Flex. Flip Chip also seems well suited for these “contactless” RF transceiver products since it offers the ultimate in miniaturization, minimum profile, and low cost potential.

Flip Chip and PTF adhesive technologies are highly compatible and synergistic. All PTF SMT adhesives assembly methods are viable for Flip Chip. These include isotropic pastes, anisotropic films and pastes and even non-conductive systems. However, the merging of Flip Chip with PTF-Flex presents major challenges in design, materials and processing. This paper will compare assembly methods and discuss obstacles and solutions for state-of-the-art Flip Chip on Flex within the RFID product environment.

Key Words: assembly, conductive adhesives, flexible circuits, flip chip, Polymer Thick Film, PTF

INTRODUCTION
Most of you may never have heard of Polymer Thick Film although it has been used for decades as the world’s most cost-effective and successful fully additive, waste-free circuitry and assembly technology. Your computer’s keyboard, hand calculator and telephone probably use PTF circuitry. Conductive adhesives, the joining materials of the PTF family, are used in most flat panel displays, telephone circuits, medical sensors, RF wireless products and, more recently, in high density memory modules using Flip Chips – bare ICs connected directly to the circuit. But what is PTF anyway?

The PTF concept is very different from the traditional subtractive copper etching method used by the majority of circuit board manufacturers. PTF is nearly the opposite of etching - conductors are applied exactly, and only, where needed. PTF is a true printed circuit concept. On the contrary, the etched circuit process is a conductor subtraction method. Circuit etching starts with a full layer of copper while PTF begins with a “clean slate” of dielectric substrate. Chemicals selectively etch or dissolve away the copper foil to leave behind the intended conductor pattern. The dissolved copper becomes hazardous waste that must be dealt with at a significant cost. Conversely, PTF does not generate any waste streams nor does it even require water for processing since materials are applied directly by printing. The favorable environmental attributes continue into the assembly stage that uses lead-free, “no clean” conductive adhesives.

The PTF circuit process was initially used to make membrane switches and other products that did not require component assembly. One reason that components were not assembled was the difficulty in making reliable junctions to PTF conductors. The polymer-based composite conductors, made with metal-filled thermosetting epoxies or thermoplastic-in-solvent binders, are very difficult to solder. Feed-through assembly on copper circuits was also impractical since adhesives do not readily flow in to holes and form fillets like molten solder. In other words, there was no adhesive equivalent to the then-common wave soldering process.

Fortunately, the Surface Mount Technology (SMT) revolution of the early 1980’s enabled PTF assembly and lead to significant developments in conductive adhesives. SMT was the perfect form factor for conductive adhesives. The SMDs provide the ideal connection, the butt joint that is strong and reliable. The growth of SMT was the incentive needed to propel the PTF circuit industry into assembly. By 1990, strong and junction-stable conductive adhesives had been developed that could be used to build reliable assemblies from PTF-Flex circuits as well as copper rigid boards. The solderless assemblies proved so reliable and cost-effective, that around 1 billion adhesive joints have been assembled in consumer, medical and business products during the 1990’s.
But adhesives can now be used to assemble bare die without any electronic component package. Flip Chip (FC) is a bare die packaging technology, a form of “packageless” Surface Mount, that has become extremely popular in just the last two years. Flip Chip was originally used only for very high-end applications, like main frame computers. More recently, Flip Chip technology has moved to 2nd generation technology – low cost processing on common organic substrates. Today, pagers, cellular phones, camcorders, PCs, disk drives, watches, hearing aids and dozens of other products embrace Flip Chip. Cellular phones that are smaller and lighter than many pagers, are made possible by this Direct Chip Attach (DCA) method. “Packageless” FC offers the smallest footprint, optimum electrical performance, the lowest profile and the most attractive high volume cost potential of any component assembly method. Conductive adhesives are well suited for FC assembly that may be an ideal technology for several areas of electronics. We will go into more detail about Flip Chip and bare die later. Before moving on to specific product discussions, we will cover the fundamentals of PTF inks and conductive adhesives.

Fundamentals of Polymer Thick Film
PTF technology consists of a simple set of basic “building block” materials: substrate, conductive inks, dielectrics, conductive adhesives and non-conductive adhesives/encapsulants. Underfills, required for Flip Chips, are commonly classified as packaging materials, but they are polymer-based systems that are a close kin of PTF and will be described later. Figure 1 shows a PTF keypad with LEDS. Figure 2 shows a more complex touch pad with encoder.

Figure 1 – PTF Keypad
Figure 2 – Touch Pad

PTF circuits and assemblies are quite reliable as validated by this blood oxygen level sensor used in clinics, emergency rooms and operating theaters to assess vital signs. Components are assembled with isotropic conductive adhesives as shown in Figure 3. The product is wrapped around the finger with an infrared LED and a photodetector positioned at opposite sides so that light can be transmitted through and detected. The level of attenuation is used to compute blood oxygenation level.

Figure 3 – Oxygen Sensor

Substrate
The most common substrate used for PTF is 3 (.003") to 5 mils (.005") thick polyester films, but almost any non-conductive flexible film or rigid non-conductor can be used. Films are often heat-stabilized by the film producer or the flexible circuit manufacturer so that very little shrinkage will occur during ink and adhesive processing temperatures of up to 150°C. While many films are viable, PET polyesters, such as Dupont's Mylar®, offer a good balance of properties at a very attractive price.

Inks
Inks are typically metal-filled composites in a thermoplastic or thermoset binder. The two most common conductive fillers are carbon and silver but sometimes blends of both. There is a well-established infrastructure with a large number of producers of silver-based inks, although some of the high volume PTF-Flex producers manufacture their own. Solvent-
borne thermoplastic inks are hardened by evaporation in one minute or less. Higher performance thermosets can also be hardened in about 1 minute but by thermally-induced polymerization. While PTF ink conductivity is not as high as etched copper, values are adequate for most applications, including contactless smart cards. High frequency signal characteristics for PTF are similar to copper well into the gigahertz range - a requirement for newer RF chips.

**Dielectrics**
Thermosets and UV (ultraviolet) cured dielectric inks are extensively utilized. UV materials have the advantage of processing in just seconds under low heat conditions. UV inks can be selectively applied by screen printing and quickly hardened by in-line exposure to UV radiation. These dielectrics are used to protect conductors and to build multilayer circuits. It is interesting that the traditional printed circuit industry is just now investigating “build-up” technology while PTF has used it for decades.

**Joining Materials – Conductive Adhesives**
The PTF-Flex industry, as well as the rigid circuit counterpart, uses isotropic and anisotropic conductive adhesives. These materials have completely different properties, processing steps and performance characteristics:

- **Isotropic Conductive Adhesives (ICA)** are highly loaded, around 80% or more by weight, with silver powder and flake. Conductive particles make intimate contact with one another so that conductivity is approximately equal in the X, Y and Z directions, hence the name isotropic. The most common systems use liquid epoxy resins and hardeners to create solventless pastes that can be printed, stenciled, needle dispensed or pin transferred. Hardening takes place at 130° - 150°C and requires only a few minutes. It is the low temperature processing and wide compatibility that makes the isotropics the assembly choice for PTF-Flex. Newer cure systems can be processed as low as 110°C, making them suitable for very sensitive components such as batteries. The isotropic adhesives must be applied selectively to the circuit for SMT assembly. Figure 4 shows the model for isotropic conductive adhesives.

- **Junction Stable ICA** – Junction stability under heat and humidity conditions has been a concern for adhesives. Although the adhesive is stable, oxide formation on some component surfaces can cause unacceptable increases in junction resistance as an oxide layer “grows” between the adhesive interface and the component finish. Solder finishes, found on most components and many Flip Chips, has produced unstable joints. This problem has been solved with special junction-stable adhesives. One successful approach has been to use penetrating particles to break through the oxide layer as shown in Figure 5. This type of adhesive can pass 1000 hours under 85% rh/85°C.

- **Anisotropic Conductive Adhesives (ACA)** contain a much lower loading of conductive particles. They are formulated to behave as insulators in the X-Y plane since particles do not touch to form conductive pathways. When sandwiched between pairs of opposing conductors, the isolated conductive particles complete the electrical path in the Z-plane. Typical conductors are solid metal spheres or metal-plated elastomeric microspheres that can provide “spring action” to compensate for thermal expansion of the binder during thermocycling. The anisotropics are available in...
film and paste form. Generally, the assembly step requires simultaneous application of heat and pressure using specialized equipment. It is important to note that these adhesives have built-in selectivity. Only opposing conductor pairs are connected in the Z-plane and no shorting results in the X-Y plane. This means that the anisotropic adhesives can be applied over the entire bonding area, not just the circuit bonding pads. It is the auto-selectivity that makes the anisotropics so appealing for fine pitch applications. ACAs are used to assemble flat panel displays and Flip Chips. The conductive path is a pressure contact construction as shown in Figure 6.

Figure 6– ACA Model

- Non-Conductive: a third class of joining adhesive is the non-conductive. These materials can be used to hold Flip Chips to circuit pads by tensional forces – acting like a spring, especially for display panels. They can also be applied over cured conductive adhesive joints for protection and also to enhance the joint, especially on flexible circuits. Wearable medical sensors utilize non-conductive adhesives over conductive joints to increase durability like the device shown in Figure 3.

PTF Processes
- Hole Fabrication: punching, drilling or laser machining rapidly and accurately can do this process. Laser drilling is becoming increasingly popular.

- Printing: screen printing has long been the most popular process for applying inks although other common printing methods have been used. Screen printing is unique in its ability to provide fine definition in a thick deposit. High performance cylinder screen print presses are used to obtain higher print quality at speeds in excess of 1,000 impressions per hour. While 8 to 10 mil wide traces are typical for high-speed production, 3 to 4 mil lines may be feasible, especially if the fine line zone is kept small.

- Curing: in-line thermal convection ovens, conduction, IR and combinations have all been used. Hot air convection ovens are popular for solvent type inks. Processing time requires only 1 - 2 minutes. In-line UV sources are also used and curing takes only seconds. Equipment has long been available for both sheet and continuous roll processing of flex.

- Blanking: this process is used to singulate, or panelize, thin circuits, especially flexible, that are typically produced in multi-up format for efficiency and high material utilization. Mechanical die cut presses are commonly used although laser cutting is gaining in popularity. Blanking equipment for continuous roll processing is also available.

- PTF Assembly: this is primarily an SMT process akin to standard solder reflow. The difference is that conductive adhesive is substituted for solder paste and no flux or cleaning is required. Assembly equipment is similar to that used for SMT solder processing. The main processing difference is that the oven is set at 110°C to 150°C instead of the 215°C to 220°C seen in soldering. This is a lead-free process! CFCs were never required or ever used.

- Testing: electrical testing can be done before blanking for higher efficiency. Alternatively, the sheet, or roll, can be partially blanked leaving small tabs to keep the circuits in place for testing. The tested circuits are then easily singulated by tearing or cutting the tabs.

MICRO-PACKAGE ASSEMBLY WITH CONDUCTIVE ADHESIVES
Now let's look closer at some of the process issues and solutions for assembling micro-packages. We will start by looking at flex as the original and preferred chip carrier. Lets next consider bare die assembly that is compatible with conductive adhesives.

Flex-Based Packaging
Flexible circuitry is becoming a popular Chip Carrier substrate in the Packaging Revolution. Flex, in the form of TAB (Tape Automated Bonding), more recently called TCP (Tape Carrier Package), has been a reliable packaging system since the 1960’s. Today, a number of BGAs and micro-BGAs are also based on flex. All of the carriers have used copper circuitry and most have used polyimide. Why not use polyester? This would reduce cost since there is more than a 1:20 materials film price differential. Polyester has excellent electrical and mechanical characteristics. Its major limitation has been lower thermal resistance. Polyester, such as the common PET (Polyethylene terephthalate), is a major component of the flexible circuit industry. Millions of automotive cluster circuits
are made every year from copper-polyester. However, its poor compatibility with soldering has limited the use of polyester for SMT assembly and general packaging. But why can’t polyester be used to package bare die?

It may surprise you to find out that the very first Chip Carriers were Mylar flex circuits made in the mid-1960’s. An early patent describes copper-polyester miniature circuits as chip carriers, called Flip Chip Strip [see Figure 7]. However, the high temperature processing of Inner Lead Bonding (ILB) brought a quick shift to polyimide film rather than a low temperature bonding solution. While most adopted higher cost polyimide for Chip Carriers, the consumer electronics industry learned how to process polyester. In the late 1980’s, Casio began to manufacture polyester-based TAB. The low cost Chip Carrier Packages were applied to calculator circuits also made from polyester. In fact, the calculators were made with PTF technology for minimum cost. But, how were the polyester TCPs assembled to PTF-polyester circuits? Adhesive was the obvious answer. Casio applied conductive adhesive to the circuit and bonded the TCPs. This process is still used today quite successfully with 100’s of millions of products as testimony.

**Figure 7 - Polyester Flip Chip Strip**

**TAB (Tape Automated Bonding)**

These film-based packages are basically a bare chip directly connected to a flexible circuit. Intel has used the method to connect Pentium chips to circuit boards in some of the laptop computers, but renamed the system TCP for Tape Carrier Package. The package is assembled to the circuit board by bonding the outer leads using either solder or conductive adhesives. The ideal type of adhesive for TAB, or TCP, is the anisotropic variety. The film is interposed between the tape carrier and the printed circuit and heat and pressure is applied to create the connections and bond. Conductive adhesive assembly is used for tape package mating to flat panel displays and to flexible circuitry including PTF type. While adhesively bonded TAB can be used for smart cards and RFIDs, the added cost of the tape suggests looking for other technologies.

**Flip Chip Technology**

Flip Chip, or Direct Chip Attach, dates back to the early 1960’s when the semiconductor industry was discovering how to package bare die including simple transistors. Two methods emerged as winners, wire bonding and DCA. IBM pursued the direct approach and the C4 (Controlled Collapse Chip Connection) process became their preferred method for very high density MCMs (MultiChip Modules). The DCA method reduced the number of interconnects by half compared to wire bonding or TAB thus improving reliability.

During the second half of the 1990’s, a sizable number of technologists have been engaged in developing 2nd generation Flip Chip. The seemingly simple transition to organic substrate has required several new developments including underfill. Underfill is the magic polymer that solves the thermal mismatch dilemma that occurs when low expansion chips are joined to relatively high expansion organic circuitry. The underfill essentially locks the die to substrate thereby restraining X-Y movement. Stress is moved to the circuit layer protecting the solder joints from thermomechanical strain. Even thin flexible circuits must use underfill if high thermal cycle performance is to be achieved.

2nd generation Flip Chip technology continues to offer new, lower cost chip bumping methods. Bumps are necessary to connect ICs to circuits. The standard aluminum pad found on most ICs is neither solderable nor compatible with conductive adhesives. While solder bumps have been the standard for Flip Chip on ceramic, many new materials are emerging for use with organic substrate. Electroless nickel plating, mechanical gold studding and conductive polymer bumping are some of the newer developments that are compatible with PTF assembly. Electroless nickel bumps, with immersion gold finish, are now considered to have the lowest cost potential and are well suited for use with all types of conductive adhesives. The Flip Chip supply infrastructure must still reduce cost if some of the very high volume markets are to reach fruition.

**Merging PTF-Flex with Flip Chip**

What about Direct Chip Attach on PTF-polyester circuits? Can we eliminate the TCP to reduce cost, weight and size? The answer is yes! Combining low cost PTF-polyester with Flip Chip makes a lot of sense. Nothing can be simpler - nothing can be more cost-effective. This is minimal packaging at its best, but there are challenges, especially for low cost very high volume manufacturing. First, can PTF, that relies on screen printing instead of photolithography, meet the fine line requirements? How will the flip chip be
assembled; what kind of bumps and joining material? Can the industry provide the right chip presentation format for high-speed assembly at an acceptable cost? Do we need underfill and can that process meet high-speed low cost targets? Figure 8 shows Flip Chip on PTF-Flex.

![Figure 8 - FC on PTF-Flex](image)

**Flip Chip Assembly to PTF Polyester**

The joining method will often dictate the type of bumps required on the Flip Chip. The PTF joining process is of course, solderless because of the high temperatures and compatibility problems posed by soldering. All three types of PTF joining materials described earlier can be considered. Each type of adhesive has advantages and limitations. The isotropic produces strong bonds with good electrical performance, but the material must be applied selectively by a highly efficient method. The anisotropic adhesives can be applied to the entire bond area because of its intrinsic selectivity. The anisotropic adhesive can be used in the more common film form or as a printable paste. Most are processed in dry form and the Flip Chip is assembled by applying heat and pressure simultaneously.

Now let's examine the RFID products to see how we can apply PTF-Flex circuits and processes successfully.

**RFID High Volume Manufacturing**

We have suggested that PTF is an ideal, high volume low cost approach to flexible circuitry that should be considered for RF tags and related products. Let's now look at the specific requirements for these rapidly emerging products and examine the technical and economic issues. But first, what is an RFID?

We can view the RF, or radio frequency devices as a micro-radio transceiver. These are self-contained products that can be queried for information using electromagnetic waves. The entire process is contactless, with radio signals used for the entire two-way transaction. The contactless characteristic of the RF tags is extremely powerful and has important ramifications. Optical methods, like bar coding, require a direct path and have a limited read range. RF can transmit through boxes, windows and even walls making this technology considerably more powerful. This means that a warehouse inventory can be taken without moving a single container. Someday in the future, moving past a reader will tally a bag of groceries.

The basic elements are an antenna and an IC although more complex products can have a battery, multiple chips and other components. PTF-polyester is an ideal technology fit for RFID tags. Antennas printed with PTF ink can generally meet the requirements being established. The printed antenna offers the lowest cost and fits the high volume capability of the PTF-Flex industry. Figure 9 shows a printed antenna on polyester.

![Figure 9 - Printed Antenna](image)

**Isotropic Conductive Adhesive Assembly**

These adhesives have a long history and good performance record for SMT assembly to PTF-Flex. SMDs are assembled to PTF-polyester circuits at the rate of millions per year using isotropic adhesives. Viewing the Flip Chip as an SMD, the use of ICAs is an obvious fit. However, finer feature, more precise adhesive dispensing is required. Stenciling has proven adequate for printing adhesive features down to 75 microns. Adhesive pastes can also be applied by the
Polymer Dip Chip process, which entails dipping the bumped chip into a thin reservoir of adhesive, withdrawing and placing the FC onto the circuit. Figure 10 shows this process which has been demonstrated by Poly-Flex Circuits, Inc. and others. ICA remains high on our candidate list.

**Rotating Disk Applicator**

We’re not done yet. Although the FC is now electrically connected, the structure is not robust. The large thermal mismatch created by bonding low expansion silicon IC to a polymer film will cause joint failure during temperature cycling. The same situation occurs with solder-joined Flip Chips on FR4. The simple solution is to interpose a bonding material between chip and substrate. These materials are called underfills and are generally applied after the Flip Chip is connected to the substrate. The polymer-based underfill simply locks the chip to the circuit to constrain differential movement and protect the interconnect joints. The underfill used here with adhesives also adds mechanical strength and protects both the IC and joints from the environment. Our challenge is to determine a very fast, high volume method of underfilling.

Alpha Metals and others have developed snap flow underfills that work well with PTF-Flex circuits and cure at less than 150°C. The materials need only be dispensed at one edge of the chip before moving to the oven. It may also be possible to dispense underfill, more appropriately called encapsulant, over the chip. UV cured materials can now be used. It may also be possible to cure underfill with UV right through the polyester film, which is partially UV-transmissive.

**Anisotropic Conductive Adhesives**

ACAs have been evaluated for Flip Chip assembly for more than a decade. The adhesives have steadily improved as their market, primarily flat panel displays, grows. A number of commercial products are available primarily in film form. The film assembly process typically involves tack bonding the ACA film to the circuit or chip as the first step. Paste adhesive can also be applied to the circuit or chip and dried or B-staged. With adhesive film or coating in place, the bonding step involves pressing the Flip Chip to the circuit while heating. The adhesive is heat-activated, allowing polymer to flow, and bonds to form. The conductive particles make a pressure contact with the FC bumps and circuit as shown in Figure 11. Cooling under pressure is often necessary to get a reliable junction.

One alternate is to deposit "wet" adhesive to the circuit or chip, place the FC and cure. This process would have obvious merits in terms of increasing throughput if the pressure application stage can be eliminated. However, good reliability without a **pressure-during-curing** step remains an elusive goal of the industry. At this juncture ACA assembly requires a relatively slow heat-bonding step. On the positive side, ACA eliminates the underfill step since the entire space between chip and circuit is occupied by the polymer binder.

**RFID Products & Markets**

Smart Cards are certainly a major target for Flip Chip/PTF-Flex technology. The expected paradigm shift from contact cards to contactless and dual mode is expected to boost the new approach. The early contact type Smart Cards used thin but rigid PCBs and wire bonding. The contactless r-type products are an excellent fit for flex and Flip Chip since the chip need only be connected to an antenna that is easily produced by printing with PTF inks.

There are a host of other RFID products that are expected to fuel the PTF-Flex bare die market. Some of the more innovative will be used for inventory, warehousing and other automated cataloging. RFID tags can be applied to boxes, machinery, grocery items, luggage and so forth to permit them to be identified and counted easily and automatically. ICs now exist that can be energized and queried from distances of several meters. The antenna can serve as both the inductive energy and signal link eliminating the need for batteries. Tags can be bonded to items allowing an RF reader to send energy and a query signal. The tag will then respond with a uniquely coded RF signal that is recorded by the reader.

The transmit-receive concept is being applied to a long list of applications that include automated fuel purchase, warehouse control, medical IDs, fast pass toll cards, etc. Even more consumer-oriented
applications are forecast in the near future such as automatic food and consumer product check out. The RFID would allow bulk scanning of items instead of the one-at-a-time bar code method in use today. RFID technology goes well beyond bar code, however. The tags can be queried, perform logic functions and written to just like a smart card. Figure 12 shows a test circuit for FC made with fine line PTF.

Figure 12 – PTF-Flip Chip Test Circuit

Cost Issues
While RFID technology marches to the beat of the smaller-faster-smarter theme that drives so much of today's electronic products, the emphasis must be on “cheaper” and very high volume manufacturing for many of the product areas. The market includes categories of products that are used for limited duration and sometimes only once. Disposable RFIDs must compete with other low cost solutions that include optical and magnetic coding technologies. The “use-once”, ultra-high volume product areas require the very lowest cost possible with optimum manufacturing throughput. Target costs for disposable RFID products can be as low as $0.10 - 0.15 per finished tag in the area of mass retail applications.

A basic cost analysis reveals that Flip Chip bumping, die packaging and FC assembly must be the focus. PTF circuit production costs are insignificant compared to the die-related costs. Table 1 provides a cost breakdown for die processing. Bumping costs are expected to drop further as such methods as electroless nickel, solder jetting and conductive polymer bumping are scaled up and optimized. But the infrastructure still needs to mature.

<table>
<thead>
<tr>
<th>PROCESS</th>
<th>@ 10 Million units/yr.</th>
<th>@ 100 Million units/yr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bumping</td>
<td>$.005 - .040/die</td>
<td>$.003 - .020/die</td>
</tr>
<tr>
<td>Sawing</td>
<td>$.005 - .012/die</td>
<td>$.005 - .012/die</td>
</tr>
<tr>
<td>Tape &amp; Reel</td>
<td>$.05 - 0.10/die</td>
<td>$.04 - .08/die</td>
</tr>
</tbody>
</table>

Assumptions: 7 k die/wafer; 1 mm x 1 mm / 5” wafer

FC assembly speed also remains a strong cost factor that needs attention. Typical pick and place speeds with the present generation of equipment range from 1,500 to 2,500 FCs per hour. These rates may be acceptable for multi-die (MCM) and more sophisticated RF products, but nearly an order of magnitude rate increase will be needed for the disposable tag markets. The leading-edge placement equipment may improve rates to about 5,000 FCs/hour, but the value needs to approach 10,000/hour in the future. Tape & reel adds a major cost penalty that may preclude its use for many applications.

Technical Challenges
The technology to deliver low cost RFID products is rapidly developing, but several obstacles remain. Most issues deal with the Flip Chip and its placement. The bump pads must be laid out to optimize high volume assembly with very high-speed equipment. As seen in Table 1, the present bumping costs are still too high for the ultra-high volume product mass consumer markets. New bumping methods continue to move from the lab to the market place, however.

Solder jetting is one of the newest bumping processes that has been commercialized. Although the concept of “shooting” molten solder at a surface has been studied for many years, hardware development has been a significant problem. The task of creating and precisely aiming a tiny sphere of metal at over 200°C is quite significant. MPM Corporation, working with others, has apparently solved the hardware and process problems. While the group has pursued both continuous jetting and Drop-on-Demand (DOD), the latter provides the microdots and extreme precision required for Flip Chip bumping. Time will tell if fluid jetting will be the low cost bumping process. Figure 12 shows the fluid jetting principles.

Our work has shown that oxide-penetrating conductive adhesive can form a very stable interface with a solder surface. This suggests that fluid jetted solder bumps, in addition to electroless nickel and gold stud bumps, can be considered for conductive adhesive assembly of Flip Chips. The lowest cost technology will likely come from electroless nickel, solder printing or solder jetting. Both the spherical solder bumps and the flatter electroless nickel type are compatible with the Polymer Dip Chip process. As would be expected, low height bumps require more precision and care.
High-speed Flip Chip assembly requires an efficient component delivery concept. Tape and reel offers very high-speed assembly and has been the most popular presentation format for SMT. Tape & Reel packaging adds the single most significant cost in die preparation. Although tape & reel remains today’s method of choice for SMD assembly, chip-from-wafer handling is the alternate that needs to be developed and is the most obvious approach to cost-reduction. While much of the packaging industry has developed wafer-level die handling, a system and infrastructure needs to be developed for Flip Chip. The technology has been developed and proven for Flip Chip within large vertically integrated companies, however.

While many of the RFID circuit manufacturing and chip assembly methods have been worked out, device protection requires more work. Will capillary-flow underfill processing be the unacceptable bottleneck for high speed FC processing? Can “overfill” (encapsulation), considered a much faster process than underfill, give the required performance?

Conclusions
Flexible circuitry has long been the enabler of many products and entire industries. The disk drive, low cost computer keyboard and a host of other significant products may not have happened without flex. Flex has also been the preferred Chip Carrier - the most successful bare die pre-patterned interface. Once again, flex is positioned as the enabler for a large emerging market - RFIDs. Even though rigid printed circuit boards can be, and are being used for RFID products, only flex can provide the efficiency and versatility to expand the market and improve the products. Polymer Thick Film applied to polyester flex, merged with Flip Chips, provides the right fit and powerful synergy for RFID and similar radio frequency (RF) products.

Bibliography
Gilleo, K., Polymer Thick Film, ITP, 1996.