COATED COPPER FOILS FOR HIGH DENSITY INTERCONNECTS

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ABSTRACT

As new printed circuit board fabrication processes evolve to build high density substrates, suppliers are developing materials compatible with these processes. This paper will discuss laser and plasma ablatable dielectric materials, available as coatings on copper. These materials are compatible with conventional PWB fabrication techniques, (e.g., layup, lamination, DES) and are amenable to mass blind via formation methodologies. With component densities increasing year after year, the need for dense, cost-effective PWB solutions is immediate. The additional demand for solutions in the same or smaller footprint, at equivalent or lower layer count increases the complexity of the problem. Both of these needs are met when large numbers of small vias are rapidly formed, by laser or plasma ablation techniques, in these dielectrics, connecting outerlayer circuitry to very dense innerlayers, laden with buried vias and fine lines and spaces. These materials play a key role in the industry's ability to produce high density interconnect solutions.

INTRODUCTION

The automotive, computer and telecom industries have embraced microvia technology as a key driver for growth in high density interconnect packaging, PCMCIA cards and reduced layer count designs. Also, rigid-flex applications and chip scale packaging alternatives are utilizing coated copper technology. Several large circuit board fabricators currently produce large volumes of boards built with microvia and buried via material enablers. Table 1 highlights the PCB design advantages of these materials and the following text explains advantages of the two largest current applications, redistribution layers and PC cards.

Table 1

PCB DESIGN ADVANTAGES WITH RESIN COATED COPPER

Redistribution
- High density interconnect packaging
- Support of high I/O devices, e.g. BGA's
- Microvia and buried via enabler

Layer Count Reduction
- 12 layers reduced to 8, eliminating 2 signal layers and 2 planes
- Drive to standardization on mass lamination type 4 layers

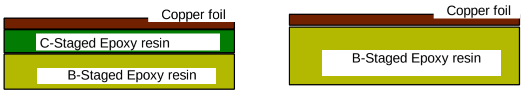
PCMCIA Cards
- Enabler of 8 layer design with 18 mil overall density
- Digital circuitry density for wireless devices
- Low Dk for thin layers

Rigid/Flex Boards
- Cover ply plus circuit layer in rigid section of rigid/flex
- Lower cost than Kapton® cover plies
- Higher flexibility than reinforced substrates

Chip Scale Packaging
- Thin layer for micro circuits
- No reinforcement for improved moisture performance
- Low Dk for high electrical performance
- No reinforcement facilitates lead formation

Figure 1

Product Constructions



Dual **Single Pass**

PRODUCT DESCRIPTION

Resin coated copper is a unique dielectric material for built-up multilayer circuitry (see Figure 1). Many resin coated foils are available in several configurations with various copper and dielectric thicknesses, offering balances between the need to fill underlying circuitry while still maintaining the desired dielectric thickness.

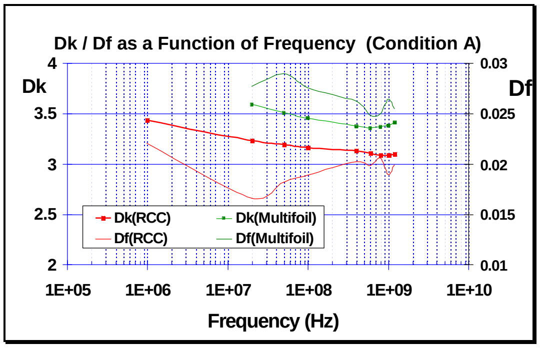
Single pass resin coated copper consists of a uniquely engineered epoxy resin system coated once onto copper in a semi-cured (B-stage) state. When laminated it has the correct rheology to fill and encapsulate underlying circuitry as well as leave resin behind to function as a dielectric.

Dual stage, or double pass resin coated copper, consists of copper foil which has two coatings applied to it. The first coating is fully cured, C-stage high temperature epoxy; the second coating is semi-cured, B-stage high temperature epoxy. The C-stage coating acts as the dielectric, electrically insulating the outer layer copper from the adjacent conductive copper layer. The B-stage coating acts as an adhesive to bond the resin coated copper to the innerlayer. During lamination, the B-stage fills the innerlayer circuitry and any buried vias in the innerlayer, while the C-stage acts as a “stop” to produce the desired dielectric thickness between layers 1 and 2 and n and (n-1).

RESIN COATED COPPER PROPERTIES

Dielectric constant, Dk (or permitivity), is one of the key properties of the PCMCIA card construction materials that has a significant impact on circuit performance. Resin coated copper is non-reinforced so that the Dk value is that of neat resin ≈ 3.4 (at 1MHz). By contrast, a comparable glass-reinforced construction is 4.3 to 4.5, with this value being heavily influenced by the higher Dk of woven glass fabric. The lower Dk of resin coated copper further enables the use of high speed circuitry. Figure 2 is a graph of both dielectric constant and dissipation factor (Df) as a function of frequency for AlliedSignal's Multifoil and RCC materials. While it is well-recognized that glass is a limiting factor for Dk in traditional laminates, pure resin has a higher Df than glass reinforced constructions.

Figure 2



General product properties of single pass (AlliedSignal’s MultiFoil) and double pass (AlliedSignal’s RCC) are shown in Table below.

Table 1

Physical Properties

PROPERTY	MULTIFOIL	RCC	UNITS
Glass Transition (Tg)	**135**	**160**	**°C**
Electric Strength	**1600**	**1800**	**volts/mil**
Peel Strength			
- Condition A	**7.8**	**6.2**	**lbs/in**
- After solder float	**7.8**	**6.0**	**lbs/in**
- At elevated temp.	**7.5**	**5.4**	**lbs/in**
Water absorption (cured resin) (D-24/23) 100% RH	**2.2**	**0.8**	**%**

APPLICATIONS

HDI: Microvias

Increased density not only reduces layer counts but enables faster processing speeds. The time it takes electrical signals to travel from device to device dramatically decreases with the increase in board density. While the capacitance of mechanically drilled through holes is approximately 1 picoFarad (pF), the capacitance of laser or plasma ablated blind vias is approximately 0.05pF, about one-twentieth that of through holes. Dense boards which demand such electrical performance will require many blind and buried vias. Economical construction of large numbers of blind vias will require new material solutions, such as those offered by resin coated copper.

The all resin construction of resin coated copper allows the capability to create ultra-small vias

(<6 mils) as well as decrease the line and space circuit features both of which enable increased circuit density. An advantage of some of the ultra-small via formation techniques is that they allow for mass hole formation. The mass, ultra-small via formation techniques being explored include laser and plasma ablation.

Laser ablation and/or plasma etching are via forming techniques that can be used with non-reinforced dielectrics to create small holes. Fiberglass is typically an impediment in forming vias using either a laser or plasma. Plasma can be capital intensive to start, but the cost savings are realized in the speed of mass via formation and also the cost reduction of consumables. Laser also holds advantages over conventional drilling in speed as well as cost reduction of consumables. When employing a plasma etch process to form microvias (i.e., the DYCOstrate® process), the copper must be patterned and holes opened to create a pathway for the plasma to eliminate the resin. Depending upon the type of laser that is used, the outerlayer copper may also be ablated with the dielectric resin layer.

Table 2

Plasma Ablation	• a process of etching organic materials using ionized gases • batch process capable of ablating multiple panels and both sides concurrently • currently used by PCB manufacturers for cleaning and preparing substrates for plating • potentially capable of mass formation of all blind vias simultaneously, independent of quantity, size, or panel configuration • typical via size is 3-6 mil
Laser Ablation	• uses directed laser beams to break down material into particulate and/or gaseous matter • different laser types exhibit different levels of applicability to via formation • current usage is in trimming and marking • potentially capable of high quality vias in any substrate

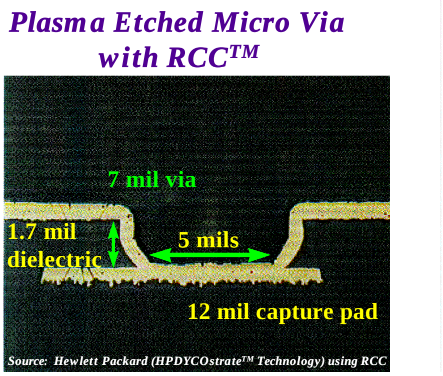
	material • smaller vias are best (sub 3 mil) but larger vias are possible

ABLATION TECHNIQUES

Plasma Ablation

The most common plasma ablation technology for the formation of microvias is the DYCOstrate® process, pioneered by Dyconex of Zurich, Switzerland. This process uses an isotropic plasma to etch vias in the unreinforced dielectric layer (e.g., resin coated copper, polyimide film, etc.). The ablation uses the copper surface of the dielectric as a conformal mask (see Figure 6); the ultimate hole size is limited by the photoprinting/etching capability. Commercial plasma units handle 6 boards with all vias on both sides of the board being etched simultaneously, with the etch time being around 30 minutes. The isotropic nature of the plasma leads to a teacup shaped via; this shape plates up easily. Figure 3 shows a DYCOstrate microvia. The DYCOstrate process is quite effective and economical for forming large numbers of microvias in the surface of a PWB.

Figure 3



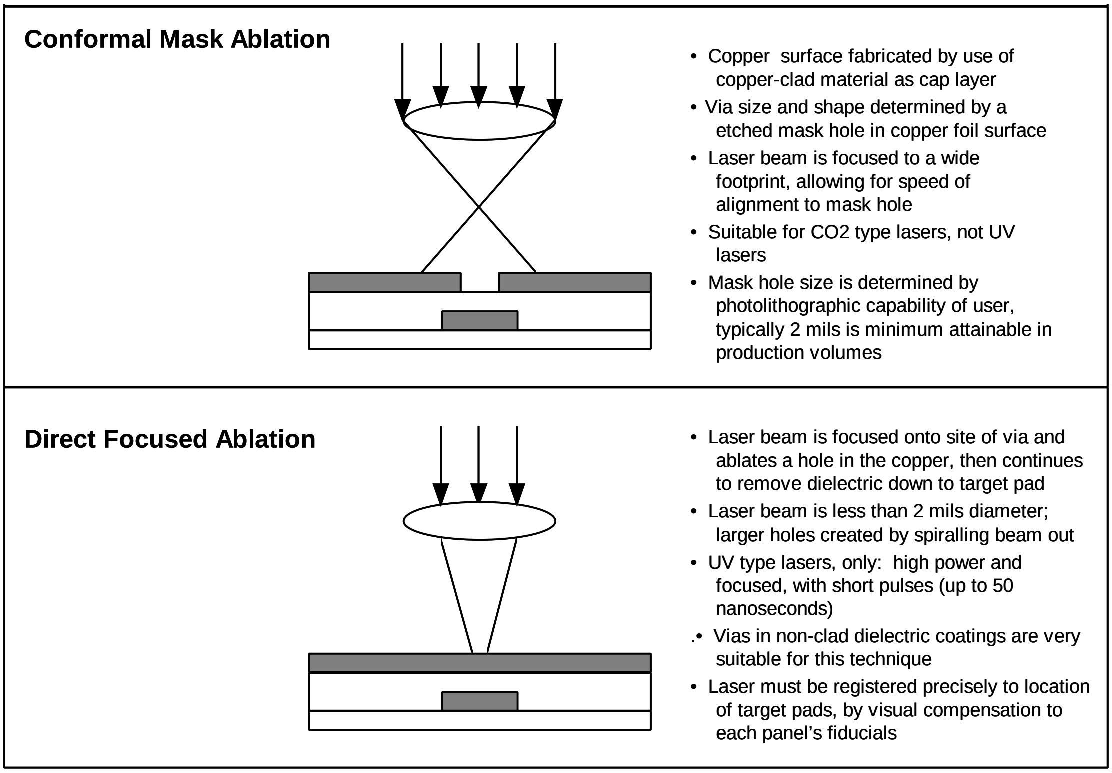
Source: Hewlett Packard (HPDYCOstrate™ Technology) using RCC

Laser Ablation

Laser ablation is another alternative for making microvias in the surface of a PWB. The picture is somewhat more complex than with plasma because of the different types of lasers available and the different processes used to make the holes. In addition, since the laser light is anisotropic, via shape is much more cylindrical. However, the physics of getting plating solution into narrow laser microvia limits the minimum via diameter size.

Two types of lasers are suitable for blind via ablation, the UV laser and the pulsed CO_2 laser. Two ablation techniques work well for copper clad microvia materials, conformal mask ablation and direct focused ablation.

Figure 4



Conformal Mask Ablation

- Copper surface fabricated by use of copper-clad material as cap layer
- Via size and shape determined by a etched mask hole in copper foil surface
- Laser beam is focused to a wide footprint, allowing for speed of alignment to mask hole
- Suitable for CO2 type lasers, not UV lasers
- Mask hole size is determined by photolithographic capability of user, typically 2 mils is minimum attainable in production volumes

Direct Focused Ablation

- Laser beam is focused onto site of via and ablates a hole in the copper, then continues to remove dielectric down to target pad
- Laser beam is less than 2 mils diameter; larger holes created by spiralling beam out
- UV type lasers, only: high power and focused, with short pulses (up to 50 nanoseconds)
- Vias in non-clad dielectric coatings are very suitable for this technique
- Laser must be registered precisely to location of target pads, by visual compensation to each panel's fiducials

The UV laser operates in the ultraviolet portion of the electromagnetic spectrum; organics, metals and ceramics are strong absorbers at 355 nm and are easily ablated. The beam size is typically 15-20 microns in size. Spiraling or trepanning is required to ablate vias larger than this size. The speed of ablation is dependent on both via diameter and dielectric thickness. Material is removed at a few microns per pulse, with this removal rate being affected by the pulse rate, the focus of the laser beam and the power output. The pulse rate is variable.

The pulsed CO_2 laser operates in the infrared portion of the electromagnetic spectrum (9.3µm). In this portion of the spectrum, organics are strong absorbers, while glass only absorbs about 60-70%. Importantly, copper does not absorb and is totally reflected. The beam size is typically 600 microns; speed of ablation is impacted by dielectric thickness and is independent of via diameter. Material is removed at 15 to 35 microns per pulse, depending upon the material; the pulse frequency is typically 150 Hz.

A good understanding of these fundamental differences must underpin the decision on which laser to use. In addition, the type and size of vias desired, the type of designs being built, and the ablation technique used are additional important considerations.

For ablating a copper clad dielectric cap layer, like resin coated copper, two ablation techniques are available (see Figure 4).

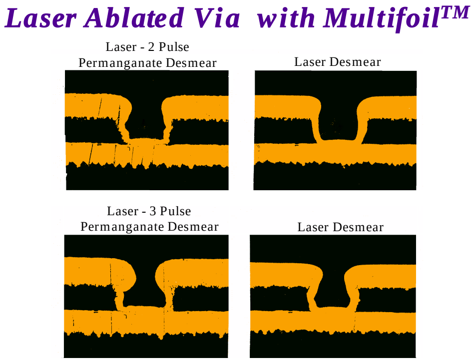
Conformal mask ablation uses an etched mask hole in the copper foil surface. The laser beam is focused to a wide footprint, allowing for speed of alignment to the mask hole. The mask hole size is determined by the photolithographic capability of the user; currently, the minimum achievable size in production volumes is about

2 mils. Both CO_2 and UV lasers can be used with this ablation technique; however, for vias 3 mils or greater in diameter, the CO_2 laser ablates more quickly.

Direct focused ablation requires no etching step; the laser ablates the outerlayer copper as well as the dielectric. The laser must be registered precisely to the location of the target pads, by visual compensation to each panel's fiducials. Only UV lasers are capable of this type of ablation; they ablate using high power, focused short pulses. This technique is one of the best ways to make sub-three mil vias and very dense boards. With via diameter size not limited by photolithography, small vias can be created. Elimination of the photolithographic step of opening a mask hole in the copper is a significant economic advantage. Innerlayer densification is possible since the innerlayer target pad is not forced to be overly large to compensate for mask hole registration effects.

Some examples of laser microvias are shown in Figure 6 below.

Figure 6



Source: Mitsui Mining and Smelting using MultiFoil

A preliminary comparison of ablation processes for resin coated copper is outlined in Table 3 below.

Table 3

Comparison of Ablation Processes for Blind Microvias in RCC and MultiFoi

Factor	CO2 Laser	UV Laser	Plasma	Mechanical Drilling
Via minimum diameter	2 mil*	1 mil^ / 2 mils*	3 mil*	5 mils feasible; 8 to 13 mils in volume prdn
Via aspect ratio	<=1:1	<=1:1	<=0.5:1	<=1:1
Via maximum diameter	14 mils**	7 mils (>2 requires trepanning / spiralling = slower)	none**	none
Via depth (RCC/MultiFoil dielectric thk)	<=3 mils**	<=3 mils**	<=2 mils**	none
Surface copper thickness	<= H oz (thinner helps etching mask holes)	Thin as possible^ / 12µ or H oz*	H oz min (foil flashetch reqd)	none
Requires mask (preformed) holes in coppe	yes	no	yes	no
Requires consistent dielectric thickness	important	somewhat important	very important	somewhat important
Capable of ablation to layer 3/N-2	yes (not thru layer 2 pads)	yes (thru layer 2 pads and not)	no	yes
Rate of ablation (5 mil diameter vias in 1.5 mil dielectric)	140/sec (8400 vias per minute)	75/sec^ (4500 vias per minute)	all vias etched simultaneously; both sides of panel	limited by sequential drilling, bit size changes, bit breakage, etc
Estimated process time (20K vias/side, 5 mil diameter, 1.5 mil thk)	2.5 minutes per side#	4.5 minutes per side# *	20 to 60 minutes both sides	Several hours to 24 hours
Total cycle time (includes adjustments to laser output, registration to fiducials, etc	est 3.5 minutes per side	est 10 minutes per side *	same as above	Several hours to 24 hours
Number of panels per run	1 per	1 per	Several; depends on chamber size and configuration	1 to 6; depends on no of spindles and size of bed
Via clean-up after ablation	yes	no (permanganate is desirable)	yes	no
Special prep prior to plating	no††	no††	surface cu overhang removal	no
Type of Equipment/Process	Pulsed TEA-CO2 laser	UV (Nd:YAG harmonic) laser	Plasma gas in vacuum	Air or mech. spindles; carbide bits
Key equipment supplier(s)	Lumonics	ESI	Dyconex; APS; others	Several (Dynamotion, Hitachi)
Proprietary process/Licensing req'ts	no	no	DYCOStrate license	no

^ UV laser onto panels without conformal mask holes in copper surface -- laser punches through surface copper.

* Using Conformal mask holes in surface copper -- dependent on hole size, a function of photoprinting/etching capabilities and the plating process. For plasma, undercutting by the isotropic etch results in a larger diameter via than the mask

** Dependent on several factors, including Aspect Ratio and Design Considerations such as density of surface features (grid pitch, number of runners, etc

†† Depends on chemistry of dielectric polymer; plating adhesion is improved by surface treatment.

\# Depends on hole pattern, path optimization, other factors.

Multilayer Board Layout: the Advantage of Resin Coated Copper for Blind Via Escape Designs

Until the development of resin coated copper, building boards which were compatible with blind vias typically used doubled-sided laminate-based constructions (e.g., Kapton® film based, nonwoven aramide reinforced, FR-4). While such double sided cores improved registration of conformal mask holes to layer 2 and (n-1), several issues arose with these designs which made them less attractive. The use of resin coated copper eliminates these issues. For example, when using double-sided laminate in a six layer build, 3 thin laminates required circuitization. This traditional approach uses several plies of prepreg to build up the dielectric; thickness consistency can be problematic and if the prepreg dielectric changes with thickness, impedance could be affected.

The use of resin coated copper avoids these issues. Only two circuitizations are needed and on thick laminates; there are minimal changes in overall dielectric layers; layup is simplified with no separate plies of prepreg and copper foil needed. Finally, the overall cost of the materials is less expensive when using resin coated copper rather than the double-sided laminate approach.

Thus, the overall cost for these types of boards is lower when microvia materials are used in their construction.

Conclusion

The need for dense PWB substrates is increasing and is expected to continue to grow rapidly. The demand on the industry to develop cost-effective technological solutions to meet these requirements is high. Microvias currently offer a solution for meeting this high density interconnect challenge. Coated coppers enable hole-forming techniques like plasma or laser ablation, offering economical HDI solutions to the fabricator. As these processes and materials evolve, smaller, thinner, lighter and faster boards will become commonplace.

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