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Latest Developments in Integrated Polymer Photonic Waveguides in PWBs

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Abstract
Highs Density Interconnects (HDI) printed circuits are now being designed in ever increasing quantities for very-high speed applications. The challenge of opto-electronics and integration of photonics down onto the printed circuit has started to take off. In the next seven years, expectations are that photonic PCBs will grow to a $2.5 billion dollar industry.

This paper looks at the issues, materials and current processes being researched to create this integrated Opto-Electronic Circuit Board by European, Japanese and N. American organizations.

Introducing the Benefits of HDI
The widespread use of new electronic components employing Ball-Grid Array (BGA), Chip Scale Packaging (CSP) and other evolving technology form-factors means new fabrication techniques must be used to create printed circuit boards (PCBs) that will accommodate parts with extremely tight lead pitches and small geometry's. In addition, extremely fast clock speeds and signal bandwidths challenge systems designers to find better ways to overcome the negative effects that radio frequency interference (RFI) and electro-magnetic interference (EMI) have on their product's performance. Opto-electronics printed circuits are based on HDI-Microvia technology. In addition to the extremely high-frequency electrical signals, the need now includes the requirement for integrated-optical waveguides. Finally, increasingly restrictive cost targets are compounding problems associated with today's smaller, denser, lighter and faster systems. When working with opto-electronics, the need for the integrated waveguides is a major program.

Staying competitive and delivering the products people want means seeking out and embracing the best available technologies and design methodologies. The use of PCBs incorporating microvia circuit interconnects is currently one of the most viable solutions on the market. Adopting microvia technology means products can utilize the newest, smallest and fastest devices, meet stringent RFI/EMI requirements, and keep pace with downward-spiraling cost targets. Integrated photonics including waveguides are built on this HDI-Microvia foundation.

What is Microvia Technologies?
Microvias, as the name implies, are vias of less than or equal to six mils (150 micron) in diameter. Their most typical use today is in blind and buried vias used to create interconnections through one dielectric layer within a PCB. Microvias are commonly used in blind via constructions where the outer layers of a multi-layer PCB are connected to the next adjacent signal layer. Used in all forms of electronic products, they effectively allow for the cost effective fabrication of high-density assemblies. The IPC has selected High Density Interconnection Structures (HDIS) as a term to refer to all of these various microvia technologies.

Why use Microvias in PCBs?
Better Electrical Performance / Signal Integrity
Due to the physical structure of microvias, there is a reduction in switching noise. This is attributable to the decreased inductance and capacitance of the via as its physical size becomes smaller and shorter. A microvia will have nearly one-tenth the electrical parasitics of a through-hole. Another advantage of using microvia technology for creating interconnects is a reduction in signal reflections and crosstalk between traces. The corresponding increase in routability area also allows designers to place traces further apart when necessary to reduce crosstalk.

Improved RFI/EMI/ESD
In the realm of RFI/EMI, increased routability area combined with the microvias physical via-in-pad implementation allows designers to place more ground plane around components. By doing this, the size of ground return loops decreases and improved RFI/EMI performance is realized. These benefits are highlighted in Figure 1.[1]

Photonics and Electrical Performance
The signal integrity improvements are certainly available to all who take the time to respect 'Mother Nature'. HDI's contribution comes mainly from the adage," Smaller and Closer is Better!" that is, HDI's main contribution is ***miniaturization***! Opto-electronics requires this precision and miniaturization. The signal integrity improvements for photonics comes from three phenomena:

1. Reduction of noise
2. EMI radiation reduction
3. Improved signal propagation and lower attenuation

Figure 1 - Benefits of HDI Come from Five Major Areas

Noise

Electrical noise is still one of the biggest problems for an opto-electronic board even if it has integrated photonics waveguides. There are really only four different categories of noise that all the various effects can be described by[2]:

- Signal quality of one net and its return path (ringing due to reflections)
- Cross talk between two or more nets (noise pulses due to switching on neighboring lines)
- Switching noise (noise on power and ground lines/planes)
- ElectroMagnetic Interference (EMI)

A simple illustration of this is provided in Figure 2 and table 1.[2]

Noise can come form many sources, many created by the layout of the board:

- Change in trace width
- Plane splits
- Cutouts in Power/Ground planes
- Via antipads
- Insufficient plane capabilities
- Excessive stubs, branched or bifurcated traces
- Component lead frames
- Improper impedance matching and termination networks
- Coupling between signals
- Varying loads and logic families

Each one has specific causes. By identifying the cause of each family of problems, design and technology based solutions can be identified and implemented.

Table 1 - HDI Features and the Signal Integrity Problem they Help Solve (SourceBogatin[2])

HDI features	Signal Quality	Cross Talk	Switching Noise	EMI
Short interconnect lengths	X	X		
Low dielectric constant	X	X		
Small vias and small features	X		X	
Vias in pads			X	
Fine lines and thin dielectric		X	X	X
Support for fine-pitch components			X	X

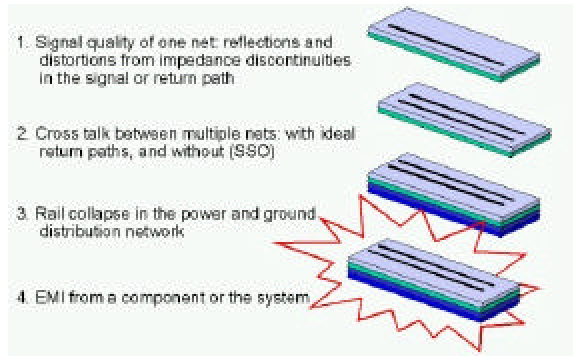

Figure 2 - All Signal Integrity Problems can be Grouped in Four Families

Photonics and Waveguides

While electrical signal can be multiplexed on a single wire or trace, many laser frequencies can be multiplexed on a single waveguide. This results in a 1000X increase in information handling while not being influenced by magnetic and electrical fields like electronic signals.

The need to route 'Long-Line Optical Signals' in an efficient manner and at lower costs has created the interest in integrated optical waveguides and methods of optical routing. The current method of signal routing is to convert the optical signal to an electronic signal, interrogate it, switch it to its next destination, and then to convert it back to an optical signal. All of this forms what the industry calls "Terabit Routers" and can require up to 42 large-complex multilayers. With integrated optics, this can probably be done by one or two unique PCB assemblies. The 'Board-to-Board' opto-electronic system will probably look like the illustration in Figure 3.

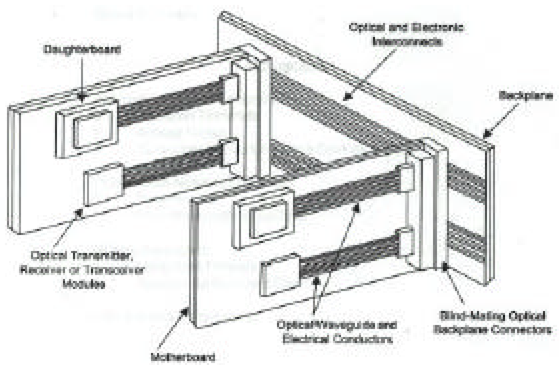

Figure 3 - Board to Board Optical Interconnections

Numerous techniques are under development for: multimode waveguide lamination, through-hole light coupling, surface finishes and soldering connectors.[3]

This integrated opto-assembly will have a number of factors new to PCBs:

- Optical waveguide materials
- 3D fabrication techniques
- 3D assembly techniques
- New components

Optical Waveguide Materials

The optical materials being considered for integrated waveguides are currently polymers. Polymers have a number of advantages:

- Stability – High thermal stability and long term photostability. Bellcore Telecordia compliance (ie. 1209, 1221) tested for >600 hrs at 85C / 85 rH, solder temperature >230C and degradation temperature >350C.
- Well established – There is a huge body of data obtained over the last 100 years on polymers including all the popular photoresists.
- Useful – Unique properties you cannot get anywhere else (bend radius, modulators, index tuning). Unique processing options (photolithographic, RIE, direct laser writing, molding, printing).

They also have a number of disadvantages:

- Unstable – Many have low thermal stability (POF below 80C) with photodegration (laser dyes<days) and are sensitive to delamination, moisture and chemicals.
- Unknown – New materials require new processes, equipment and experience.
- Useless – Some polymers have losses of POF of 20 dB/km, while optical glass is <0.1 dB/km. The packaging cost of polymers is 80% of the cost in devices.

Candidate materials are acrylates, halogenated acrylates, cyclobutenes, polyimides and polysiloxane. A list of many of the most popular is shown in Table 2.

3D Fabrication Techniques

Three waveguide techniques have been described in the literature:

- OptoFoil4
- PolyGuide
- TOPCat[5]

OptoFoil

This process uses an embossing mold (shim) to hot-emboss the foil structure of the waveguide. Topas, the optical materials fill the deformed core. After curing, it is laminated into the EOCB, the Electrical Optical Circuit Board.

Table 2 – Polymers for Optical Waveguides, Candidate Materials

Polymer Type	Patterning Techniques	Waveguide 840nm	Optical Loss 1300nm	[dB/cm] 1550nm
Halogenated Acrylate	Lithographic, RIE Laser	0.01	0.03	0.07
Acrylate	Lithographic, RIE Laser	0.02	0.2	0.5
Benzocyclobutene	RIE	0.8	1.5	
Perfluorocyclobutene	RIE	0.01	0.02	0.03
Acrylate (Polyguide)	Lithographic, RIE	0.2	0.6	
Teflon AF	RIE			
Fluorinated polyimide	Lithographic		0.4	1.0
polynorbornenes	Lithographic	0.18		
Polyetherimide	RIE, Laser	0.24		
Acrylate	RIE			0.6
Halogenated Acrylate	RIE	0.02	0.07	1.7
Polysiloxane	RIE	0.17	0.43	
Cytop	RIE		0.3	
RIE= Reactive Ion Etching		source:Lucent Technologies		

PolyGuide

PolyGuide is a photosensitive polymer developed nearly 10 years ago. The fabrication process requires vacuum lamination, adhesion promotion and then a photo mask to expose the material to UV light. The material is then post-cured and will now perform as a waveguide.

TOPCat

TOPCat is the results of a NIST sponsored ATP Project. The TOPCat is a planar polymer waveguide. The material is a polynorbornene. The manufacturing process is a “Core-first” microreplication. Laser is used to create embossing tool. The tool is coated with the pre-polymer material. The excess is struck off and the materials cured. It is then overcoated with a cladding. The waveguide core can be lifted out and an overcladding is applied. Figure 4 shows one of the finished planar polymer waveguide.

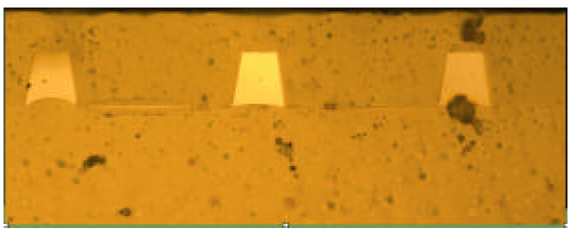

Figure 4 – TOPC at Planar Optical Waveguide Cores with Overcladding[5]

New Components

New key components are required to use an integrated waveguide. The two components are:

1. VCSEL (vertical cavity surface emitting laser) - A VCSEL emits light normal to the surface of the wafer in a beam with small angular divergence.
2. Micromirrors – small mirrors that can reflect the laser signals and integrate into the polymer waveguide channels.

3D Assembly Techniques

With these new optical components, new 3D assembly techniques are going to be required. Many optical components require micron-level tolerances to create the proper optical alignment. Key to these assembly capabilities will be the Z-axis plateau tolerances of the printed circuit. X-Y-Angular alignment will be new kinematic mounts that provide micron-precise alignments. A future opto-electronics assembly might look like the one portrayed in figure 5.

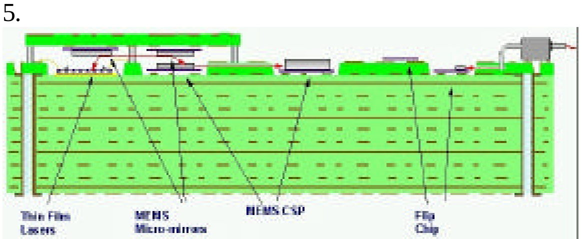

Figure 5 – Integrated 3-D Assembly with Thin-Film, Flip Chip, MEMS and PWB

Conclusion

Blame it on Maxwell’s Equations, but signal integrity is getting more important and. *more difficult*. HDI provides small geometries and dielectrics. Providing you take advantage of the other benefits of HDI, like lower costs and higher densities, signal integrity will benefit as well. All of the problems listed get worse as signal rise times decreases. With current IC geometries shrinking, decreasing signal rise time is assured. Unfortunately, the amount of time to solve these problems is also shrinking. The successful company will be the one that masters opto-electronics, signal integrity problems and HDI.

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