Substrates for Advanced PCB Technologies: What Will the Future Hold?
未來的先進PCB技術

The UK chapter of the global IMAPS community of electronics and microelectronic packaging engineers shared a wealth of knowledge and wisdom about PCB substrate technology trends, developments, and future requirements in a webinar on the first of November. The webinar was introduced on behalf of IMAPS-UK by National Physical Laboratory’s electronics interconnection expert Martin Wickham and featured presentations by Piers Tremlett and Jim Francey.

"Who knows which future substrate will be successful?" Aware of a need to exercise caution when attempting predictions, Piers Tremlett, engineering specialist at Microsemi, quoted an example from ancient Greece: "The Oracle at Delphi knew how to ensure her future predictions. Everyone else gets it wrong; it's just a question of by how much." Nevertheless, his presentation painted a very clear picture of the future for printed circuit substrates, even exploring the possibilities for "substrateless" circuits.

Driven by a need to satisfy the desires of users, substrate technology aimed to improve performance and eliminate waste whilst minimizing cost. Tremlett discussed the fluidity of future circuit structures, the potential growth of flexible substrates, the rise in substrates for handling power and heat, and trends from two-dimensional to three-dimensional circuit assemblies. He focused on four relevant topics: miniaturisation for mobile products, heat and power, printed electronics, and substrateless circuits.

Mobile products, especially smartphones, and the cost savings of using less material were the primary drivers for miniaturisation. As an example, Tremlett showed a cross-section of an iPhone 7 with

esting explored “無基板”電路的可能性。

In满足用户需求的驱动下，基板技术旨在提高性能并消除浪费，同时最大限度地降低成本。Tremlett讨论了未来电路结构的易变性，挠性基板的潜在增长，可处理功率和热量的基板的增加，以及从二维到三维电路元件的发展趋势。
a coreless 10-layer 500-micron substrate and sub-20-micron tracks densely populated with components and a lot of interconnect in a very small space. The interconnect was realised by semi-additive processing, pattern plating on a very thin base copper, and flash etching. As laser direct imaging capability improved and track widths trended towards 10 microns, it was preferred to embed them into the substrate surface to improve reliability, as demonstrated by the Daisho Densei ultra-narrow pitch flush pad interposer. In his iPhone 7 example, the memory chip was mounted on a very thin three-layer PCB, underneath which was the processor chip with no substrate as such - all the tracks were laid on the packaging material itself and had produced significant performance improvements. He commented that fan-out wafer-level packaging was moving from silicon wafer technology to PCB technology with more than one component inside the mould compound, which could be seen as a paradigm shift away from FR-4 and surface mount.

Conventional assembly technology was giving way to embedded die technology and ultra-thin chip technology, leading to smaller and thinner devices. But whereas the trend had always been to push components off the PCB and on to the silicon, this was now becoming a more expensive option, and the components were being pushed back up into the packaging fab to continue the drive towards integration. Packaging was moving towards complete subsystems, placing more emphasis on substrate capability in terms of layer count and track width and presenting considerable competition to conventional PCB concepts.

Tremlett turned his attention to thermal management, increasing heat being generated by faster processors, RF chips, power chips and LEDs. It was becoming less practicable to use ceramic substrates except for special applications because of considerations of cost, small panel geometries, and high-temperature processing. So, could organic substrates be used as alternatives? He discussed thermal via designs, several forms of integrated metal substrates, metal inserts, and even water-cooled PCBs, and compared their efficiencies as a means of heat dissipation. He reviewed innovations in chip embedding for power packaging that had proven benefits for low- and
high-power analogue and digital and RF products and described proprietary embedding package solutions such as SESUB and aEASI. The EmPower project was an international consortium developing embedded power semiconductors for the drive electronics in electric vehicle applications in a module that enabled heat removal on both sides over the shortest possible heat conduction paths.

Printed electronics was Tremlett’s third focussfully additive technologies as opposed to the subtractive etching processes associated with conventional PCB manufacturing. Conductors, components and transistors could be created, generally on thin flexible substrates, although even the substrate itself could be created by additive processes. The AMOLED (active-matrix organic LED) display was a good example of what could be achieved by printed electronics technique glass substrate with a thin-film transistor array and functional cathode, organic and anode layers applied as liquid solutions, and metallic nanopastes using classical print media processes at low temperatures. 3D printers were now available, capable of rapid prototyping of multilayer PCBs and nonplanar electronics; however, only silver inks were available currently, and the rough and porous sintered structure of conductors was not ideal for power and RF applications.

Developments in ultra-thin flexible integrated circuits were opening up opportunities for introducing intelligence and interactivity into everyday items, enabling smart packaging, labels, and objects. The proprietary PragmatIC technology utilised thin-film metal oxides on a polymer substrate with a total thickness of fewer than 10 microns at a fraction of the cost of equivalent silicon devices, and the capital cost of the manufacturing plant was far less than that for silicon semiconductors. Fujikora’s WABE hybrid die technology could mass-produce multilayer polyimide PCBs embedded with background ICs and low-profile passive components through a roll-to-roll process. The thin flexible body of the WABE package favoured applications in medical and wearable electronics.

Tremlett concluded his presentation with a brief overview of “substrateless” circuits and moulded interconnect devices with automotive application.
examples where the circuit was created directly on an existing substrate, and in wearable applications where the circuit was deposited directly on to a piece of fabric.

Martin Wickham then introduced Jim Franey, sales manager Northern Europe for Optiprint and well-known for his expert knowledge on low-loss materials for microwave and RF applications, to discuss organic substrates for PCBs and the factors influencing substrate development and user selection criteria.

Franey began with a broad overview of the available classes of organic substrate: paper, polyester films, FR-4 epoxy, high-Tg epoxy, polyimide, and PTFE. Although paper-phenolic laminates had been used since the early 1960s, there was growing interest in the use of paper coated with biodegradable polyimide as a low-cost PCB substrate. Polymers such as polyethylene terephthalate (PET) and polyethylene naphthenate (PEN) were well-established flexible-circuit substrates, especially in high-volume real-to-real applications, and were being used as substrates for emerging near-field communication (NFC) smart labels with printed memory and printed sensors.

FR-4 woven-glass-reinforced thermoset epoxy resin laminates and prepregs were the established substrates of choice for multilayer PCBs, and blends with resins such as bismaleimide triazine, cyanate ester, and polypropylene ethers had given improved electrical and mechanical properties. Lead-free assembly requirements had driven a transition from di-functional to multifunctional epoxy for improved temperature capability. The addition of thermally conductive inorganic fillers conferred thermal dissipation properties. Woven-glass-reinforced thermoset polyimide laminates and prepregs had become the industry standard for applications where operating temperatures exceeded the capability of multifunctional epoxy. For many military and aerospace applications, non-reinforced polyimide film was used as the basis of flexible and rigid-flex circuits. Further, adhesiveless materials were increasingly used where reduced thickness, increased thermal robustness, and improved high-frequency electrical properties were required.
Woven-glass-reinforced and non-reinforced PTFE substrates were used predominantly in RF and microwave designs and increasingly in millimetre-wave applications. These materials combined a low dissipation factor with a stable dielectric constant through a wide frequency range. Volume markets were cellular base-station power amplifiers, base-station antennae, and increasingly in automotive radar antennae. Inorganic fillers could be used to modify dielectric constant and thermal conductivity. Woven-glass-reinforced laminates based on thermostet hydrocarbon resins with inorganic fillers were being widely used in microwave and high-speed digital applications, and new hydrocarbons were seen as cost-effective replacements for PTFE in the automotive safety electronics market. Non-reinforced liquid crystal polymer (LCP) thermoplastic with negligible water absorption was increasing in popularity as a substrate in microwave and millimetre-wave applications.

Cyclic olefin copolymer was a crystal-clear plastic frequently used in medical applications and in conjunction with additive technology.

Moving on from this comprehensive survey of established and emerging substrate materials, Francy discussed the topic of satisfying PCB transmission requirements in some depth, beginning with some comments on miniaturisation. Thin-core dielectrics gave the opportunity to reduce plated via diameter and increase packaging density. Adhesiveless polyimide flex substrates available in thicknesses down to 12.5 microns, and an ultra-light-weight glass fabric style - 1017, only 15 microns - enabled the manufacture of 30-micron laminates and prepregs. Francy showed an example of a 6-layer sequentially laminated rigid-flex with 12-micron single-sided polyimide cores and 12-micron bond plies, and 50-micron stacked via laser-drilled and copper-filled. Thin-core rigid organic substrates with low-expansion woven glass and copper-filled vias were increasingly being used as alternatives to ceramic substrates in semiconductor packaging. Francy considered basic requirements for maintaining high-speed signal integrity: low-loss polymers with stable dielectric constant through a range of frequencies, low-profile copper foil, and spread-glass fabrics to minimise the effect of glass-weave skew. He also demonstrated the importance of good layer-to-layer registration in minimising signal losses.

Jim Francy
Frequencies between 30 GHz and 300 GHz were classed as millimetre-wave, and it became increasingly critical to use low-loss materials with stable dielectric constant in applications such as 77-GHz automotive radar and V-band and E-band telecommunications which could use PCB technology on PTFE and LCP substrates although the choice and thickness of substrates and positional accuracy of PCB features would be critical considerations. Microstrip, stripline, and coplanar waveguide transmission line technologies were all employed in millimetre-wave PCB design, and substrate-integrated waveguide principles were becoming popular for power dividers, signal couplers, filters, and antennae with the benefits of low-radiation leakage and low interference compared with microstrip and coplanar waveguides.

Francey used the example of a beam-switching Rotman Lens antenna to illustrate typical millimetre-wave PCB structures and discussed the defining features and critical tolerances that had to be satisfied within the PCB manufacturing technology. To summarise, he quoted the words of a microwave engineer: "When the frequency increases, everything has got to shrink. Manufacturing tolerances start to become a problem at about 20-30 GHz. Below that, you can pretty much design anything you want, the production will not fail. Above that, it is no exaggeration to say that everything is about manufacturing tolerances and producibility. Being a microwave designer is a completely different job at 77 GHz compared to one GHz.*

In his concluding comments, Francey observed that the laminate industry was meeting the needs for system miniaturisation, signal integrity, assembly, and reliability with thinner cores and engineered polymer composites to satisfy dielectric and thermomechanical requirements. Moreover, the PCB industry was reacting to the needs for higher packaging densities, signal integrity, and the use of PCB technology in IC packaging. However, he stressed that the convergence of future needs for circuit miniaturisation, feature tolerances, and feature-to-feature positional could only be achieved with additive technology, which would require a step change in PCB manufacturing capability and know-how.

 francey介紹了保持高速信號完整性基本要求：在一定頻率範圍內具有穩定介電常數的低損耗聚合物、低介電損耗和玻璃纖維布製鐵，以提高減少玻纖組織歪斜影響結構。他還表達了良好的層與層對準對最小化信號損耗的重要性。

Francey以波束交換Rotman透鏡天線為例說明了典型的毫米波PCB結構，並討論了PCB製造技術中必須滿足的定義特徵和關鍵公差。最後，他引用了一位微波工程師的話作為總結：“當頻率增加時，一切都必須縮小。”在約20~30 GHz的頻率下，製造公差開始成為問題。在20~30 GHz以下，你可以設計出任何你想要的產品，生產不會失敗。在20~30 GHz以上時，可以毫不誇張地說，一切都與製造公差和可生產性有關。作為一名微波設計師，77 GHz和1 GHz是完全不同的設計。

Francey在他的總結中指出，層壓板行業正在滿足系統小型化、信號完整性、組裝和可靠性的需求，採用更薄的芯和工程聚合物複合材料來滿足介電和熱機械要求。此外，PCB行業正在對更高封裝密度、信號完整性和在積體電路封裝中使用PCB技術的需求。不過，他強調，未來對電路小型化、特徵公差和特徵與特徵定位的需求只有通過增材技術才能實現，這需要PCB製造能力和專有技術的逐步改變。

我發現這個網路研討會很有啟發性，也很有趣。我從中學到了很多，非常感謝IMAPS-UK（國際微電子與封裝協會-英國分會）給我機會參加此次研討會。對Piers Tremlett和Jim Francey的演講品質和內容表示敬佩，並感謝他們慷慨地分享知識和經驗。還要感謝Martin Wickham擔任主持人，以及無處不在的Bob Willis對此次研討會的專業管理。

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