第1回・北米篇

来たる5月末に神戸で開催が予定されているIMC '86をはじめ、毎年秋、米国で開催されているISHM年会、隔年春にヨーロッパで開催されるEHMCなどは、回を重ねるごとに盛大となり技術面での国際交流は年々その緊密度を増している。

近年、ハイブリッドの展開には、世界のマーケット、世界の技術を考える必要が出てきており、特に、マーケット、新応用などに関する新鮮な情報は貴重なものとなっている。そこで、最新の海外ハイブリッドの状況を紹介すべく、“各国ハイブリッド事情”シリーズを企画した。

第1回目は北米におけるハイブリッド事情とし、以後、ヨーロッパ、アジアなどの国々について数回にわたり計画している。

このシリーズについては、本誌編集委員会が執筆者の人選をさせていただき、書いていただいた原稿は、そのまま原文で掲載することにした。
(機関誌委員会)

THICK FILM HYBRIDS IN NORTH AMERICA

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Hybrid microcircuits were originally conceived in the U.S. to provide circuit integration and miniaturization when IC technology was still in its infancy. In most early hybrid circuits, small signal transistors and diodes were soldered to thick film substrates along with passive discrete components such as capacitors and inductors. Resistors were generally printed and fired on the substrate.

The largest early application combining printed and fired substrates and IC's was the SLT module of IBM. The SLT modules interconnected a small number of flip-chip IC's and demonstrated the utility of thick film technology as a semiconductor packaging technique.

Since today's hybrid circuit is simply a means of modifying, packaging, or interconnecting IC's, hybrid technology must evolve with semiconductor developments or become extinct. The North American hybrid industry includes a wide spectrum of circuits from the sophisticated multilayer hybrid with numerous IC's to the "old fashioned" circuit with discrete transistors and diodes.

The market value of assembled thick film hybrids produced in North America is greater than \$3.5 billion. This market may be divided into two major segments:

HIGH RELIABILITY

Military/Medical	45%	*Excluding IBM
Data Processing*	10%	
Instrumentation	5%	

COMMERCIAL

Telecommunication	20%
Automotive	15%
Consumer/Industrial	5%

The value of high reliability circuits makes it the larger segment, more than \$2.0 billion, although the commercial segment is more significant on a volume basis.

HIGH RELIABILITY HYBRIDS

High reliability circuits are used where reliability and performance are dominant driving forces, often at the expense of cost.

Thick Film materials used for high-reliability circuits have traditionally been:

- o Gold conductors (including Platinum and/or Palladium where solderability is required), which are non-reactive and offer high conductivity.
- o High tolerance Ruthenium-based resistors, resistor paste volume is often low in the high reliability segment because resistors are small and relatively few in number.
- o Air-fired multilayer dielectrics that provide insulation between conductor layers.
- o Encapsulants which protect the circuit.

Since the early 80's, there has been a move towards nitrogen firing base metal systems which are made up of:

- o Copper conductors, which are used primarily for IC interconnects and offer high conductivity and reduced cost compared with gold conductors.
- o Nitrogen-fireable multilayer dielectrics, which have lower dielectric constants than air-fireable materials.

The industries which use high reliability hybrids are vital to the public interest and therefore government regulated. Examples are the military, aerospace and medical industries. Those industries which must have guaranteed long term performance. These external controls place a heavier burden on quality control than is normal in commercial applications. Elaborate evaluation procedures, strict material requirements, intermediate Quality Control and traceability are all demanded, and indeed are judged to be most cost effective over the long term.

Both the military and data processing industries are experiencing a move towards increasingly complex digital IC's and away from analog devices. These advanced IC's have more I/O connections, higher power requirements and faster switching speeds.

- o Military - End uses include missile control systems of all types (air-to-air, air-to-ground, ground-to-air, etc.), functional systems (radar, guidance, communications, electronic warfare, fire control, etc.) as well as distributed processing through embedded computers in submarine and surface ships, remote portable shelters, aircraft, and tracked vehicles.

Beginning in the latter years of the Carter presidency and continuing throughout the Reagan administration, the U.S. Military budget grew at a high rate. Major new programs were approved and substantial funding for Research and Development became available. These factors led to the development and introduction of very complex electronic system and in many cases these systems included gold multilayer hybrids. Some of these

hybrids have as many as 12 metal layers although the normal number of layers is 6 to 8. However, these gold multilayers have remained relatively small with only a few being larger than 8 x 8 cm. Base metal technology using copper conductors has been adopted in the production of large "motherboards". For example, in the Hughes AMRAAM (Advanced Medium Range Air-to-Air Missile Program) IC's in chip carrier format are mounted onto such a board. In many cases gold based hybrids, using gold wire bonded active devices are also assembled onto the copper motherboards. These motherboards can be as large as 15 x 20 cm and typically have six metal layers. When adopted in this and other major programs, production rates of these very complex circuits can be surprisingly high, on the order of 2000 per month.

- o Data Processing - Here, hybrids are used to interconnect and package IC's. Hybrids are primarily to be found in the central processing units and memory banks of large mainframe computers, although this application is declining as conventional printed-and-fired hybrids are replaced by a combination of high temperature co-fired alumina and polyimide technologies.

In the U.S., thick film does have a growing penetration in circuitry used to control peripheral devices (e.g. printers, disk drives, etc.) and is beginning to find limited application in the expanding mini, micro, portable and home computer segments.

- o Instrumentation - Applications of high reliability hybrids here are often due to the broad acceptance of military specifications by instrumentation manufacturers. It is easier to design within the limits of preformulated standards and accept the material cost penalties than to establish a set of dedicated procedures and standards. There are exceptions, however, where the ultimate in reliability is genuinely required such as in instruments used in oil well logging operation. In general, instrumentation environments are often not very harsh.

In summary, high reliability circuits are growing at an attractive rate of something over 12% per year. Increasing emphasis is being placed on large multilayer interconnect circuits using high conductivity conductors and low dielectric constant dielectrics rather than on single layer hybrid circuits incorporating resistors.

COMMERCIAL HYBRIDS

Commercial hybrids in the U.S. and Canada are produced in large volumes and are sold for applications where cost is a particularly important factor.

Cost effectiveness versus other technologies is the main reason thick film has proved so successful in these markets. The commercial hybrid manufacturer is constantly seeking yield and throughput improvements to further reduce his cost. He is also seeking performance benefits while trying to meet new system demands.

Most of today's commercial hybrids are single layer circuits with crossovers which require excellent long-term environmental stability. In addition they must be capable of sustaining high manufacturing yields. The thick film materials are generally fired at 850° in air on alumina substrates, although beryllia substrates are used for a number of high power applications. In addition, there is some use of metal core substrates and a growing interest in high thermal conductivity ceramic substrates other than beryllia, such as Aluminum Nitride.

The choice of silver alloy (either Palladium or Platinum) conductors is consistent with the objectives of the commercial circuit manufacture. Gold conductors are too expensive; pure silver conductors, although cheaper than silver alloys, are still not generally perceived as having the performance (principally solder leach and silver migration resistance) necessary for commercial circuit end-uses. However, in the past several years, there has been a trend toward lower Palladium or Platinum content products and pure silver

materials are being used in a number of back-plane applications.

This drive for cost-effectiveness plus performance is leading some commercial hybrid manufacturers into base metal technology. A dual atmosphere system (Air/Nitrogen) using copper and today's air firing resistors has been adopted by some users and others are starting to use a totally nitrogen-fireable system with new thick film resistor technology. Manufacturers are also investigating new processing techniques such as infrared (IR) firing.

Many new commercial applications require sophisticated circuits, but also have tight restrictions on space and weight. Real multilayer hybrid circuits, made of two or more layers of palladium/silver conductors separated by dielectric and with resistors printed and fired on top of the final dielectric layer, are an excellent response to this need and are being introduced. Benefits include reduced circuit size and improved electrical performance.

The three major end-use industries for commercial hybrid circuits are:

- o Automotive - Until recently the applications have primarily been remote functions such as spark and ignition control, voltage regulation and sensor elements for various parameters such as pressure, temperature and fuel level. There are now a number of examples of SIP (Single In-Line Package) hybrids being used in engine control modules in addition to the remote applications. The SIP units are conventional air-fired hybrids using silver bearing conductors. There are some copper hybrids as large as 3.5 x 12 cm being used in an advanced radio cassette entertainment system.

The use of automotive electronics is increasing rapidly. More sophisticated functions are being designed into the central electronics unit, placing a further premium on circuit density. At the same time space in the passenger compartment is becoming increasingly scarce and Radio Frequency Interface/Electro Magnetic Interface problems are growing with the result that serious consideration is being given to placing engine control functions under the hood. This could result in broader use of hybrid technology, in the form of multilayer circuits with resistors on the top layer. Another possible application for hybrids is in the distributed circuits required by multiplexed wiring.

- o Communications - Major applications are in private automatic branch exchanges (PABX), central office switching systems, transmission equipment, and in mobile communications and pagers.

With the recent break-up of the Bell System and the continuing growth of digital switching technology, the North American telecommunications market is in a state of flux. Equipment manufacturers are looking for more function, at lower cost and in less space. These requirements have resulted in the design of more advanced hybrids which are of higher density and require high conductivity conductors. In a number of cases circuits have evolved towards the use of very large numbers of second level crossovers, sometimes with limited areas of third level metalization while in others, copper technology has been introduced. True multilayers with complete planes of dielectric are being considered and single-function hybrids can be as large as 7.5 x 12.5cm.

- o Consumer - In North America, the consumer market is much smaller than in Japan and is declining with the majority of remaining applications being in color televisions. Most other consumer electronic products, either equipment or components, are imported from Asia.

The commercial segment has a high growth rate of approximately 15% per year. Many of the more sophisticated hybrid designs and manufacturing techniques, now common in high reliability circuits are beginning to be used for commercial applications. This increased sophistication of individual designs as well as many new applications are the driving forces behind growth in the commercial sector.

SUMMARY

Manufacturers of electronic equipment in North America use hybrids extensively and continue to find new applications, among these are:

- o copper motherboards for military applications
- o telephone line interface circuits in telecommunication switching systems
- o engine control hybrids in automobiles

Hybrid manufacturers are responding to the increased complexity of IC's and the variety of new opportunities in a number of specific ways. General trends are:

- o Larger area substrates - For many years hybrid manufacturers have used master substrates to take advantage of economies of scale and have manufactured several circuits at once. With the decrease in the cost of ceramic in the late 70's and increase in quality (particularly with respect to camber) larger substrates are being more widely used. Five years ago circuits of 2.5x5 cm were standard, today substrates of at least 10x12.5 cm are used by most hybrid manufacturers.

The size of individual circuits is also increasing. Some military circuits are routinely designed and manufactured at sizes up to 15 x 20 cm. Telecommunications and automotive circuits have not yet reached these extremes, but many new circuits for these applications are as large as 7.5x10 cm.

- o Greater Print Density. As feature size of add-on components and semiconductor ICs have been reduced, hybrid manufacturers have followed suit and designed circuits with finer lines. 500 micron lines and spaces were commonly used five years ago, but again the high reliability segment took the lead and developed finer line capability in conjunction with the paste suppliers. 125 micron lines are now considered the norm for this segment. The commercial segment routinely uses 250 micron lines and is moving toward the 125 micron resolution achieved by the high reliability segment.
- o Multilayers - Many of the new applications place a premium on small size. This challenge is being addressed by multilayer technology. Today almost all new designs in the military and data processing segments use multilayer technology (typically six or more metal layers) either in precious or base metals. Telecommunication and Automotive circuits are still primarily single layer, however many new designs are moving from one-to-two layers with extensive crossovers to full multilayers with as many as four metal layers.
- o High Conductivity Conductors - The increase in semiconductor IC speed has placed a premium on conductivity for hybrid circuits. Within precious metal conductors, there has been a move towards lower palladium and platinum content materials, and there is a parallel move towards copper conductors.
- o High Thermal Conductivity Substrates - Again advances in ICs have created new needs in hybrids. The increased heat generated by the more complex ICs is becoming a general concern, rather than the specialized problem of a few very advanced designs. There is as yet no clear trend as to how this problem will be solved, but there is a great deal of activity investigating alternate substrates, chief among these being Aluminum Nitride.
- o Polymeric Thick Film - Traditionally thick film has been a cermet technology. However, as designers search for lower dielectric constant K and lower cost processes, polymeric technologies are being explored.

The North American hybrid market is large, vigorous and growing. It continues to be dominated by the high reliability applications, both in terms of dollar value of circuits produced and leadership in development of new technology. The commercial segment represents an area of considerable growth and opportunity today, and a number of advanced hybrid designs are being introduced in both telecommunications and automotive applications.

要 約

北米電子機器業界におけるハイブリッド技術の使用割合は高度に達しており、その新規用途への展開は拡大の一途をたどっている。その主なものとしては、軍事用途の銅材料を用いたマザーボード、電話回線中継回路、自動車エンジンコントロール回路等が注目される。

一方ハイブリッドメーカーはこれに呼応して、ますます複雑多岐化するIC技術に対応しつつも、新規用途を目指し個々の面で努力改善を重ねている。一般傾向としては、

○ 基板サイズの拡大化——基板のコスト低減化と基板品質の向上に伴い、多数個どり基板サイズの拡大化傾向がより顕著になった。5年前では 2.5×5 cmが標準であったが、今日では 10×12.5 cmが主流である。一個一個の基板サイズも拡大化傾向にあり、軍事用では 15×20 cmが普通である。通信機器、自動車ではまだ 7.5×10 cmが主流である。

○ 高密度印刷——5年前は、 $500 \mu\text{m}$ 線幅は主流であったが、高信頼性ハイブリッド分野において改良がすすみ今では $125 \mu\text{m}$ 線幅がごく普通になっている。商業用分野においては、 $250 \mu\text{m}$ 線幅が使用されている ケースもまだ残っている。

○ 多層配線回路——高密度化を図るため、今日の軍事用およびデータプロセス用分野では、ほとんど多層技

術（金属層にして6層以上）が貴金属、卑金属システムを問わず採用されている。通信機器、自動車関連では1層が未だ主流だが、新規設計では多層化傾向（2～4層）が強い。

○ 高導電性材料——貴金属システムでは、PdあるいはPt比率を下げる方向にあり、一方で、銅システム採用への方向が出ている。

○ 高熱伝導性基板材料——IC技術の高度化に伴い基板の放熱性が一般関心事になっている。アルミナ以外の材料の基板への応用研究がすすみ、なかでも窒化アルミ基板は注目を浴びている。

○ 低温硬化型厚膜材料—— K 値のより低い材料、あるいはプロセスのコスト低減化を目指して低温硬化型材料の開発がすすんでいる。

北米におけるハイブリッド市場の規模は大きく（約35億ドル）常に力強い成長を続けている。この市場は主に高信頼性用途分野によって支えられており（20億ドル以上）新技術開発面では、リーダー的役割を果している。商業用分野においても、今日ではその進歩は顕著で、特に通信機器および自動車分野においてはなおいに高度ハイブリッド技術が採用されるにいたっている。

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