MCM & Hybrid Technologies

Originally, both Hybrid and MCM designs used traditional silicon die, internal construction, and packaging techniques; most could be classified as subminiature modules. True Hybrids consisted of passive discretes combined with active, and often passive, silicon chips. Hybrid and MCM substrates were primarily component carriers, often double-sided ceramic or small glass-epoxy boards. The silicon die, which differed little from the die used in standard microcircuits, gave little performance improvement, but these designs provided a smaller, space-saving component and a unique circuit for a specific application. The following describes the modern trends in accomplishing improved performance and reliability with greater space saving packaging techniques.

Hybrids

Although there are a variety of Hybrid configurations, the design involves a substrate with deposited circuitry (usually thick film), with separately produced active elements that are added to complete a circuit function. Separately produced, passive elements may also be used. These added elements might be produced as silicon chips or as discretes. The Hybrid package can be found in several design configurations discussed separately. The deposition methods used for Hybrids are essentially the same as for MCMs. Deposition technologies are discussed separately, as the technology used is based more on the choice of metallization, thick film or thin film. The primary Hybrid design emphasis is to satisfy a unique circuit function with a minimum requirement for real estate.
In the true Hybrid, the base material is usually glass, alumina (Al_2O_3), or beryllia (BeO), with deposited thick film circuitry of conductors and resistors. Thick film is defined as a deposition greater than 0.5 mil. Thin film (used occasionally) is normally less than 10,000 Angstroms, but may only be slightly less than 0.5 mils. Glass substrates are desirable for their inherit surface smoothness (important in thin film technology). Ceramics are preferred when high thermal conductivity is important, as alumina is 20 times higher than glass and beryllia is 200 times higher than glass. Ceramics also have excellent strength, electrical properties, and ease of producing holes.

MCMs

The MCM concept is a multi-monolithic, multi-functional design, consisting entirely of chips (predominantly silicon die, but GaAS or SiGe may be used when necessary). The variations in MCM design technologies primarily effect the packaging, metallization deposition, and die/substrate configuration. Packaging is discussed separately, and the deposition technologies are essentially the same as for Hybrids. The classification of modern MCMs is usually by the die/substrate technology, with the more popular configurations being:

a. MCM-C (Co-fired ceramic or glass). Ceramic substrate-based technologies with a dielectric constant of five or less. Conductors are usually a fired material, e.g.: tungsten, molybdenum, or a screenable frit metal thick film conductor (Au, Ag and Cu). Vias are formed during screening using the same metallurgy as the metal traces.

b. MCM-L (Laminated layers of resins, often reinforced). A substrate of laminated printed circuit board construction, with predominantly copper conductors and vias.

c. MCM-D (Deposited, un-reinforced dielectric). A deposited substrate construction of un-reinforced dielectric materials (e.g.: polyimide, KAPTON^{tm}, $Si0_2$, etc.) grown on top of a base substrate. Stability is achieved from the base substrate, which may be ceramic, silicon, glass-reinforced laminate or metal/metal composite materials. Conductors are sputtered or plated (usually Al, Cu or Au). Vias are formed using the same material with barrier metals/adhesion promoters as required. Some MCM-D examples include:

1. MCM-D (Typical). A typical product of this technology is one with a ceramic substrate, surface-mount die, polyimide dielectric, Cu conductors, and is multilayered. The ceramic substrate is usually Al_2O_3 , but the interconnect technology may be one (or a mixture) of chip and wire bond, TAB, and Flip-Chip C4 (Controlled Collapse Chip Connection, an IBM proprietary process). The Flip-Chip C4 technology provides good thermal dissipation and may be preferable when good thermal management is required.

2. MCM-Si (Silicon based). The silicon substrate base is the traditional wafer industry material and therefore keeps costs relatively low. This Si-on-Si process supports a high density interconnect network, to which multiple varieties of bare die may be assembled. The metallization is normally Al and Al-Si, while SiO_2 forms the dielectric. The top passivation layer is usually Si_3N_4. This technology provides a uniquely perfect TCE match between the substrate and die.

3. MCM-HDI (Hi-Density/Embedded chip). The ceramic substrate is usually Al_2O_3, however other materials (e.g. AlN) may be used. The substrate is milled to accommodate a multiple variety of bare die. Die pads, accessible at the top of the milled cavity,

are attached to successive layers of interconnect structures. The interconnect structures are copper traces, with copper vias between laminations of polyimide dielectric (KAPTON™). These structures are produced by processes similar to established laminating and plating techniques. This is an inherently robust design, offering a very high circuit density and a cost effective technology.

d. COB (Chip-on-board), This technology can be classified as an MCM, when only chips on a substrate are involved. Although Flip-Chip attachment is possible, typically, the chips are wire bonded using Au to Al at the die and Au to Au at the substrate. The die is normally protected with a "glob-type" covering, e.g., silicone. This design eliminates one tier of interconnects but because of the die-size footprint, necessitates a more difficult pattern of fine-line interconnects. The substrate may be ceramic, polyimide or glass epoxy (standard PCB). COB is a popular technique for competitive commercial products and may be a cost-effective alternative for benign environment, short life applications.

e. MMICs GaAs Die. Although MMICs are in GaAs chip form, they are normally used together in an MCM fabrication process, rather than as separate entities. Since GaAs devices are used nearly exclusively in MMICs, they are discussed as follows:

1. GaAs Digital/ Analog Microcircuits. GaAs digital microcircuits include gate arrays, memory devices, and various logic circuits. These digital devices employ a GaAs substrate and GaAs analog microcircuits, RF devices, and include medium and high power amplifiers, low noise amplifiers, and oscillators.

2. GaAs Combination (Mixed Digital/Analog) Microcircuits. These microcircuits are fabricated on GaAs substrates and employ a mixture of digital and analog circuits. The combination circuits examined in this manual include phase shifters and attenuators, which are the predominant functions.

Hybrid and MCM Deposition Mythologies

Traditionally, aluminum has been the preferred interconnect material for the primary conductor metallization, but, recent advances in deposition techniques has brought copper metalization[1][1] forth as the current preference. Copper has the potential to reduce overall resistivity, capacitance, power consumption, transition times, and metal levels. Each has a significant advantage for future smaller and faster devices; and, copper has better resistance to electromigration, a significant problem with aluminum. The following, however, pertains to techniques where aluminum is the primary conductor material. Although there are numerous deposition techniques, there are only three that currently warrant discussion: vacuum, screened and fired (SAF), and chemical. A brief discussion of each follows:

a. Vacuums. Two common types of vacuum deposition are evaporation and cathodic sputtering. Both depend upon the film to condense onto the substrate, because of heating under a reduced atmospheric pressure. Cathodic sputtering is a combination of a partial vacuum, a voltage potential applied between the anode (substrate) and cathode (film material), and in a mixture of gases. Cathodic sputtering provides control over the characteristic properties of the deposited film, resulting in the formation of conductors and passive elements, which make up a circuit. The required circuit patterns may be formed by masking, etching, or when passive elements are involved, a combination of masking and selective etching.

b. SAF (Screened and fired). SAF methods are economically popular for high volume production. Inks/pastes (frits or cermets), consisting of noble metals and metal oxides, are mixed with powdered glass, binders and solvents, which when screened and fired, leave conductor and passive element patterns on the substrate surface. The choice of compatible materials is critical to the end item performance and reliability.

c. Chemical. The four most common types of chemical dispositions used are vapor plating, electro/electroless plating, chemical-salts reduction, and chemical reactions. The processes used by fabricators are routinely classified company proprietary; therefore, little detail is available. Vapor plating techniques, not as well known as the other methods, may be used to deposit conductors, semiconductors, resistors, and insulators. Electroplating is limited to conductive materials, while electroless plating may also be used to deposit non-conductive materials. Chemical-salt reduction is used primarily to deposit titanium on alumina, in preparation for further processing by electroplating and photolithography. Chemical reactions in these processes are not direct depositing techniques, but are used to remove material or alter materials characteristics.

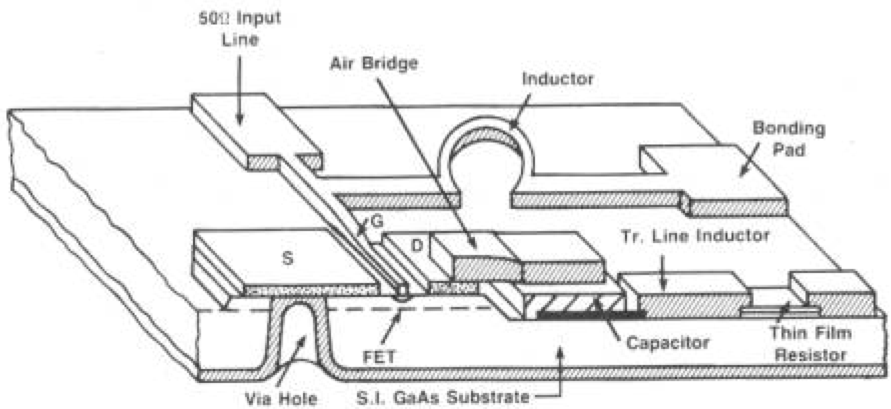
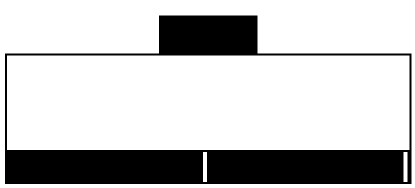


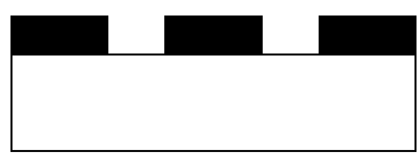
Figure 1. Passive Circuit Elements on a GaAs Substrate (MMIC)
(Source: Inder Bahl, Microwave Solid State Circuit Design, John Wiley and Sons, New York, 1998.).

Passive Structures

Passive structures used in microwave device applications, e.g. GaAs monolithic microwave integrated circuits (MMICs), include transmission lines, vias, airbridge metallizations, thin film resistors, metal-insulator-metal (MIM) capacitors, and inductors. Figure 1 is an illustration showing these passive elements. They can also be used as distributed circuit elements of capacitance and inductance. To be useful in microwave integrated circuits (MICs) and MMICs, transmission lines must be "planar." Microstrip and co-planar waveguide (CPW) are two common types of planar transmission lines. These structures are shown in Figure 2. "Planar" implies that the characteristics of the element can be determined by the geometry in a single plane. Planar transmission lines have the distinct advantage of being lightweight, small, reproducible, and reliable and most importantly, compatible with solid state integrated circuit technology.



Microstrip



Coplanar Waveguide

Figure 2. Planar Transmission Lines

The field pattern in micro-strip is commonly referred to as a quasi TEM pattern because the field lines are not contained entirely in the substrate. The electric field lines have a discontinuity in direction at the interface. Since some of the electric energy is stored in the air and some in the dielectric, the effective dielectric constant for the waves on the transmission line will lie somewhere between that of the air and that of the dielectric. Typically, the effective dielectric constant will be 50-85% of the substrate dielectric constant.

Vias are metallized holes that connect circuit elements on the top of a GaAs MMIC to the backside metallization of the chip and are used to provide a low inductance ground path to topside components. Vias are formed by deep etching of GaAs, using high-density plasmas, including inductively coupled plasmas (ICP) and parallel plate reactive ion etch (RIE). Via profiles can range from highly anisotropic to conical.

Air bridges are suspended metallization crossovers, designed to minimize the parasitic capacitance between signal lines. Figure 3 shows an air bridge structure. Air bridges are generally electroplated with thick gold plating and can carry substantial current.

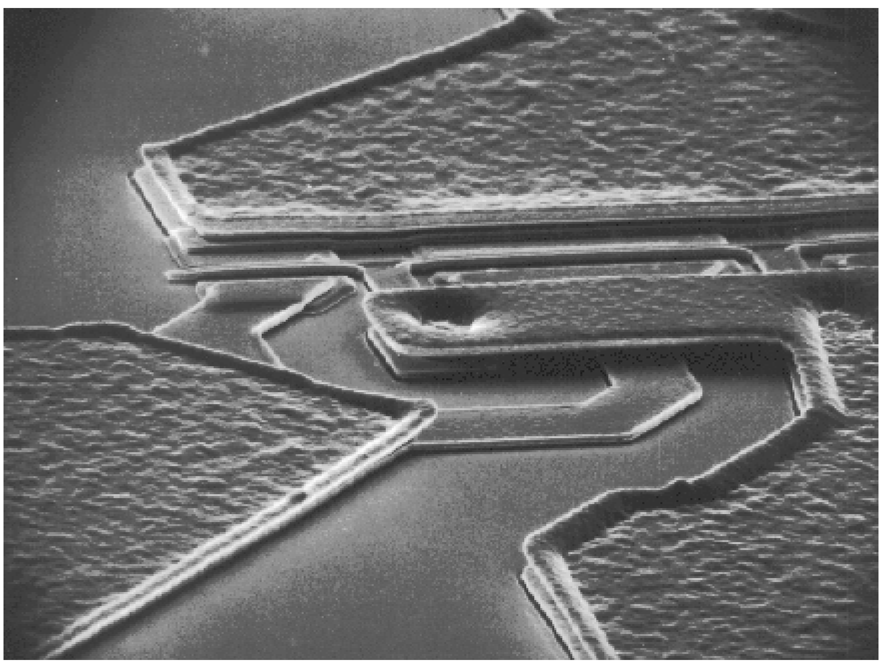


Figure 3. Airbridge Interconnect on a GaAs MESFET

Nickel-chromium (NiCr) and other resistive materials are used on GaAs-based circuits to produce thin film resistors. Current ratings vary with respect to the manufacturer; however, most designs use a maximum current density approximately $1x10^6$ A/cm^2. Thin film sheet resistance depends on the manufacturer's fabrication process. A typical value for NiCr sheet resistance is 50 ohms/sq.

Though various types of capacitors may be used in MMIC circuits, the most popular is the MIM capacitor, because of the high capacitance per unit area that can be obtained. This thin film capacitor is made of two metal plates separated by a dielectric material.

Inductors also have necessary functions in MMIC device designs. They typically serve as tuning elements and RF chokes in DC bias circuits. They are also one of the easiest passive elements to fabricate. Lumped element inductors can be used to provide inductance up to 20nH. Lumped inductors are typically comprised of a transmission line in a spiral shape. Spiral inductors can be realized in the form of a single air bridge, air bridges over an underpass, general air bridges, and use of two metal levels for an underpass.