CERAMIC HYBRID CIRCUITS:
MATERIALS, PLATING AND MANUFACTURE

INTRODUCTION
The printed circuit board has become well known even to those who have no formal knowledge of electronics. A lesser-known but firmly entrenched and growing method of circuit manufacture uses ceramic hybrid microelectronics technology. In this process, circuit wiring is printed on a base material of ceramic (nonmetallic mineral oxide) instead of a PC board, and chips and/or other discrete components are mounted directly into the surface of the metallized substrate rather than pin-mounted in plated through holes. Although surface mounting of devices is also used on PC boards, ceramic hybrids offer a number of advantages that make them more attractive and in some cases mandatory. Among these are miniaturization, reliability, thermal coefficient of expansion, the ability to withstand mechanical, vibrational, and thermal shock, the ability to be cut and drilled to extremely fine tolerances, ease of multilayer manufacture and high dielectric constant.

MINIATURIZATION AND RELIABILITY
The miniaturization that is possible with hybrid circuits is known. The functions performed by a section of a PC board, or one, or more entire boards, can be condensed into a single, small, and highly reliable unit. Hybrids can be mounted onto PC boards to perform their circuit function, or in some applications can be used as a complete self-contained electronics package. By comparison, on a standard PC board, all integrated circuit (IC) chips would be mounted in DIPs (dual in-line packages) and along with all resistors. Capacitors and other components would be discretely mounted and soldered in place.

Although the tight assemble tolerances of a miniature hybrids require delicate manual component placement or expensive automated precision pick-and-place assembly machines, the elimination of lead mounting greatly increases circuit reliability. The sealed hybrid packages are not subject to failure because of mechanical stress on component leads during manufacture, handling, or operation. Hybrids can also withstand greater thermal, vibrational and mechanical shock than that of PC boards. For example, Components can be bonded by conductive epoxy or paste. De bonding is also often achieved using a gold/silicon eutectic preform that is brazed by heating. Wire bonding is achieved by applying thermal-sonic, thermocompression, or ultrasonic energy to wire end so that they deform plastically and bond to metallized pads. Soldering is also used to mount components and connect them.

Electroless nickel plated deposits, especially electroless nickel-boron deposits can produce a surface with the characteristics necessary to achieve mounting and connecting of components. Most electroless nickel-boron deposits are solderable, brazable, and can be wire bonded. Most, but not all epoxy bonding materials adhere to these deposits well. Some prefer amine-hardened epoxies. Electroless nickel deposits provide the needed corrosion protection for molybdenum and molybdenum-manganese metallizing frits. They also provided conductivity improvement for these and other metallizing frits. They also provide conductivity improvement for these and other metallizing materials such as tungsten. There materials are selected because they most closely match the coefficient of expansion of ceramic substrate materials such as 96% alumina.

Aluminum wire can be boded to "Niklad" nickel-boron deposits using ultrasonic or thermal-sonic methods but cannot be bonded with thermocompression methods. Gold wire can be boded to NiB only by thermal-sonic techniques. Some electroless nickel-phosphorus deposits with 10-11% phosphorus by wt. can also be wire bonded using these techniques. However, it seems to be more difficult to find the correct operating conditions of temperature and energy (more pressure) than bonding to gold.

"Metallized" refers to conductive mounting pads and circuit traces that have been "silkscreened (patterned) onto the ceramic with a conductive molybdenum, moly-manganese, or tungsten past or a glass-metal frt. The metallization is fired to cure and harden onto the substrate. The metallization can be applied onto pre-cured ceramic and then fired or applied onto uncured ceramic and both materials fired together ("co-firing"). The metallized areas are often plated with electroless nickel to improve their conductivity, die and wire bendability, and solder ability. In some cases, where the hybrid will not be exposed to great thermal shock, it is possible to plate electroless nickel directly onto the ceramic using proprietary preparations and plating chemicals, thus eliminating the expensive frit.

The thermal coefficient of expansion (TCE) of various ceramics closely matches the TCE of Kovar and other metals and alloys used in the electronics industry. This means that during "burn-in" testing or high-temperature operations there will be no mechanical stress in connections or between the substrate and metallization due to mismatched thermal expansion. Ti provides improved component mounting and interconnection reliability in this application, and also reduces variation in inherent circuit capacitances that can become a design nuisance. The minimal thermal expansion also enables very fine, closely spaced circuit lines to be used without fear of failure by cracking during stress.
Ceramic materials are easily machined and drilled to tight tolerances in both relatively soft and uncured state, called the green state, and the final fired or cured state. Ceramic materials contract by about 17% during firing, so machining and punching operations performed prior the firing must take this dimensional change into account. The cured ceramic is easily cut and drilled by laser and machining for precision. Through-holes and circuitry can even be added after fabrication by these methods to alter or customize circuitry.

The case of manufacturing multi-layer circuits with ceramic materials allows complex and numerous interconnections to be made within a small area. These circuits are not easily accommodated on single-plane substrates and would require large surface area and some hard-wiring. PC boards can also be multi-layered, but each layer must be manufactured and then laminated together. Multi-layer PC boards also presents difficulties with plating through-holes (interconnections between board layers). These holes must be plated with a conductive material (usually electroplated copper over electroless copper, poor throwing power of the electroplating baths may not provide adequate plating thickness and continuity, especially if the through-holes of high aspect ratio (small diameter compared to depth of hole). Electroless nickel has been used to overcome the high aspect ratio successfully, but the resistivity is little higher than that of copper. These problems can be eliminated with ceramic hybrids. Ceramic layers can be formed, fired, metallized and then laminated together, but can also be formed metallized and layered in the uncured state and the entire package furnace-cured at the same time (co-fired). The thickness of ceramic layers is less than PC boards, and the through-holes are not plated but metallization past screened into them to completely fill the hole and form a solid conductor. The completed and fired multi-layer substrate contains buried layers of complex wiring and interconnecting through-holes in a compact package of exceptional reliability.

Another advantage of hybrid technology is that resistors can be made by screening a known area of substrate with a metallizing paste of known resistance. These resistors can be laser or abrasive trimmed after manufacture to fall within specified tolerances. Capacitors can also be manufactured and trimmed in the same manner by applying metallization areas that are insulated by layers of the ceramic dielectric. The high dielectric constant of ceramic materials allows thinner spacing between capacitor conductors to produce the specific characteristics in a smaller area.