LPKF Laser & Electronics Application Report

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Multilayer prototype and series production

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The Author:

Klaus-Dietmar Müller studied electrochemistry and electrical engineering at the Technical University, Ilmenau, (Germany) and graduated in 1982 following research into sulfuric acid copper electrolytes. From 1982 to 1983 he was employed at the Zentrum für Forschung und Technologie der Mikroelektronik [Micro-Electronics Research and Technology Center], Dresden, working in the field of galvanic mask production. From 1983 he worked in the fields of electroplating, environmental protection/wastewater treatment, metalization and vacuum deposition. Since 1996 he has been responsible for the technical supervision of circuit board prototyping processes and metalization at LPKF Laser & Electronics AG in Garbsen.

What are multilayers?

Multilayers, or multilayer PCBs, are circuit boards made up of several (more than two) electrical layers (copper layers) superimposed on one another. The copper layers are bonded together by resin layers (prepreg).

What manufacturing processes are available?

Multilayers are produced by bonding together inner layers and outer layers with prepreg. Prepreg is fiber-glass fabric impregnated with partially hardened resin. The individual layers must be arranged in a pressing tool to prevent misalignment of the layers. Following bonding, the bonded layers are further processed as double-sided through-plated circuit boards. However, additional hole wall cleaning is required before through-hole plating can take place. The outer layers may consist of either copper foil and prepreg or of single-sided or double-sided copper-clad laminates. The inner layers consist of double-sided copper-clad, etched (structured conductor tracks created) and through-plated board material. The surface area of the copper must be increased by micro-etching and subsequent oxidation to improve bonding between the inner prepreg and copper layers. Immersion tinning may be used as an alternative to oxidation. However, the impedance values of the additional metal layer formed are different from those of copper inner layers formed by standard oxidation.

How does bonding take place?

In principle there are three methods of forming multilayers. These are described below using a 4-layer multilayer as our example:

- Two double-sided copper-clad laminates (cores) with prepreg in between. One double-sided copper-clad inner layer, at least two prepregs and two single-sided copper-clad laminates or laminates coated on both sides where one copper side is fully etched away.
- One double-sided copper-clad inner layer with at least two prepregs and copper foil.

Construction using prepregs and copper foil to create the outer layers (the copper foil technique or MassLam technique) is the preferred construction method because of its lower cost.

Bonding may be performed in a hydraulic press or in an overpressure chamber (autoclave). In the case of hydraulic presses, the prepared material (press stack) is placed in the cold or preheated press (170 to 180°C for material with a high glass transition point). The glass transition temperature is the temperature at which the amorphous polymers (resins) or the amorphous regions of a partially crystalline polymer change from a hard and relatively brittle state to a viscous, rubbery state.

The bonding pressure is 150-300N/cm^2. The curing temperature and time must be selected according to the type of prepreg used, the number of layers and the thickness of the press stack.

In the case of overpressure chambers (autoclaves), gas or oil is used to convey the compression force and heat to the press stack. The press stacks are placed on platforms in the tiered stand that has a vacuum connection and are vacuum-sealed in temperature and pressure-resistant foil. Once the pressing chamber is loaded, it is closed and the inert gas or oil is introduced into the chamber. The isostatic pressure (pressure exerted evenly in all directions) for bonding is 80 to 200 Newton/cm^2.

In contrast to hydraulic press, different press sizes may be bonding simultaneously in an overpressure chamber. The advantages of this method of bonding are improved heat transmission and a more favorable thermal time gradient. The all-round application of pressure has a particularly positive effect on the multilayer stack. It prevents resin flow – the main cause of stresses in the fiberglass fabric. Dimensional stability, torsion/warping and thickness tolerance are significantly improved if stresses of this nature are not generated. Furthermore, no resin deficiencies will be found within the board. A lower bonding pressure is required for vacuum bonding (vacuum chamber press, vacuum frame or vacuum autoclave). Fewer stresses are generated in the multilayer with the lower bonding pressure. This gives considerably better dimensional stability of the inner layers, improved thickness tolerance and reduced inner layer misalignment. Because the melting point is lowered in a vacuum, volatile components, including air and moisture, are removed from the press stack and virtually void-free multilayers can be achieved.

What are the particular features of the production of inner layers and the use of copper-clad outer layers?

The copper surface area of the inner layers must be increased by microetching and subsequent oxidation to improve bonding between the prepreg and the inner copper layers.

A registration system is required to achieve precise alignment of the several copper layers bearing a layout in a multilayer during bonding. This registration is done using locator holes drilled in the production board or in the individual layers. An exception to this is the „floating„ bonding process used for 4-layer multilayers. This involves bonding the inner layer with prepregs and copper foil in the same way as an outer layer. The locator holes for drilling the multilayer are then obtained by milling and drilling the targets (registration marks) on the inner layer.

How can typical faults be avoided or reduced?

In general, the warp direction of the fabric material used for the laminate (e.g. fibre-glass fabric) should run parallel to the longer side of the laminate because the warp direction is subject to definite shrinkage after bonding. This distorts the layout (and is also characterized as variable or low dimensional stability).

However, warping and torsion of the multilayer can be minimized by improving the design. Torsion and warping are reduced by even distribution of copper over the entire layer and by ensuring symmetrical construction of the multilayer (i.e. the same order and thickness of prepreg, copper and laminate layers should be present from the center of the multilayer layers to both outer layers). The prescribed minimum distance (dielectric thickness) between two copper layers is = 0.089 mm. The rule of thumb for calculating the minimum distance states that the minimum thickness of the prepregs after bonding must be at least twice the thickness of the copper being embedded. In other words, where you have two adjacent copper layers, each of which is 30 µm thick, a minimum prepreg thickness of 2 x (2 x 30µm) = 120µm is required, which can be achieved by using two 1080 prepregs (1080 is the type of fiber-glass fabric). The cooling rate for bonding multilayers must be as slow as possible as too great a temperature gradient within the press stacks gives rise to varying rates of shrinkage between the outermost and innermost layers in the press stack, thus causing distortion in the multilayers. In extreme circumstances, the press's cooling system may be switched off so that the multilayers take 12 or more hours to cool down (e.g. metal-core multilayers). Before the drilled multilayers can be through-hole plated, hole wall cleaning must be performed as the action of drilling can heat the resin to above the glass transition temperature, allowing the resin to soften and be smeared over the end face of the inner layer copper by the drill bit. This smear layer must be removed so that copper is present not only on the wall faces and so that contact between the inner layers is not impeded in any way. This thickness of the smear is generally 2-6 µm; however, it may be as thick as 12 µm if the drilling parameters are not selected properly. Chemical processes or plasma de-smearing may be used to perform hole wall cleaning. Three-stage cleaning with permanganate is the most suitable and widespread of the chemical processes available.

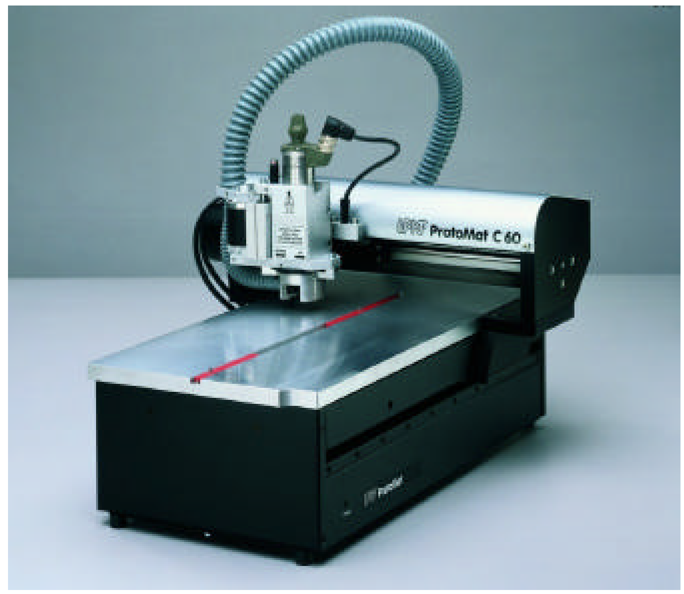
Processing microwave substrates in multilayers

Prepreg materials with low relative dielectric constants are suitable for use in radio frequency and microwave engineering. The low dielectric constant gives rise to a low signal delay at radio and microwave frequencies. Electrical losses are minimized by low loss factors in the substrates.

Prepreg RO® 4403 is a new material produced by ROGERS CORPORATION (http://www.rogers-corp.com/mwu/index.html). This material is compatible with other substrates (such as RO 4003 or RO 4350, used for microwave boards) used in the construction of standard multilayers (FR-4 material).

Which production method can be used for prototyping?

Floating bonding in a hydraulic press is ideal as a cost-efficient process for prototyping multilayers (4-layer) and does not require expensive equipment. The inner layer carrying the layout and registration marks is bonded with prepregs and copper foil as an outer layer. The locator holes for drilling the multilayer and the layout for the outer layers are obtained by milling and drilling the registration marks (inclusion of registration and locator holes to ensure perfect alignment of the inner and outer layers, including the holes for through-hole plating). This is followed by the creation of the layout for the outer layers, drilling and through-hole plating of the multilayer. Computer-controlled systems, such as the LPKF MultiPress II, enable highest-quality floating bonding of 6-layer multilayers to be carried out within your own laboratory, due in no small part to the fact that the cooling phase can be monitored and performed under pressure.



LPKF ProtoMat C60 -
Circuit board plotter for in-house PCB prototyping

Technology for prototyping multilayers

The general technique used for prototyping is the same as that commonly used in the production of multilayer construction. It is possible to make a few modifications since prototyping is generally only used for small and sample runs rather than large-scale series production. Oxidation of the inner layers and de-smearing of the holes is not absolutely necessary for prototyping. Best possible prototyping may be achieved using a suitable process for bonding and through-hole plating.

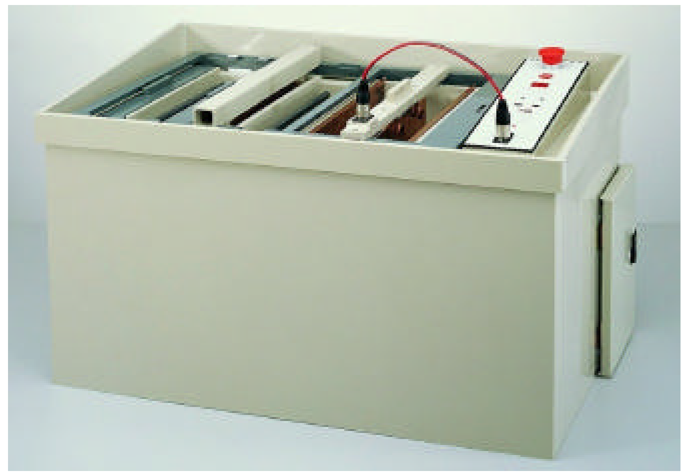
LPKF MultiPress II -
Lamination press for in-house multilayer prototyping

The milling-drilling process developed by LPKF (http://www.lpkfcadcam.com) is particularly suited to the creation of conductor tracks, enabling fully independent production of multilayer circuit boards within your own laboratory. Product development cycles are thus shortened enormously and prototype production is no longer dependent on a supplier.

Bonding technology for prototyping

The recommendations made by ISOLA for prepreg 2125 (AT 01), for example, are a main bonding temperature of 180°C, a main bonding pressure of 150 N/cm2 and a main bonding time of 60 minutes. The cooling phase in the press begins when the heating is switched off and the lasts a minimum of six hours. The long cooling phase prevents resin smearing during drilling. Furthermore, the de-smearing process can be omitted from the through-hole plating process if prolonged cleaning is carried out during through-hole plating. The prepreg material RO 44039® for microwave engineering produced by ROGERS Corp. can be bonded with other RO 4000 substrates produced by ROGERS Corp or FR-4 material at a main bonding temperature of 180°C, a main bonding time of 90 minutes and a main bonding pressure of approximately 300 N/cm2.

Through-hole plating multilayers in prototyping



LPKF MiniContac - Electro plating system

The use of „direct„ metallization to create the electrical connection between the various conductor track layers in the multilayer through holes in the multilayer is an environmentally friendly process. Once the holes have been cleaned and coated with carbon particles or palladium (which have no impact on the environment), metallic copper is deposited from a solution of copper salts in sulfuric-acid, to which an electrical current is applied. This copper acts as a connector element between the various conductor track layers and as reinforcement of the external conductor tracks. In the case of some substrate types, through-hole plating for microwave engineering can be performed using the standard process of direct metalization. Some types of substrate require an additional etching process as part of the standard direct metalization process. However, user-friendly etching processes are available. Prepreg RO 4403 produced by ROGERS does not require de-smearing before through-hole plating. Multilayers constructed from RO 4403, RO 4003 or RO 4350 can be through-hole plated using conventional methods.

Cross section of a 6-layer board made with LPKF prototyping equipment.

Laboratory systems, such as LPKF's MiniContac and Contac, are available for through-hole plating multilayer prototypes. These types of systems are based on the familiar black-hole process and are very low-maintenance and display long-term stability. Bath analysis is required once a year only and these systems make professional multilayer through-hole plating possible in your own laboratory.

LPKF Laser & Electronics

LPKF Laser & Electronics is a wholly owned subsidiary of LPKF Laser & Electronics AG of Garbsen, Germany, a publicly traded company. Founded in 1976, LPKF has established itself on the international market in the fields of advanced circuit board prototyping, SMD stencils and high-density circuit board designs, eliminating the need for hazardous chemicals. Their revolutionary MicroLine laser circuit structuring processes are transforming the design of smaller, lower cost, higher-performance products for telecommunications, computing, medical, video and measurement applications.

LPKF high precision circuit board plotters, multilayer devices and plating systems have become the standard of the industry with more than 8,000 installations worldwide. The drilling and milling process is simple, safe and economical. High precision tools and superior mechanical design turn circuit designs into holes and traces on a card by removing material. A typical multilayer card can be produced within on work day for $15 to $20 in materials and tools.

Sources:

Huschka, M.: Leiterplattentechnik in Frage und Antwort [Circuit board technology – Questions and answers]; Eugen G. Leuze-Verlag 1993

Herrman, G.: Handbuch der Leiterplattentechnik, Band 3 [Manual of circuit board technology, volume 3]; Eugen G. Leuze-Verlag 1993

Company Manual for the MultiPress® by LPKF Laser & Electronics AG

Company Manual for the MiniContac® by LPKF Laser & Electronics AG