Fig. 6.12 300 x SEM micrograph of developed via formed in fired Q42DP after Reference 14. (Courtesy of Du Pont)

The main properties of the dielectric are:

via diameter	0.15 mm
dielectric constant	K = 9-11
dissipation factor	tan δ = 0.2%

All processes applied in diffusion patterning except development are from standard thick film technology. In return, misaligning of the second dielectric print is eliminated, flow of the dielectric occurs just once for the given layer and the properties of the image paste give an opportunity to obtain well defined vias of small diameter.

Those who wish to achieve even smaller diameters of vias and better line resolution conductors may apply thick film technology aided by photolithography. However, here the technology arrangement is somewhat different. All pastes of the system are applied by screen printing. To produce fine line resolution (small vias) photolithography must by carried out. Thus, all the pastes need to be photoimageable. This means that they should be based on organic vehicles sensitive to UV light. A printed layer of such a paste, irradiated with UV light through a mask and properly developed with aqueous Na_2CO_3 solution, gives, after firing, a very fine pattern with very sharp definition of the edges. This is an advantage in certain applications, especially in microwave devices.

The Fodel thick film photoprintable system includes a dielectric paste, Du Pont 6050, with the following main properties:

via diameter	75 μm
dielectric constant	K = 7-9
dissipation factor	0.4%
typical conductor line resolution	40/40 μm-50/50 μm[15]

Minalgiene[16] reports a similar system of photoimageable pastes named Saule with even better properties.

6.4.2.2 Low Temperature Cofire Ceramic (LTCC)

As stated above, unfired ceramic foil can be utilised to produce multilayer structures. The foil, commonly called green tape, is composed of ceramic powder and a temporary binder (organic resin) which makes the foil flexible but solid enough to handle. All conductors are printed and dried in parallel on the foil. The separate sheets of foil with conductive pattern are stacked and fired in one process.

Historically, earlier, High Temperature Cofire Ceramic, HTCC, used alumina green tape layers which required firing at high temperatures (above 1500°C) to become a uniform and reliable dielectric insulator. To produce interconnections, refractory metals (e.g., tungsten) were used. These had to be fired in a reducing atmosphere (N_2/H_2). This technology allows for parallel processing and leads to uniform and very reliable dielectric isolation of high layer count circuitry. However, the refractory metallisation reduces electrical performance and requires complex and expensive processing.[17]

LTCC combines the benefits of HTCC and thick film technology.[17, 18] The system is composed of a glass-ceramic tape with a shrinkage characteristic which upon firing, at the temperature of 850°C common to thick film materials, provides a dielectric layer that is well matched to high performance conductors. It offers parallel processing, uniform and very reliable dielectric isolation of high layer count circuitry, as well as high performance conductors and relatively inexpensive processing.

Figure 6.13 presents the concept of an LTCC multilayer circuit containing: conductive lines, pads and vias, resistors – both on the surface and buried, buried capacitors, and thermal vias. A complex set of materials is required to manufacture such a multilayer. All the pastes used – conductive, via filling and resistive – must match the X, Y shrinkage of the green tape.

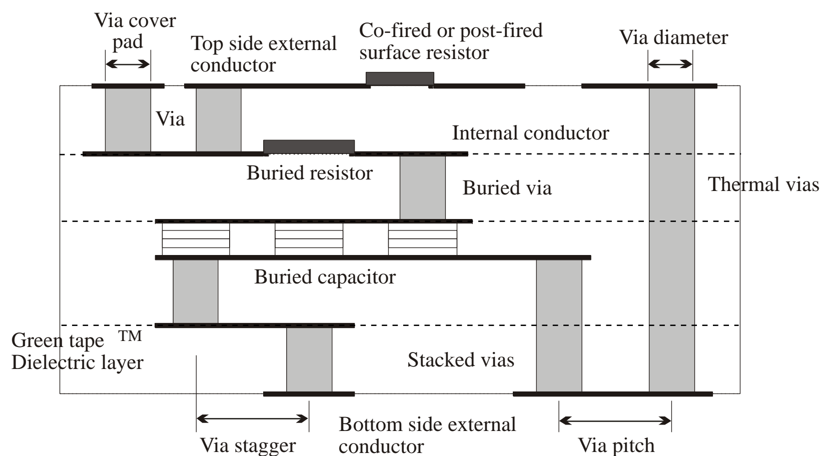

Fig. 6.13 The concept of LTCC multilayer circuit, after References 18 and 19. (Courtesy of Du Pont)

To perform LTCC technology, some operations must be added to standard thick film technology, for example via formation (punching), stacking and pressing. This requires additional equipment and tooling, such as a punching machine, a screen printer equipped with a porous stone plate, precise aligning devices, a uniaxial or isostatic lamination press, and a laser machine for cutting green or fired tape.

The firing profile of LTCC differs from the profile for standard thick film dielectric layers. An example of such a profile is shown in Figure 6.14. It varies according to the application (e.g., number of stacked layers). In any case, in order to remove relatively large amounts of organic substances, firing of LTCC requires a dwell at a temperature around 400°C.

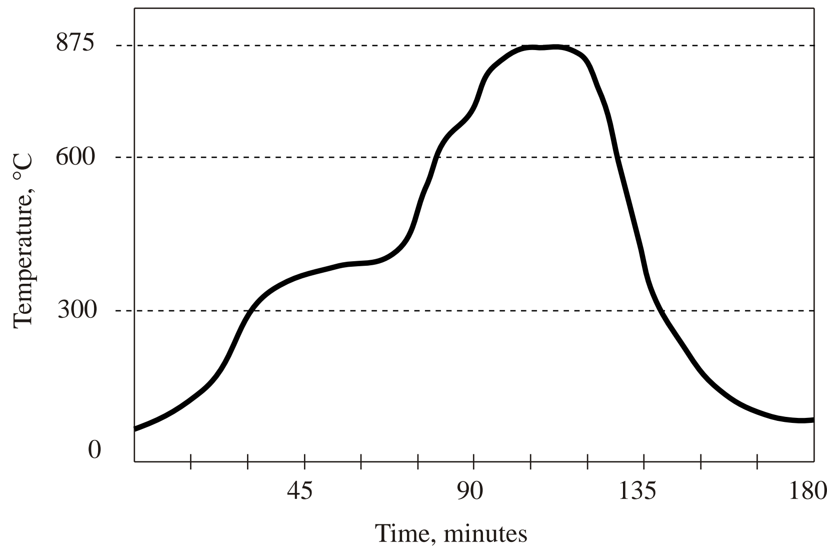

Fig. 6.14 An example of a firing profile for Du Pont green tape 951 after Reference 19. Other producers offer green tape requiring more complex firing profiles.

LTCC material systems are available from several manufacturers including Du Pont, ESL, Ferro and Heraeus. In general, tape manufacturers offer more than one brand of tape. For example, tapes coming from the same manufacturer may be of three or four different thicknesses in the range from 100 to 350 μm. X,Y shrinkage of the tapes is in the range 12-15%, whereas Z shrinkage is 15-17%. Normally, round vias are recommended with a diameter of 125-250 μm, and spacing (via pitch) of 300-500 μm. Most of the tapes exhibit a dielectric constant of 7-9 after firing, a thermal conductivity of 3.0-4.3 $Wm^{-1}K^{-1}$ and thermal coefficient of expansion 5.8-6.7 x $10^{-6}K^{-1}$. The recommended circuit size is up to 5 in. x 5 in. (125 x 125 mm) with 10-80 layers.

Table 6.2 presents more details of the basic properties of selected green tape products from different manufacturers (see Bibliography).

Table 6.2

Basic Properties of Green Tape Products from Different Manufacturers

	DuPont DP 951	*Heraeus CT700*	*ESL 41110-70C*	*Ferro A6-M*
Properties – Unfired				
Thickness [μm]	114 165 254	130 200 300	100-130	127 254
Shrinkage (X, Y)	12.3	14.4	13.9	15.0
Shrinkage (Z)	15.0	14.9	16.0	24.0
Properties – Fired				
Electrical				
Dielectric Constant	7.8	7.5-7.9	4.3-4.7	5.9
Dissipation Factor [$x10^{-3}$]	1.5	2.1	4.0	2.0
Insulation Resistance [Ω]	10^{12}	10^{12}	$>10^{12}$	$>10^{13}$
Breakdown Voltage (V/25 μm) [V]	>1000		>1500	5000/layer
Physical				
Thermal Expansion (25-300^{0}C) [ppm/K]	5.8	6.7	6.4	7
Density [g/cm^3]	3.1	3.2	2.3	2.45
Thermal Conductivity [W/mK]	3.0	4.3	2.5-3.0	2
Flexural Strength [MPa]	320	240		>170

Execution of LTCC technology requires careful selection of materials other than green tape. They may be divided into two groups:

– co-fired – specially formulated to be fired at the time when the green tape (the package) is fired;
– post-fired – those that are applied on already fired green tape and then fired.

The major rôle is played by conductors. Apart from pastes for producing inner conductive lines, there are conductive pastes for via filling, for co-fired top layer conductors, and for post-fire conductors which may be wire bondable, etc. There are other pastes that are specially designed for LTCC technology, such as materials for post-fire resistors, overglazes and brazing, as well as for embedded components (resistors, capacitors, etc.). However, the latter are, at the time of writing, mainly under development. Manufacturers provide their users with a guideline for proper selection of LTCC materials. The properties of the conductors compatible with green tape, shown in Table 6.3, do not differ greatly from those used on traditional ceramic.

Table 6.3

Properties of Conductors Utilised in LTCC Technology

	Au	*Ag*
Inner conductors		
– line resolution [µm]	100-150	100-150
– thickness [µm]	6-10	7-12
– resistivity [mΩ/square]	5-10	~3
Via filling conductors		
– diameter [µm]	100-250	100-250
– resistance [mΩ/via]	5-15	3-10
Post-fire conductors		
– line resolution [µm]	100-150	100-150
– thickness [µm]		10-15
– resistivity	5-10	3-8
– solderability	-	+
– wire bondability	+	-

Silver based, post-fire conductors are also offered in mixed metal versions (e.g., Pd/Ag or Pt/Ag) for better leach resistance. Similarly, mixed metal conductors are available (e.g., Au/Pt) to permit a soldering process within Au conductor systems.

6.4.2.3 The effects of faulty firing conditions

Concluding the firing process, it is worth mentioning that the dielectric layers – crossover and overglaze – exposed to lack of control of firing conditions may exhibit non-standard behaviour.

The Du Pont Process Guide[20] lists the following cases:

Poor burn-out
– blistering (particularly over conductors);
– high porosity;
– low K values;
– high dissipation factors (DF) values
– low breakdown voltage;
– discoloration.

Halogen contamination
– unusual fired appearance of overglazes (rough, matt, porous structure);
– slight discoloration of crossover;
– inferior electrical/environmental performance.