Next Generation Ceramic Multilayer Systems

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Abstract

Conventional screen printed multilayer systems are not capable of producing the high density circuits required for the next generation of circuits. Present photo patterned multilayer systems do not have the wide range of material options of the conventional screen printed systems. To meet the ever increasing demand for higher circuit density and circuit performance, next generation multilayer systems with advanced patterning techniques were developed using a crystallizable glass technology with proven reliability and performance. A diffusion-patterned dielectric that images 125 micron vias is coupled with a complete material system of conductors and resistors. For circuits that require higher density 75 micron features have been produced with a photo-imaging dielectric and photo-imaging conductors. Increased circuit density for a conventional screen printed multilayer was demonstrated by integrating the conventional multilayer circuit with a top layer photo-imaging dielectric and gold. Discussed are process strategy options for automotive, military and commercial applications.

Key Words: Multilayer process strategies, Ceramic-filled crystallizing dielectric, Diffusion Pattering™ process, Photo-imaging, Photopatterning, Fodel® process.

Introduction

A thick film material system must provide the density, reliability, electrical and mechanical properties for present and future circuit designs at a cost that is competitive with other technologies.

Previous papers have described an advanced thick film system for producing multilayer circuits (QM44 system) using screen printing. Lower-cost processing was made possible through the use of a ceramic-filled, crystallizing dielectric where the filler loading and crystallization kinetic are controlled to optimize electrical and mechanical properties. Use of the dielectric system reduces process steps through the substantial use of cofiring and reduced number of dielectric and via fill prints between metal layers [1].

Current screen printing techniques are not capable of producing vias smaller than 200-250 microns (8-10 mils) in high yield when a circuit is built in high-volume production. Given that there are printing techniques that can produce conductor lines and spaces of 100 microns [2], a via that is 200 microns in diameter represents a design limitation to future applications.

This paper describes processes that extend via resolution capability of QM44 dielectric down to that currently achievable with conductor technology, as well as providing an update of the standard QM44 system. Three versions of the advanced ceramic-crystallizing dielectric system, on which QM44 is based, have been formulated. QM44H, a higher viscosity version of QM44, now the standard screen printable material, Q44DP which is chemically patternable using the Diffusion Patterning™ (DP) process [3, 4] and QM44F which is photo-patternable using the Fodel® process [4, 5]. These additional dielectric formulations extend the system capability well beyond its original objectives, and by integrating the process strategies of the systems

based on a single dielectric chemistry, functionality,

Process Strategies

Examples are provided in Table 1 below. Alternative conductor technologies (vertical or y-axis) have been matrixed with the three QM44 formulations (horizontal or x-axis).

Table 1
High-density Interconnect Process Strategies

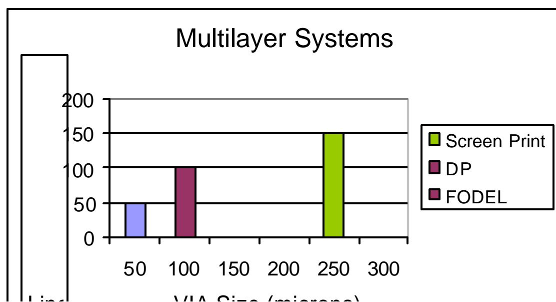
Photo-formed	FODEL® Conductors on screen printed dielectric	FODEL® Conductors on Diffusion Patterning™ dielectric	FODEL® Multilayer System
Etched	Au etched on screen printed dielectric	Au etched on Diffusion Patterning™ dielectric	Au etched on FODEL® dielectric
Screen Printed	Screen printed Multilayer System	Diffusion Patterning™ Multilayer System	Standard conductors with FODEL® dielectric
	Screen printed	**Chemical diffusion**	**Photo-formed**

Dielectric via size and conductor line pitch of the screen printing, DP and photoimaging processes are shown in Fig 1. The highest via and line density is achieved with the photoimaging system, however at a higher process cost than screen printing and DP.

The challenge for design engineers is to use the system by themselves or to combine process strategies to maximize circuit function for the highest productivity and lowest cost. Design engineers are the most capable of finding the best optimization schemes for their circuit applications.

Figure 1. Process Resolution Capability

Design and performance modeling studies have



yield, reliability and cost can be optimized.
been published for photo imaging, DP and LTCC (Green Tape™) [6, 7, 8].

A conventional screen printed multilayer system can be integrated with the more advanced process strategies, DP and Fodel® to optimize productivity, cost and circuit density. Advanced screen printing, which is capable of 125 micron lines and spaces, is used in combination with DP to produce 125 micron diffusion patterned vias. An integrated design strategy was demonstrated for a four conductor level multilayer circuit, by processing the initial three conductor levels using advanced screen printing and using photoimaging as the top dielectric and conductor. This new Fodel® system can also be used for custom designs over Green Tape™ (LTCC).

Multilayer – Screen Printed System

Conventional screen printed mutilayer systems require as many as 6 print, dry, fire steps between each conductor level. A new advanced screen printed QM44H system reduces the process steps between conductor levels to 4 prints and 2 fires. The reduction of process steps is accomplished by fewer dielectric prints and a co-fire strategy as shown in Table 2.

Table 2 Process Steps Screen Printed Systems

QM44H cofire build versus standard build			
Conductor Layers	Standard Build	QM44H Build	Steps Eliminated
2	7 prints 7 firings	5 prints 3 firings	2 prints 4 firings
3	13 prints 13 firings	9 prints 5 firings	4 prints 8 firings
4	19 prints 19 firings	13 prints 7 firing	6 prints 12 firings
5	25 prints 25 firings	17 prints 9 firings	8 prints 16 firings
6	31 prints 31 firings	21 prints 11 firings	10 prints 20 firings

An advanced ceramic crystallizing dielectric, along with specially formulated conductors and via fill compositions, make the cofire strategy possible. One key feature of the QM44H dielectric is high breakdown voltage with only two prints of dielectric with a fired thickness of 30 +/- 2 microns. The

dielectric properties and reliability for the screen printed QM44H system, are similar to the previously presented QM44 system, since the crystallizable glass chemistry is the same. The broad conductor compatibility with silver, gold, and the mixed metal resistance to blistering and shorting are essential features of the system [9]. The print resolution for printing vias with the QM44H dielectric is 250 microns, using a conventional 280 - 325 mesh screens with 8 microns emulsion.

The conductors and via fill compositions for the QM44H system were designed to be cofired to reduce the number of firing steps. The other components to the screen printed, QM44H system are shown in Table 3.

Table 3
Screen-printed System Components

	Silver System	Mixed metal system	Gold system
Dielectric	QM44H		
Top conductor	**Ag/Pt** QM18 **Ag: Pd (co)** QM22 (3:1) QM26 (6:1) **Ag:Pd (seq)** QM24 (6:1) QM25 (3:1)	**Au (co)** 5771 QG150 5775 4597 (solderable)	**Au (co)** 5771 QG150 5775 4597
Inner conductor	**Ag/Pt (co)** QM17 **Ag (co)** QM14	**Ag/Pt (co)** QM17 **Ag (co)** QM14	**Au (co)** 5771 QG150
Inner via fill Top via fill	**Ag (co)** QM34	**Ag (co)** QM34 **Ag/Pt (co)** QM35	**Au (co)** 5747
Resistors	S1X0	S1X0	S1X0

Table 4 shows the typical physical and electrical properties of the QM44H system. 280 - 325 mesh screens were used to print the dielectric and conductors. The conductors were cofired with the 2nd print of dielectric at 850°C /10min. peak.

A further addition to the QM44H system is a cofireable Ag/Pt conductor. Aged adhesion for the new low resistivity (5 mili ohm/sq.), Ag/Pt conductor, QM18 cofired on QM44H dielectric is shown in Figure 2.

Table 4
Typical Fired Properties QM44H

Physical	
• Total Fired thickness	30 ± 2 microns
• Via Resolution	250 microns
• Max. no. circuit layers	<8
• Camber: 5”x1” substrate with 5 circuit layers	<2 mil/in
Electrical	
• Dielectric Constant at 1 MHz	8-10
• Dissipation Factor at 1 MHZ	<0.2%
• Leakage Current at 10 VDC	<1 u /A.cm ²
• Insulation Resistance	>10^{12} at 100 VDC
• Breakdown Voltage	>1000 V/25 um
• EMF Blister Resistance	> 30 firings

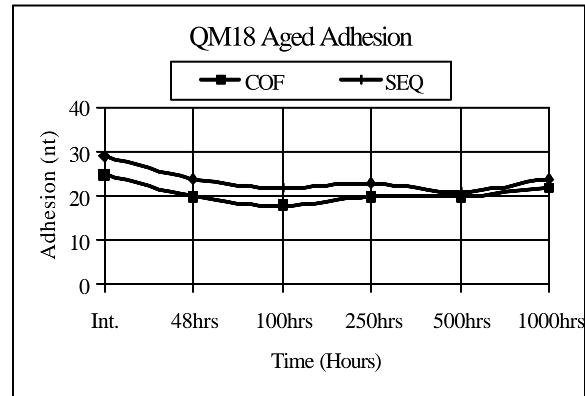


Figure 2. Adhesion of QM18 on QM44 following storage at 150°C

Multilayer - Diffusion Patterning™ System with Advanced Screen Printing

Although sequentially fired the Q44DP dielectric has all the advantages of the QM44H mutilayer system. The system consists of Q44DP, dielectric and Q95IP, Imaging Paste. The conductors, resistors and via fill compositions used for the DP system are shown in Table 5. The dielectric is diffusion

patterned, but the conductors, resistors and via fills are screen printed.

The DP system is capable of creating 125 micron diameter vias. The via size capability matches with the line resolution capability of the advanced screen printed conductors. Advanced screen printing requires the optimization of the rheology of the conductor composition, the wire and emulsions of the screen and the printing process. Screens with high tensile wire, small wire diameter (16 to 20 microns) and advanced emulsions are used to print 100 to 125 micron lines and spaces. The advanced screen printing process is capable of printing 100 micron lines and spaces in volume production [2]

A new double print silver/platinum, QS300, is a high yield interlayer conductor for the DP system. The conductor was double printed with a 350 mesh screen with 16 micron wire and 8 microns of emulsion. The first conductor was printed and dried. The second conductor, overprint, was printed, dried and fired. The conductor processed with advanced screen printing has exceptional high yield as seen in Figure 3.

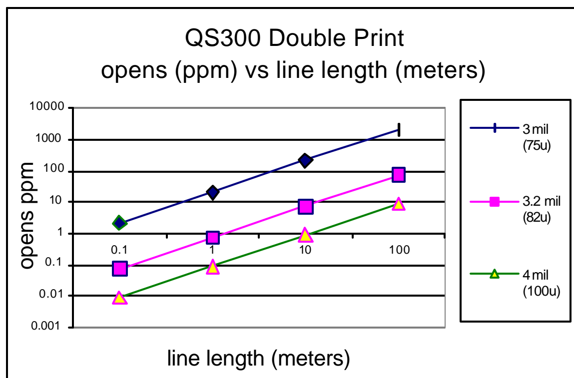


Figure 3 QS300 Yield

The basic chemistry for imaging vias by DP is shown in Figure 4. Dots of via imaging paste are printed on the dried Q44DP dielectric. The image paste, Q95IP, contains base [OH-], the dielectric, Q44DP contains an acrylic polymer [H+].

Regions where the dielectric and the imaging paste meet are the reaction zones, which become water soluble, allowing vias to be formed. The areas where the dielectric and the imaging paste are not in contact remain water insoluble. After the imaging

Table 5 DP System Components

	Silver System	Mixed Metal System	Gold System
Dielectric	Q44DP		
Top Conductor	**Ag/Pt** QM18 **Ag/Pd** QM25 (3:1) QM26 (6:1)	**Au** 5771 QG150	**Au** 5771 QG150
Double-print conductor	**Ag/Pt** QS300	**Ag/Pt** QS300	**Au** QG150 (thin)
Inner conductors, via fills resistors	As in **Table 3**		

dots (Q95IP) are printed on the Q44DP dielectric, the diffusion temperature and time are controlled for optimum vias as shown in Figure 5. A more precise drying profile is required with smaller via sizes. [3, 4].

After the drying process, the vias are developed in a conveyor water spray developer. Table 6 shows the via developing parameters.

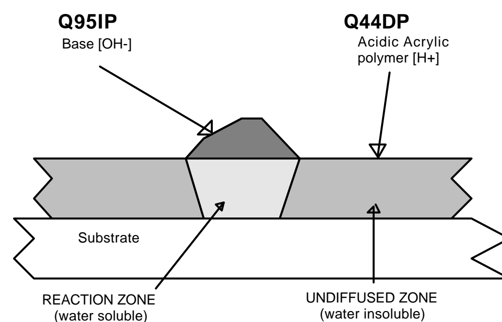


Figure 4. Diffusion Patterningä Reaction

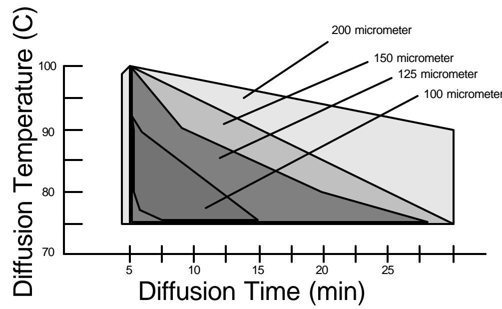


Figure 5 Q44DP Process Window

Table 6 Via Development Conditions

Water Temperature, °C	35-45
Water pH	6.5-8.5
Nozzle pressure, psi	10-25
Development time, s	8-25

Multilayer – Fodel ® (Photo Imaging)

Fodel® combines the inorganics used in thick film with photoresist organics from the PWB industry. The process to image conductor lines, and dielectric vias is photochemical. A polymerization reaction occurs when the materials are exposed to UV light through a photo-negative. The polymerized areas are “hardened” by the UV light while the unexposed areas are not changed. It is the unexposed areas that are washed away with a spray of water plus 0.8% sodium carbonate during development of the image. The general process sequence has been described in detail in several referenced papers. It is important to note that the exposure energy required for optimal polymerization of some compositions can be reduced if a post-bake step is added.

The newly developed Fodel® material system has a broader processing window than the previous system. This was accomplished by blending monomers with different polymerization rates.

The process parameters for the Fodel® compositions are shown in Table 7. The Fodel® system can be used as a stand alone technology for producing multilayer circuits or in combination with fired LTCC (green Tape) and screen printed multilayers [5].

Table 7
Process Parameters of Fodel®

Material	Ag, Ag/Pt	Au	Dielectric	Resistor
Thickness (dried, μm)	15-24	15-25	26-30	10-14
Leveling time (min.)	5-10	10	10	10
Drying time @80°C (min.)	20-25	20	12-15	12-15
Exposure time (s) / energy (mJ)	15 / 203	40 / 540	2-3.5 / 22-38.5	100 / 2450
Post bake	5min @120°C	20min @80°C	NA	10 min @80°C
Time to clear (TTC) (s)	8-12	12	8-12	8-12
Development time (x TTC)	1.3-1.7	1.3-1.7	1.5-1.7	1.3

A key feature of Fodel® processed compositions is the precise shape of line edges and via walls. The new Fodel® dielectric, QM44F, based on the proven chemistry and reliability of the screen printed version, is capable of 50 micron vias as seen in Figure 6. See Table 8 for the performance capability.

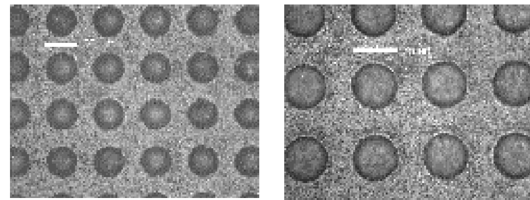


Figure 6 Fodel ® 50 and 75 Micron Vias

Table 8.
Performance Capability of Fodelâ Dielectric

Material	Fodel® QM44F	Thick Film QM44 Specifications
Via Resolution (μm)	75	250
Dielectric constant K	8.3	8 -10
Volt. Break down	1840	≥1600

@30µm (V)		
IR at 100V (xE+12)	17.4	≥1.0
Diss. Factor, dry (%)	0.1	≤0.2
Diss. Factor, wet (%)	0.1	≤0.5

The photoimageable system uses silver, silver-platinum (100:1) and gold conductor compositions capable of 40 micron lines on 80 micron pitch. The gold composition is designed to be both aluminum and gold wire bondable. The silver and silver-platinum conductors are solderable. The performance capability of the next generation Fodel® conductors is shown in Table 9. Edge curl was significantly reduced.

Table 9
Performance Capability of Fodel® Conductors

Material	Ag/Pt (100:1)	New Fodel® Au	High performance screen printed Au
Line resolution (µm)	40	40	150
Conductivity (mΩ/sq)	< 3.6 @8µm	<5 @ 10µm	<5 @ 10µm
Al wire bond (g)*	NA	5-6	7
Au wire bond (g)*	NA	11	11
Edge curl (µm)	4-10	2-5	NA

Conclusions

The proven performance and reliability of the QM44 multilayer system has been enhanced by the increased capability of DP and Fodel® dielectric versions. Coupled with advanced screen printing techniques, size limitations are greatly reduced. 4-6 mil (100-150 um) dielectric vias with DP, and 2-3 mil (50-75 um) vias and line/space dimensions with Fodel® are possible. The integration of these materials and processes provides the means for circuit designers to optimize performance, reliability and cost, while increasing circuit density. A flexible system of materials has been developed, including a full range of conductors and resistors.

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