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New State-of -Art Dry Film Technology for Fine Lines in High Yield

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Abstract
Dry film photoresist to produce highly integrated and advanced PWBs has been developed to meet more demanding fine line requirements.

Advantages for volume production of fine features below 50µm with high yield are now available with newly developed dry film photoresist that is designed to have specific features. In order to develop such a highly reliable dry film photoresist, Quality Function Deployment (QFD) helped significantly to well interpret 'Voice-Of-the-Customer' (VOC) into specific requirement of dry film photoresist performance and how it can be achieved by formulation design. The developed dry film photoresist resulted in L/S resolution and isolated adhesion better than 1:1 aspect ratio to thickness, with very wide exposure range, and with wide developing latitude

Introduction

The ever increasing need for smaller and functionally more integrated electronic devices such as cellular phones, digital devices and IC package substrates is forcing changes in circuitizing processes and materials for PWBs. In particular, dry film photoresist has been advanced to meet more demanding fine line requirements. In this paper, the analytical and technical approach for the development of advanced dry film photoresist will be discussed in detail, with a focus on the employment of QFD analysis, environmentally conscious material technology, newly designed binder polymer, monomers with controlling molecular weight, and its distribution. Fine line capability with very wide processing latitude can in this manner be realized in conjunction with extremely high reliability for fine line imaging. Furthermore, advanced new dry films for semi-additive processing (differential etching) to achieve 20 to 25µm features as needed in high-end IC package substrates is also discussed.

From Customer Needs through Product Design and Specification

During the first phase of product development, extensive effort was focused on Quality Function Deployment (QFD) that included detail interviews with major target customers in particular application and technology segment (ex. T&E fine line below 50µm) as well as down-stream customers in the value chain. It is especially important to understand the embedded need behind direct voice by hearing from down stream customers in a way that the need can be practically segregated into device functionality needs, assembly design needs, process needs in PWB house, etc. QFD is the methodology that provides a flowdown process for CTQs (Critical to Quality). The flowdown process begins with the result of the customer needs mapping (VOC) as input. From that point it cascades through a series of quality to arrive at internal controllable factors. VOC is in many cases vague and therefore needs to be broken down to 2nd level and 3rd level requirement. As the result of interviews, priority numbers are given to this 3rd level of customer needs. In the QFD "House1", many performance aspects of dry film photoresist are taken as the measures relative to this customer need and the relationship is analyzed in detail to assign a point value to each of these relationships. (See Figure 1.)

The sum of the point values assigned to each relationship, multiplied by the priority number would become the CTQ point in that particular column for performance measurement. These CTQs with regard to photoresist performance are now put into vertical columns in QFD "House2" as 2nd level cascade. In this QFD "House2", the photoresist design/formulation element is taken as the measurement relative to photoresist performance. (See Figure 2.)

At this point the kind of formulation elements that have to be considered to meet customer needs is well identified and prioritized. This analysis needs to be followed by mapping of how a particular performance of the photoresist is affected by designing related formulation elements to what extent. This would be the "House3" analysis, (Figure 3) although this aspect is not introduced in detail in this paper. "House3" analysis is important to look into trade-off of properties, because one solution to one property need at times often leads to lowering of properties in another dimension. An example is that higher resolution with wide exposure energy latitude and faster photospeed involve trade-offs.

QFD House1 (Customer Needs vs. Photoresist Performance) — Photoresist Performance / VOC(Customer needs)			1st	Imaging／Circuit patterning performance										
			2nd	Adhesion										
			3rd											
			Priority	Instant adhesion	Isolated line adhesion after developing	Isolated line adhesion with hold time after lam	Isolated line adhesion with hold time after exp.	Isolated line adhesion after etching	Isolated line adhesion at over developing	Isolated line adhesion at low exposure energy	Physical resistance for conveyer scratch	Resist physical strength after developing	Flexibility	Conformation of resist to laminate surface
1st	2nd	3rd												
High yield	Fewer nicks & cut (open)	Good adhesion												
		Good conformation												
		Wide developing latitude												
		Wide exposure latitude												
		No film chip during lamination												
		No resist sliver, nicks by conveyer												
		No resist lifting during etching												
		No resist crack during process												
		Uniform resist adhesion on entier panel surface												
	Fewer short, copper residue	Clean developing (no developing residue)												
		Clean isolated space												
		Uniform developing												
C T Q (Critical to Quality) point														

Figure 1 – House1

QFD House2 (Resist performance vs. Formulation element) — Formulation element / Resist performance			1st	Binder polymer									
			2nd										
			CTQ point in House1	Binder copolymer formulation	Aromatic % in binder polymer	Binder polymer molecular weight	Binder polymer molecular weight distribution	Solution binder vs. suspension binder	Tg of binder polymer	Acid number of binder polymer		Binder／Monomer ratio	
1st	2nd	3rd											
Imaging/Circuit patterning performance	Adhesion	Instant adhesion											
		Isolated line adhesion after developing											
		Isolated line adhesion with hold time after lam.											
		Isolated line adhesion with hold time after exp.											
		Isolated line adhesion after etching											
		Isolated line adhesion at over developing											
		Isolated line adhesion at low exposure energy											
		Physical resistance for conveyer scratch											
		Resist physical strength after developing											
		Flexibility											
		Conformation of resist to laminate surface											
	Tenting	Tenting strength after development											

Figure 2 – House2

Specifications for product X

Items	Priority	Goal	Reasonable Balance	Boundary OK	Boundary NG
Lamination					
Conformation	A	**Referance A**		Referance B	Referance C
Lamination wrinkle	A	Referance A	Referance B	**Referance C**	Referance D
Instant Adhesion	B	Referance A	**Referance B,C**	<--	Referance D
Exposure					
Photospeed (mJ/cm^2)	A	**16**	**20**	25	32
Exposure latitude	A	▵ 16RST	**▵ 12RST**	▵ 10RST	▵ 7-9RST
RST held	B	Functional, Energy, Absolute	**Functional, Energy**	Functional	-
Developing/etching					
TTC(sec.)	B	18-20	**20$^+$**	22-24	>26
BP latitude	B	**25$^-$ - 75%**	25-75%	33-75%	50-75%
Concentration latitude	B	**0.7-1.5**	0.7-1.3	0.8-1.2	0.8-1.0
Resolution (μm)	A-B	**25-3RST** **30-10RST** **40-16RST**	**25-0RST** **30-6RST** **40-12RST**	25-0RST 30-1RST 40-9RST	25-0RST 30-0RST 40-4RST
Isolated line adhesion (μm) when<40μm L&S	A-B	**30-15RST** **20-8RST**	**30-11RST** **20-3RST**	30-6RST 20-1RST	30-2RST 20-0RST
Flexbility	B	**Referance A**	<--	Referance B	Referance C
Sidewall shape	A	Trapezoid, no foot	**Trapezoid, slight foot**	Reverse trapezoid. No foot	Negative foot

Figure 3 – House3

At this point of QFD analysis, direct VOC is revisited and a technology roadmap (it usually comes from down stream customers) is considered to quantitatively understand to what level a particular performance need has to be achieved to meet customer need.

This analysis would assemble into product specification.

As the result of QFD analysis the following properties for example were identified as representing performance requirements if not all for fine line T&E, P&E segment. The technical approach for these areas for designing fine line dry film photoresist will be discussed in section below:

- Resolution and isolated line adhesion
- Conformation
- Wide processing latitude (exposure, development)

Design for Resolution

The technology roadmap (Figure 4) tells when 0.5 mm pitch CSP assembly became predominant, and circuit features with less than 60µm with SBU (build up structure) may inevitably be required. As such a fine line requirement was more advanced, resolution requirements for dry film photoresist became more demanding naturally. If we look at circuitization in production, it is a general understanding that resolution of dry film photoresist in evaluation tests needs to be 10 to 15µm better than production resolution. Therefore, in order to achieve 60µm, we designed DF resolution targeting better than 40µm throughout the working range conditions. The challenge was that this resolution needs to be achieved under various customer production conditions, which implied that it had to come together with latitude. We looked into all elements identified in QFD "House2" for designing fine line resolution by balancing properties for latitude. From a formulation point of view, higher resolution can be generally designed by having low molecular weight binder. However, it does not necessarily address the issue that resolution deteriorates during developing when DF is swollen. Introducing a hydrophobic portion in the binder polymer at a certain level dramatically reduces susceptibility of DF swell in developer while too much of it adversely affects system solubility. Therefore balancing hydrophobicity and hydrophilicity for the binder polymer in use was very important. Employing high quantum yield photo initiator is another aspect to achieve high resolution. We thus developed newly designed co-polymer and carefully selected photoinitiator and sensitizer system for this new dry film photoresist.

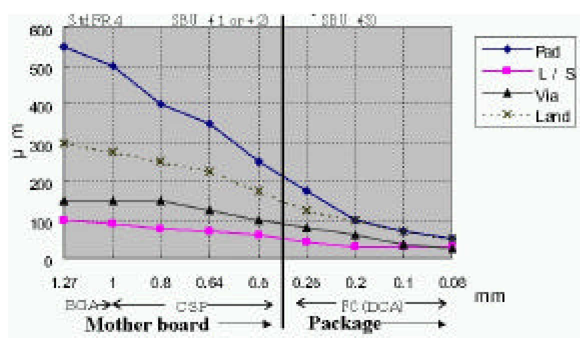

Figure 4 – PWB and Tnterposer Technology Roadmap vs. Assembly

If we look at dry film as a whole system, thinning of the resist layer is one possible approach to improve resolution. This approach has been commonly considered not only because of resolution but other drivers like productivity, and effective turn over of etching solution between resist tracks (in subtractive method). However, thinning resist would naturally lead to weaken tent strength and cause inferior conformation. Therefore, thickness optimization to best balance these properties is required. As far as outer layer T&E application is concerned, the need is higher to have thicker resist while giving good resolution, which is understandable to prevent having higher risk of though-hole void due to weaker tent. Using higher transparency PET (polyester cover film) with low scattering and diffraction is another contribution for the resolution. The new dry film photoresist we developed has better than 1:1 resolution relative to thickness. (See Figure 5.)

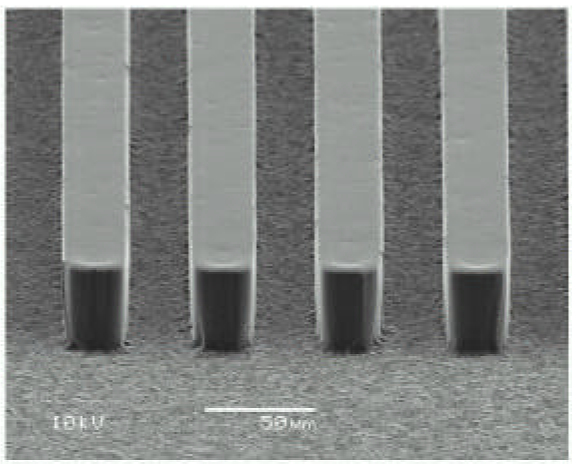

Figure 5 – 25mm L/S of 30mm Thickness Product

Isolated Line Adhesion and Exposure Latitude

Controlling conductor width is one important element to give high and consistent performance for advanced electric devices because of controlled impedance requirement for the end use. From dry film photoresist imaging point of view, minimizing resist line width variation as a function of exposure energy change is important. We need to design resist with isolated line adhesion equal to that of paired lines (L/S) under various development conditions with minimum change of width for this purpose. Designing balanced hydrophobicity and hydrophilicity for the system again is the key. As an isolated line is the most susceptible to damage from DF processing steps, designing good adhesion into the system is also important. Adhesion of the resist comes generally from two parts. One is physical adhesion and the other is chemical adhesion. One of the trends for recent surface treatment technology for fine line is micro etching with organic acid, which gives roughness at micro dimension and in this case physical adhesion is not necessarily good compared to conventional mechanical scrub. Therefore adhesion modifiers are carefully selected to compensate for this by increasing chemical adhesion. As can be imagined, isolated line adhesion becomes better with higher exposure energy. However, higher exposure energy worsens the L/S resolution and the line width becomes wider. In order to address this issue, the approach we took was to reduce photospeed. (energy vs. step held) in a way that L/S resolution and line width are not necessarily inferior at higher exposure energy. (See Figure 6.)

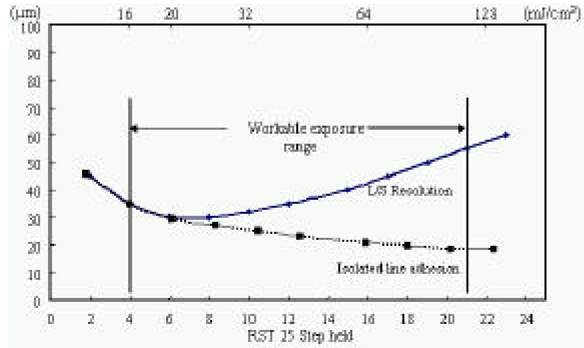

Figure 6 – Resolution and Isolated Line Adhesion and Working Exposure Range for Designed Product

Conventional resist historically had weak isolated line adhesion at low exposure energy and this was why a high step held was generally recommended. (See Figure 7.)

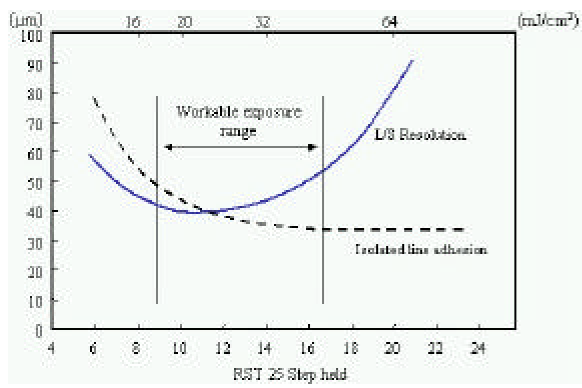

Figure 7 – Resolution and Isolated Line Adhesion and Working Exposure Range for Conventional Product

Instead, we designed resist that works at low exposure energy by giving good isolated line adhesion at low exposure energy. As a result, this new DF has extremely wide exposure latitude and photospeed is not necessarily slow because one can use low exposure energy, functionally fast photospeed.

Design for Conformation

Conformation became particularly important as dry film thickness came down due to aforesaid reasons. Generally it is highly desirable dry film property to have it properly conform to rough substrate surface, which inevitably exist. In addition, recent progress for build up technology also forces to have better conformation as its surface topological condition varies depending on technology.

Measuring viscosity versus temperature can quantitatively monitor flow characteristics of the resist. However, monitoring viscosity versus temperature does not tell the whole story because resist is exposed to external force (shear stress) during lamination. Therefore the response needs to be measured with periodic function. In this case, response (viscosity) needs to be measured at different "frequencies" and at various temperatures to predict how it behaves during lamination and during storage. In the lamination process, assuming the lamination speed is 1m/min, the time resist is exposed to pressure would be (δ/100) x 60sec assuming the width of resist contacting the roll is δ cm. At δ=1cm, this equation would be 0.6sec, which is about 1.7Hz in frequency. Practically most of the resist conformation will be completed during quite a short time and therefore we usually looked at the range of several Hz to 100 Hz. (See Figure 8.)

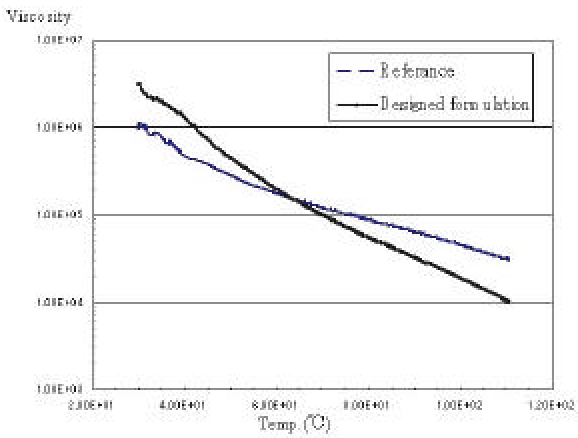

Figure 8 – Viscosity vs. Temperature at 10Hz Frequency

On the other hand, because resist squeezes out (edge fusion) during storing would occur slowly over longer periods of time, it is considered to be a change in a very low frequency range. If we look as change within 1 month, and as 1month=2.6 x 10^6sec, viscosity at the range of 10^{-6}~10^{-7}Hz would become a reference in this case. With reference to this analysis, formulation changes need to be made to give relatively high viscosity at low frequency low temperature range to address the edge fusion issue while giving low viscosity at high frequency, high temperature range to assure good flow during lamination. Conformation of new dry film photoresist is shown in Figure 9.

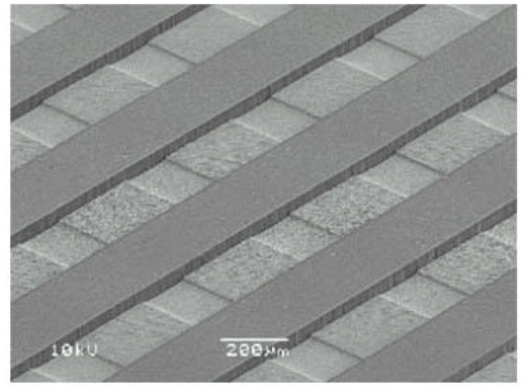

Figure 9 – Conformation of New Product for 15mm Depth Gap

Developing Latitude

In large panel format, it can happen that one area on the panel is subjected to a longer developing time than the other area. However, one would expect uniform clean development and good-paired line resolution and isolated line adhesion throughout the working panel format. This is the why customers expect dry film photoresist to have wide developing latitude. Binder polymer in dry film photoresist is the key component for developing property as it has carboxylic acid groups, which chemically react with developer solution. The higher the molecular weight of the binder, the slower the developing is and vice versa is also true. Therefore it is not difficult to imagine that binder polymer with wide distribution of molecular weight causes a wide variation of developing property. In this case there could be developing residues in some areas while the others are overdeveloping (narrow developing latitude). The solution to this problem is clear now that we developed a binder polymer with its molecular weight tightly controlled so that MW distribution is very narrow. The new dry film photoresist we developed has extremely wide developing latitude so that one can expect uniform, clean development over the entire panel surface (See Figure 10.)

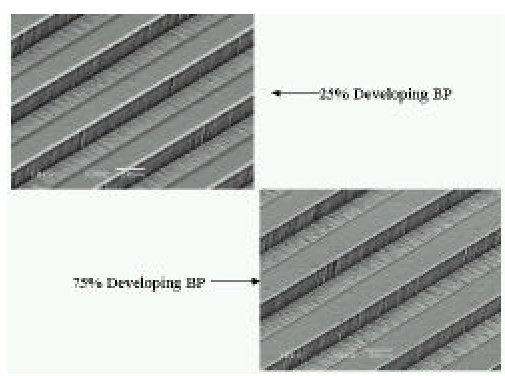

Figure 10 –Developing Latitude (Side Wall Shape) for New Product

Environmental Considerations
As environmental consciousness was highlighted in the global business context, ensuring friendliness to environment became a key task for the PWB industry as well. Many material suppliers are trying to comply with developing halogen-free materials, lead-free materials, etc. We also have been extending efforts from many aspects but we recently addressed the issue of sludge accumulation in the developer solution in the dry film photoresist process. This issue was gradually growing in importance as fine line capability of dry film photoresist was advanced and not only sludge accumulation itself but also using cleaning agents and its waste treatment became concerns for operational environment. At the early stage when this issue was raised, one of the approaches taken was to add surfactant-type of additives to the dry film photoresist system which is not a necessarily solution to prevent having sludge. Recently, newly developed material technology was patented to fundamentally solve the issue. Newly developed and introduced dry film photoresist employs this technology.

Dry film Photoresist for Super Fine Line
As shown in figure previously, as more CSPs with fine pitch packages and/or FC assemblies are employed, 15 ~20µm L/S circuit design is expected to happen in the near future. Right now, 25~30µm L/S package substrate PWB is produced in mass production for computer MPU purpose mainly, these package substrates are produced by the so called semi-additive method, differential etching. (See Figure 11.) In this semi-additive method, once dry film photoresist has the extremely high (space) resolution with clean stripping after plating, fine lines can be realized by electro-plating and flash etching after resist stripping. Therefore dry film photoresist needs to have such a good space resolution and clean stripping. A new dry film photoresist was developed for this purpose that has 2:1 resolution aspect ratio vs. thickness (15µm L/S resolution with 30µm thickness, (see Figure 12) which can also be stripped by conventional sodium hydroxide stripper solution. In this extremely high resolution area, resist swelling during development needs to be as small as possible as was previously discussed, and since resist needs to have chemical resistance against plating solution etc. it is designed to have very high cross-link density when exposed. As a result, stripping became not only difficult but it's the stripped skin size tends to become large.

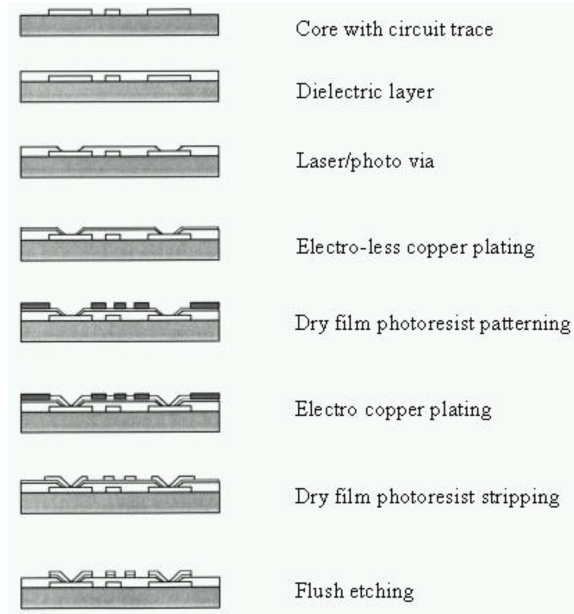

Figure 11 – Differential Etching

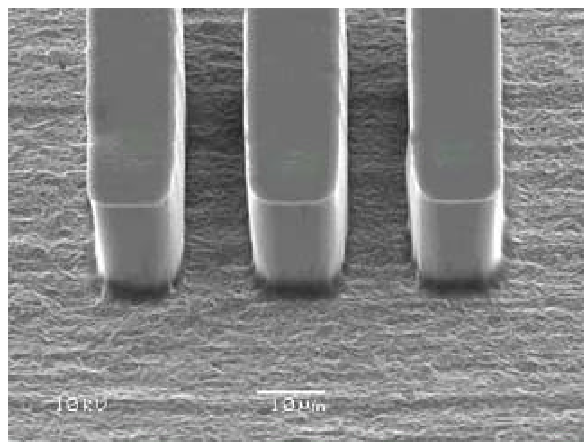

Figure 12 - 15µm L/S with 30µm thickness product Developed for Semi-Additive Method

In the past, proprietary stripping solutions were employed to force stripped skins to break down. A newly designed binder co-polymer with controlling molecular weight as well as a new monomer designed for this super fine line dry film photoresist was utilized to permit such fine features.

Conclusion
As build-up PWB spreads in use and IC package substrates are shifting to organic materials, PWB for these advanced applications will further require higher density and functionality. In order to comply with these technology needs, requirements for dry film photoresist resolution, reliability become even more demanding. As a supplier of dry film photoresist, it was clearly recognized that continuous efforts need to be extended in terms of dry film formulation design together with new material and technological development.