Novel Photo Imageable Film for RDL Application

Mitsuya Uchida, Yasuyo Kanazawa, Yuna Kawata, Yusuke Naka,
Kazutaka Nakada, Kazuyoshi Yoneda and Hidekazu Miyabe
Taiyo Ink MFG. Co. Ltd.,
Address 900 Hirasawa, Ranzan-machi, Hiki-gun, Saitama 355-0215 Japan
Ph: +81-0493-61-2711
Email: uchida.mitsuya.fp@taiyoink.co.jp

Abstract

This paper presents the development of novel photosensitive films designed for use in the redistribution layers (RDL) of advanced semiconductor packages. Traditional photosensitive polyimides, being liquid-based, suffer from challenges such as inadequate surface planarization and distortion caused by high curing temperatures. The newly developed films aim to address these issues effectively. Key advancements include enhanced surface flatness achieved through vacuum lamination, eliminating the need for additional processes like chemical-mechanical polishing (CMP). These films exhibit reduced cure shrinkage and lower curing temperatures compared to conventional polyimides, significantly minimizing package distortion. With a low dielectric loss tangent of approximately 0.005 at 10 GHz, they can be developed using polar organic solvents. Moreover, the films facilitate microvia formation via photo-imaging processes, playing a critical role in RDL applications. These innovations enable the new photoimageable films to deliver superior performance and increased utility in semiconductor packaging, particularly suited for high-speed communication RDLs. The material is a dry film type that forms flat insulating layers over various circuit patterns without requiring additional processing, while also offering exceptional dielectric properties unattainable with traditional RDL materials.

Key words

RDL film, photo imageable film, low Df, exposure and development

I. Introduction

Traditionally, thermosetting epoxy films and photosensitive liquid polyimides have been widely used as materials for redistribution layers (RDL) in semiconductor packaging. Each material, however, possesses distinct advantages and disadvantages.

Thermosetting epoxy films offer two primary benefits: (1) minimal warpage due to their low curing temperature (approximately 150–180°C) and low coefficient of thermal expansion (CTE) (approximately 15–25 ppm); and (2) the ability to maintain surface planarity through a straightforward film lamination process. Figure 1 illustrates the conventional buildup process using epoxy-type thermosetting films via the semi-additive process (SAP) method.

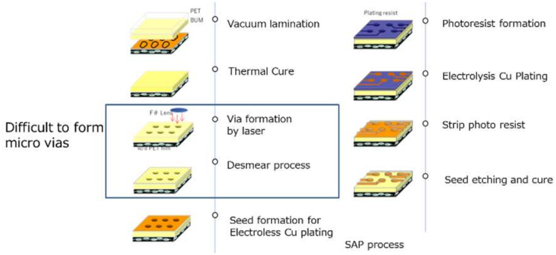

Figure 1. Conventional buildup process using the SAP method.

In this process, epoxy thermosetting films are used as interlayer insulating materials, constituting the standard buildup process for FC-BGA type substrates. However, in comparison to photosensitive liquid polyimides, a significant drawback of epoxy films is their via formation process. Microvias smaller than 20 µm cannot be created using conventional UV laser systems, necessitating the adoption of costly excimer lasers, which increases costs and process complexity. Furthermore, laser via formation can introduce smears within vias, requiring additional desmear steps employing environmentally hazardous oxidizing agents.

Photosensitive liquid polyimides, on the other hand, have the advantage of facilitating the formation of sub-20 µm microvias via standard photolithography processes. Nevertheless, they suffer from high shrinkage during drying and curing, high curing temperatures (approximately 250°C) prone to inducing warpage, and challenges in achieving surface planarity. As shown in Figure 2, polyimide layers formed by spin coating and drying often exhibit nonuniform thickness, necessitating additional planarization steps such as chemical–mechanical polishing (CMP).

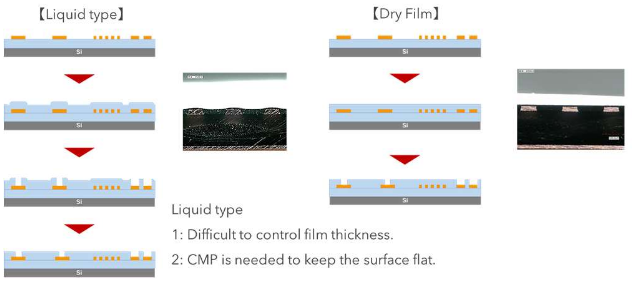

Figure.2 Differences in process flows between the liquid type formed by spin coating and the dry-film type formed by lamination.

An ideal RDL material should integrate the advantages of both material types. Additionally, as RDLs for high-speed communication, materials with reduced transmission loss are in demand. Transmission loss consists of both conductor and dielectric losses, with dielectric loss being proportional to frequency, dielectric constant, and dielectric tangent, and conductor loss proportional to conductor surface resistance and dielectric constant. Thus, for efficient signal transmission at high frequencies, the formation of circuits on surfaces with low dielectric constants, low dielectric tangents, and high smoothness is required (Table1.).

Table1. Target value for ideal RDL material and those of two existing RDL materials (epoxy film and photo imageable liquid poly imide).

		Target Value	Thermosetting film (conventional)	Photo PI Liquid (conventional)
Warpage	Elastic modulus (GPa)	<5	8 ~ 15	**3 ~ 5**
	CTE (ppm)	<60	15 - 25	**50 - 60**
	Curing temperature (℃)	≦200	150-180	**250**
Process ability	Surface flatness	OK	O	**× (Wet process)**
	Via formation	Photo process	**× (Laser)**	O
	Desmear	No	**× (Required)**	O
Dielectric Properties	Dk (10GHz)	<3.2	3.4	3.2
	Df (10GHz)	<0.005	0.005	0.01
	Water absorption (%)	<0.3	0.4	1

To this end, we established three criteria for an ideal RDL material:

1. It should be a film, ensuring surface planarity through a simple lamination process.
2. It should exhibit a low dielectric tangent to reduce transmission losses.
3. It should be photosensitive, enabling microvia formation through conventional exposure and development processes.

We report the development of a new photosensitive film that satisfies these criteria and presents promising potential for high-speed, high-frequency RDL applications.

II. Experimental

A. Materials Development

1. Film Type:

To ensure excellent flatness and surface uniformity during subsequent fabrication processes, the synthesized resin material was applied as a coating onto polyethylene terephthalate (PET) support films and subsequently dried to yield self-supporting, free-standing films. This approach ensures compatibility with existing roll-to-roll film formation and handling processes used in current semiconductor and packaging manufacturing. Furthermore, to achieve sufficient embedment of patterned underlying copper wiring, the resin formulation was specifically engineered to exhibit a low melt viscosity at temperatures around 100°C. Low melt viscosity at this temperature is essential; if the uncured film does not reach a sufficiently low viscosity, it will be unable to fully infiltrate and cover the topographies of the copper lines during the vacuum lamination process. This can result in surface irregularities, voids, or incomplete filling of fine features, which compromise both electrical and mechanical reliability of the final device.

2. Improvement of Dielectric Properties:

The resin design placed highest priority on the elimination of polar groups within the polymer matrix, with the intention to reduce both the dielectric constant and the loss tangent—properties critical for high-frequency applications. Polyphenylene ether (PPE), a polymer well-known for its outstanding intrinsic electrical insulation characteristics, was selected as the core polymer backbone. However, conventional linear PPE lacks suitability for this application due to its solubility only in halogenated solvents and its thermoplastic nature, which results in insufficient heat resistance for demanding microelectronics processes. Therefore, a newly-synthesized branched PPE resin with a crosslinkable architecture was developed. This branched PPE was designed to be readily soluble in common organic solvents (Figure 3), facilitating both film fabrication and post-processing steps.

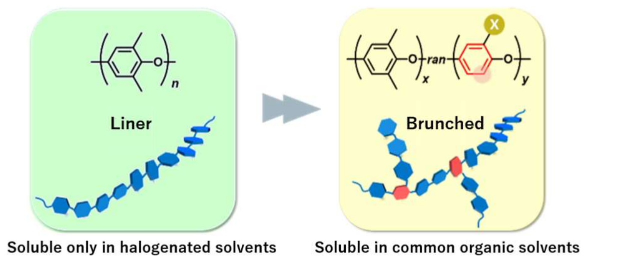

Figure 3. Branched structure of new resin component.

By utilizing this cross-linkable, branched PPE as the matrix resin in concert with carefully selected low-polarity crosslinkers, inorganic fillers, and heteroatom-containing oligomers, it was possible to precisely tune the chemical and physical properties of the film and meet demanding electrical and processing targets simultaneously.

3. Photosensitivity:
The photosensitivity of the material was tailored for high-resolution patterning through a solvent-developable system. Due to the deliberate minimization of functional groups such as —OH and —COOH, which typically impart alkaline aqueous solubility, the system was optimized for development in organic solvents rather than the aqueous alkaline developers used for conventional photoresists. This strategy enabled selective and efficient pattern development without compromising film integrity.

B. Film Properties
Melt Viscosity and Laminatability:
To evaluate practical film formation and processing, the optimized resin formulations were uniformly coated onto PET films and allowed to dry, resulting in robust, self-supporting films suited for downstream handling. Melt viscosity measurements (Figure 4) indicate an onset of softening and flow below 100 °C, with the film maintaining a consistently low, stable viscosity across a broad thermal window. This processing window is highly favorable for industrial manufacturing, allowing the film to effectively fill and conform to intricate features and fine copper wiring during vacuum lamination. Practical effectiveness was verified by cross-section imaging following lamination and cure, revealing excellent embedding and conformity to copper patterns with a line width of 3 µm and space of 7 µm (L / S = 3 / 7) (Figure 5).

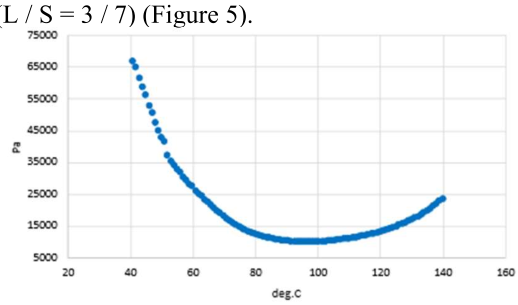

Figure 4. Melt viscosity for the new film formulation

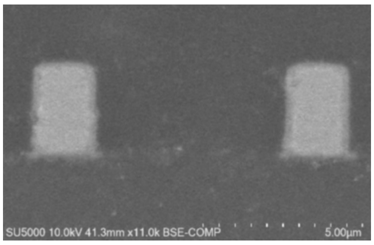

Figure 5. Cross-sectional image of embedded film features after lamination and post cure.

Dielectric Properties:
The dielectric constant and loss tangent were measured at 10 GHz using a split-cylinder resonator. The developed film was laminated onto a PTFE substrate, exposed and cured, and then delaminated to obtain a free-standing specimen. As shown in Table 2, the film exhibited a dielectric constant of 2.9 and a loss tangent of 0.004.

Table2. Dielectric properties of developed film, epoxy film and photo imageable liquid poly imide.

		Target Value	Thermosetting film (conventional)	Photo PI Liquid (conventional)	Developed film
Dielectric Properties	Dk (10GHz)	<3.2	3.4	3.2	2.9
	Df (10GHz)	<0.005	0.005	0.01	0.004

Both values were substantially lower than those of typical epoxy-based films, indicating strong potential to reduce transmission loss and signal degradation in high-speed, high-frequency electronic applications.

Via Formation Capability:
Processability for fine via creation was evaluated in detail. As shown in Figure 6, high-resolution 10 µm-diameter microvias were successfully fabricated through photolithographic exposure and solvent development in a 60% cyclohexanone solution. The formation of vias was characterized by sharp feature definition and high pattern fidelity, with no evidence of via smearing or residue. The resulting clean features obviated the need for any additional post-development cleaning steps, contributing to process simplification and yield improvement.

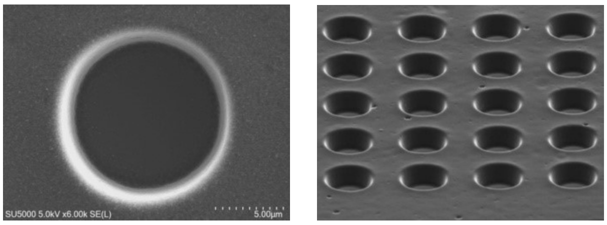

Figure 6. Microvia formation in developed film.

Mechanical Properties:
The mechanical properties of the developed film were evaluated, and the results are presented in Table 3.

Table 3. Mechanical properties measured by DMA and TMA

	Target value	Developed film
Elastic modulus (GPa)	< 5	3.5
Tensile Strength (MPa)	>50	70
Elongation (%)	> 2.5	3
T_g (°C)	≧ 180	200
CTE (ppm)	<60	55

The developed film met the targeted material properties and is expected to exhibit high reliability.

Water Absorption
After drying the cured developed film, the specimen was immersed in boiling water for 1 h. Water absorption, calculated from the mass change before and after boiling,

was extremely low at 0.1%. The reduction of polar functional groups in the resin matrix resulted in very low water absorption(Table 4.).

Table 4. water absorption of developed film, epoxy film and photo imageable liquid poly imide.

	Target Value	Thermosetting film (conventional)	Photo PI Liquid (conventional)	Developed film
Water absorption (%)	<0.3	0.4	1	0.1

Stability of Dielectric Constants:
The film's dielectric constant remained stable over a wide range of temperature and humidity conditions, which is attributed to the resin system's high glass-transition temperature (Tg) and low moisture uptake.
Investigation of the temperature dependence revealed that the dielectric constant exhibited a smaller temperature dependence than that of an epoxy film (Figure. 7).

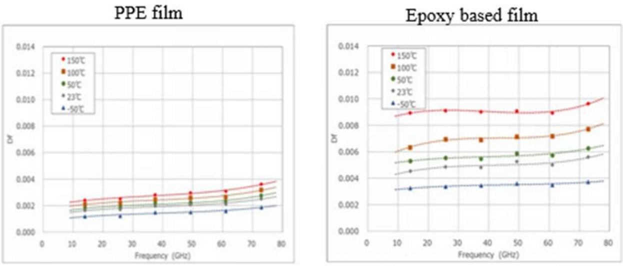

Figure. 7 Dielectric constants as a function of temperature and humidity conditions.

Adhesion Test:
Adhesion of electroless-plated copper to the cured film was thoroughly evaluated (Figure 8 for procedural details). A titanium/copper (Ti/Cu) seed layer was sputter-deposited on the film surface, followed by copper electroplating to a final thickness of approximately 18 µm. Peel testing of the resultant plated copper showed an adhesion strength in the range of 0.5–0.6 N/m, which is sufficient to ensure reliable circuit formation and durable metallization adhesion throughout standard processing and operational lifetimes.

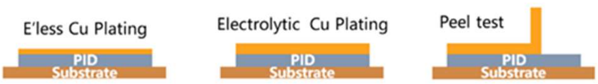

Figure 8. Test flow for electroless copper adhesion.

Thermal Cycling Test:
The material formed on the wafer was subjected to thermal cycling between −55 and 125 °C (30 min dwell), and no cracking or delamination was detected after 200 and 500 cycles, as assessed by optical microscopy. Future work will assess potential adhesion degradation under long-term high-temperature storage and include validation using assembled structures.

Insulation Reliability:
The combination of high glass transition temperature and minimal water absorption yields a material that is highly electrical insulation resistance, especially in fine-pitch (L/S = 5 µm /5 µm) wiring environments. As demonstrated by reliability tests including highly accelerated stress conditions (HAST), the developed film maintained insulation integrity even in dense circuit patterns, confirming its suitability for advanced electronic packaging and high-density interconnect applications (Figure 9).

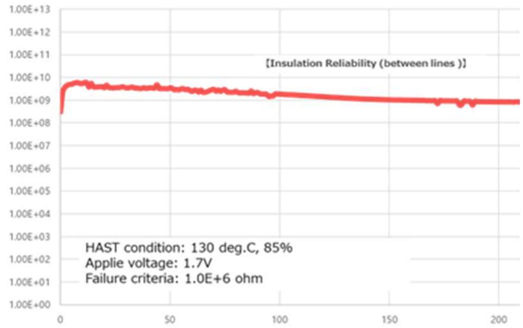

Figure. 9 Insulation reliability in fine-pitch configurations.

III. Conclusion

In summary, we have successfully developed a novel photosensitive film tailored for advanced RDL applications in semiconductor packaging. This new dielectric enables interlayer insulation and precise microvia patterning without resorting to laser drilling or environmentally harmful desmearing steps. The film provides a unique combination of low dielectric constant, low dielectric loss tangent, high planarity, and robust thermal and mechanical reliability—all essential attributes needed for the next generation of high-speed and high-frequency electronic assemblies. Notably, these attributes are achieved through film lamination at low temperatures, eliminating the risk of warpage, and bypassing the requirement for additional planarization or high-temperature curing steps.
The practical advantages of this film, including compatibility with existing fabrication processes, enhanced electrical performance, and operational reliability in demanding environments, position it as a promising solution for future RDL technologies. Ongoing research will aim to further refine material properties and validate performance in full-scale device assemblies to facilitate widespread adoption in both consumer and industrial electronics.