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Reliability Evaluation of a Low Loss Photodielectric

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Abstract

A series of stress testing was completed to evaluate the mechanical, electrical, and thermal performance of low loss dielectric, PRL-029. Highly accelerated stress testing (HAST) assesses the reliability of insulator materials to protect copper structures. Electromechanical migration is a failure mode due to poor moisture resistance during electrical biasing and forced moisture uptake. To address these potential failure modes, HAST (JESD22-A110) at 130°C, 85% relative humidity, for 96 hours, was conducted with and without biasing at 5V. Pressure cooker testing (PCT) is an extreme test to determine when a material will fail by assessing humidity resistance. PCT (JESD22-A102-C) was run at 121°C, 100% relative humidity, 2 atmospheric pressure, for 96 hours total with a mid-point inspection at 48 hours. PRL-029 was coated, photopatterned, and developed to test the adhesion on various substrates. Due to the material's low moisture uptake, the adhesion of the material did not degrade after PCT. To observe the copper protection performance, copper structures were fully covered by PRL-029. The sample ran through PCT and no dendrites, oxidation, or degradation of the copper was observed confirming protection. Additionally, the bulk film mechanical and dielectric properties of the sample were evaluated to see any shift in values. Young's modulus, elongation, and tensile strength were evaluated at -55°C, ambient, 125°C, and 200°C, after hard cure and after 48 hours of PCT. The dielectric constant and dissipation factor from 28 to 50GHz were measured after cure and after 48 hours of PCT. The dielectric constant stayed consistent at approximately 2.6 from 28 to 50GHz. The dissipation factor increased by a factor of 1.3 from 0.003 to 0.004 after 48 hours of PCT from 28 to 50GHz. Temperature cycle testing (TC) (JESD22-A104 Grade 2) was performed to understand the endurance of exposure to extreme temperatures at -55°C and 125°C. Thermal mismatch between the resist and substrate can lead to cracking, warpage, and delamination. PRL-029 passed 2000 cycles of TC and the integrity of the bulk film properties did not deteriorate. A low loss dielectric material has been developed, capable of enduring reliability test standards that are required for current and next generation polymeric dielectric packaging designs.

Table of Properties

	ITEM	UNITS	VALUE
Process	Sensitivity (Tone)	-	Negative
	Photospeed	mJ/cm^2	250
	Developer Type	-	PGMEA
	Cure Temperature	°C	200
	Aspect Ratio	-	1:1
Mechanical	Internal Residual Stress	MPa	14
	Young's Modulus	GPa	1.6
	Tensile Strength	MPa	60
	Elongation at Break (max) 10mm x 50mm, 50mm/min	%	65
	CTE α1 (< Tg)	ppm/°C	60
Thermal	Tg	°C	220
	5% weight loss (Air)	°C	403
	Thermal Conductivity (-25°C to 150°C)	W/m/K	0.23
Electrical	Dielectric Constant	1-50 GHz	2.5
	Dissipation Factor	1-10 GHz	0.0017
	Dissipation Factor	28-50 GHz	0.0025
	Volume Resistivity	6.7 x 10^{16}	Ohm·cm
	Breakdown Voltage	270	V/µm
Moisture Uptake	Water Absorbance 85°C/85%RH, 120hr	%	0.3

Background

While market forces are affecting innovative package designs, the fundamental objectives of addressing reliability has remained the same. Regardless of package formation, the development focus is on material types, adhesion, stress, and thermal management. As packages move towards adopting automotive standards, protective passivation and insulation materials must demonstrate the ability to withstand stringent reliability at an early stage. Dielectric polymers are applied as passivation materials. Their applications range in isolating signal-carrying conductors from each other, fast signal propagation, interlayer dielectrics to minimize resistance-capacitance (RC) time delays, crosstalk and power dissipation in high density and high-speed integration. This can range from mmWave to SiP and WLP designs as well as in optoelectronic designs wherein coupling between very close metal lines need to be suppressed to prevent degradation in device performance.

Table of Reliability Testing

Reliability Test	Pass?	ASTM Standard
PCT 121°C, 100% RH, 2 atm, 96 hours	✓	JESD22-A102-C
TCT -55°C to 125°C, 2000 cycles	✓	JESD22-A104 Grade 2
HAST 130°C, 85% RH, 5V, 96hours	✓	JESD22-A110

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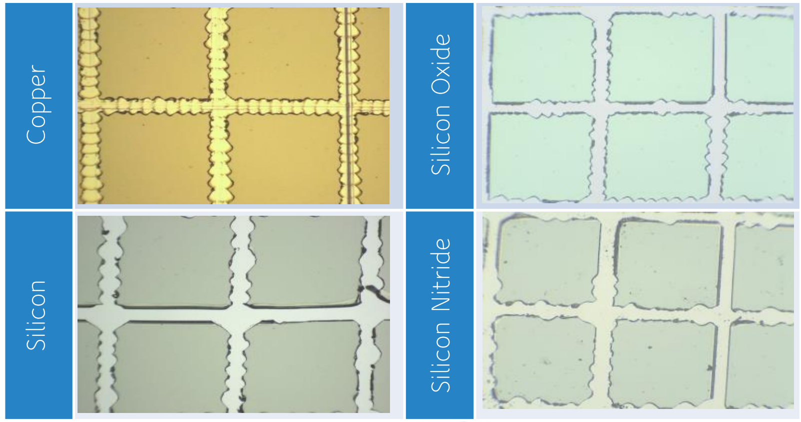
Pressure Cooker Test (PCT)

Test Conditions:
121°C, 100% Relative Humidity, 2 atmospheric pressure

Property Evaluations:
- ✓ Cross Hatch Tape Peel Test
- ✓ Shear Adhesion Test (DAGE 4000)
- ✓ Mechanical Properties (Instron)
- ✓ Dielectric Properties (Split Post Resonator 10-50GHz)
- ✓ Copper Protection

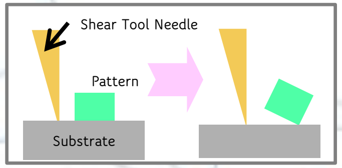
Pressure Cooker Test (PCT): Cross Hatch

Cross Hatch Tape Peel Results Post PCT:
121°C 100% Relative Humidity, 2 atmospheric pressure, 48 hours



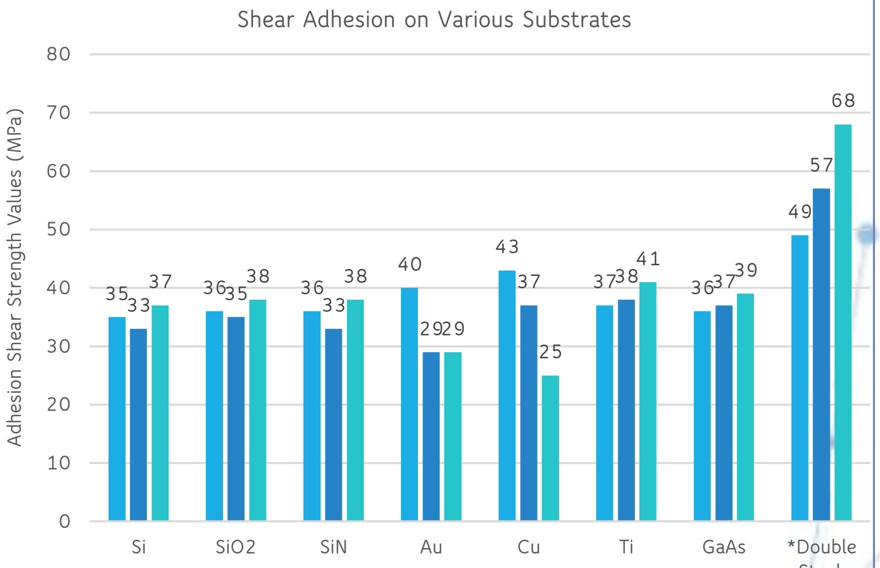
Shear Adhesion Testing Schematic

Tool: Dage 4000
Dimension: w x d = 100um x 100um
Film Thickness: 15µm



Shear Adhesion Testing

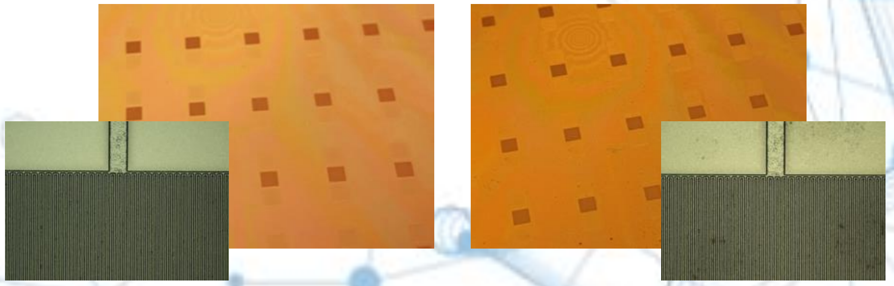
Cure: 200°C/1hr N_2



*Double Stack = Polymer layer photopatterned and cured over itself

Copper Protection

After Cure (200°C) After PCT (48hrs)



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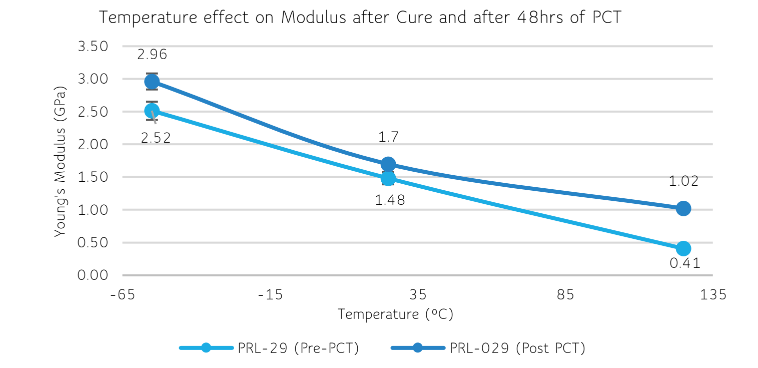
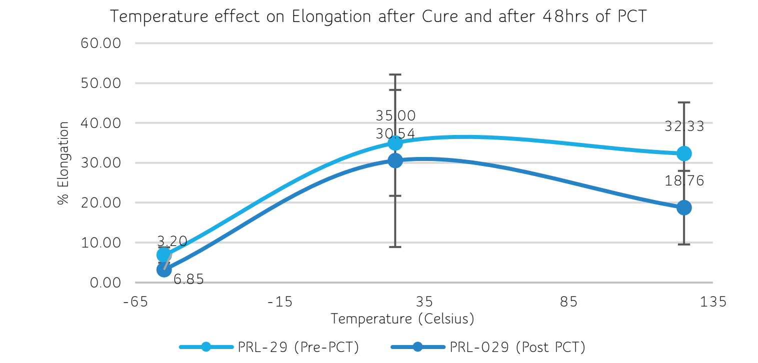
✓ No Cu Oxidation ✓ No Delamination ✓ No Film Deformation

Mechanical Properties





Dielectric Properties

	Frequency	28GHz	40GHz	50GHz
After Cure (200°C)	Dk	2.57	2.61	2.54
	Df	0.0031	0.0031	0.0032
After PCT (48hrs)	Dk	2.55	2.63	2.75
	Df	0.0044	0.0043	0.0041

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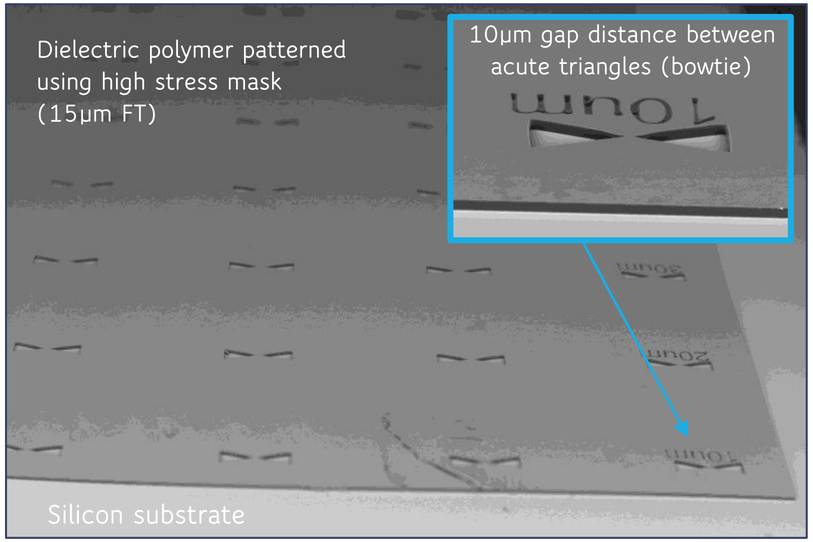
Thermal Cycling Test

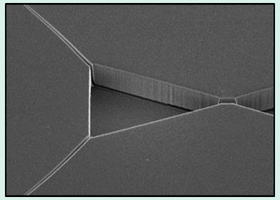
Test Conditions:
-55°C to +125°C, 2000 cycles

Property Evaluations:

- Stress mask for CTE mismatch
- Mechanical Properties (Instron)



EXAMPLE of FAIL:
Material: Photo-Epoxy
Post thermal shock

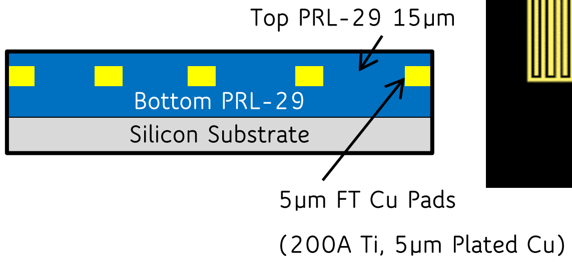


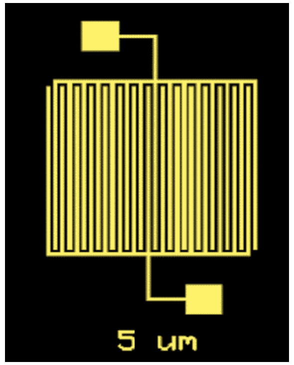
Bowtie structures were chosen for an extreme environment of stress induced failure with typical failure being cracking at the corners (as seen on the left) and/or delamination of the film from substrate.

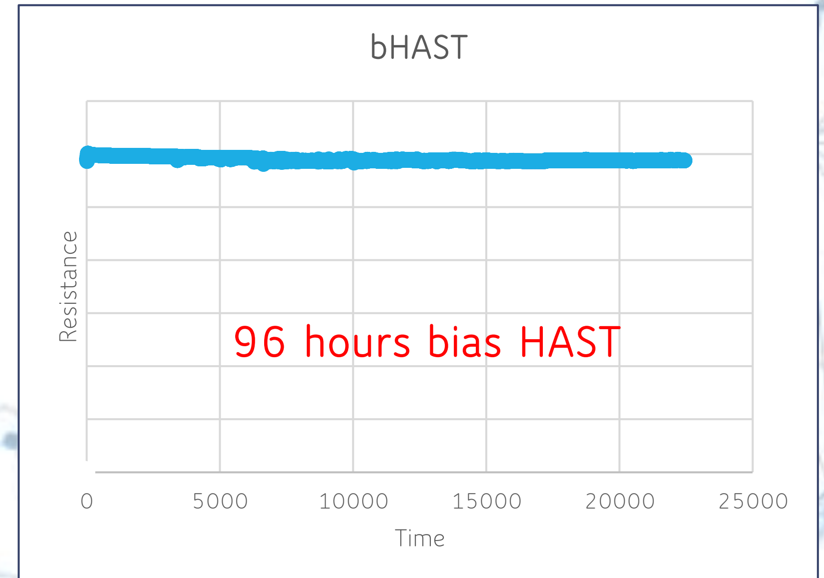
Highly Accelerated Stress Test (with Biasing):

Test Conditions:
130°C/85% RH, 96hrs, 5 Volts

Design Method and Device Stack:







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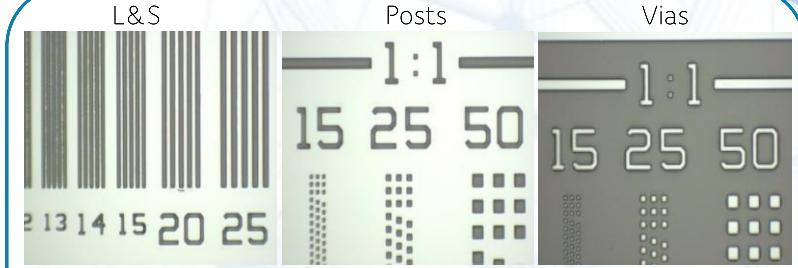
High Temperature Storage:

Test Conditions:
225°C for 24 hours under Air

Property Evaluations:

✓ Photolithography / Film Performance
✓ Mechanical Properties



✓ No cracking
✓ No delamination

Substrate: Si
Film Thickness: 15um

Mechanical Properties

HTT Conditions:	Young's Modulus (GPa)	Elongation MAX (%)	Tensile Strength (MPa)
After Cure (200°C)	1.75	35.83	59.42
After HTT (225°C/ 24hrs in Air)	3.57	8.03	126.12
After HTT (225°C/ 24hrs in N_2)	1.94	21.13	84.87
After HTT (200°C/ 24hrs in Air)	2.67	9.39	113.17