

# **Radiation Hard, Hermetic, Low Cost Packaging for Microelectronics, MEMS and Optoelectronics**

**Amaresh Mahapatra and Robert Mansfield**

**Linden Photonics Inc.**

**James J. Foshee**

**AFRL Wright Patterson AFB**

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Contact information: Tel.: 978-392-7985  
am\_lindenphotonics@msn.com

# Key Satellite Programs Present and Planned

Geodesy	Meteorology	Communications	Navigation	Early Warning and Attack Assessment	Surveillance and Reconnaissance
Landsat	Defense Meteorological Satellite Program (DMSP)  <b>National Polar-orbiting Operational Environmental Satellite System (NPOESS; 833 km, 98.7 degree inclination polar orbit/high radiation environment)</b>	Defense Satellite Communications System (DSCS)  Ultra-High Frequency Follow-on (UFO)  Milstar (Initiated 1980s, Geosynchronous orbit)  Global Broadcast System (GBS)  Advanced Extremely High Frequency System (AEHF, Lockheed Martin)  Wideband Gapfiller Satellites (WGS)  Mobile User Objective System (MUOS)	Global Positioning System (GPS)	Defense Support System (DSP, Early Warning System deployed for about 30 years)  Space-Based Infra-Red System (SBIRs High, to monitor and track enemy missiles)  Space Tracking and Surveillance System (STSS, Northrop Grumman, 2002)	Keyhole (KH) Series  Signals Intelligence Satellite (SIGINT)  <b>Future Imagery Architecture (FIA, Boeing, Initiated in 1999)</b>  Integrated Overhead SIGINT Architecture (IOSA)  <b>Space-Based Radar</b> (Complements terrestrial radar such as AWACS and Joint STARS)

Source: Northrop Grumman Review, Summer Issue, 2003

## Packaging Technology Requirements

- RadHard
- Hermetic
- EMI Shielding
- Light Weight
- Manufacturable
- Low cost
- COTS based

## Linden Business Strategy

- Develop low cost hermetic packaging that will survive space radiation for decades using liquid crystal polymers
- Enable manufacturing technology for the above

# Barrier Properties of Liquid Crystal Polymers (LCP)

<b>Material</b>	<b>Water vapor transmission rate (gm/m<sup>2</sup>/day/barr)</b>	<b>O<sub>2</sub> transmission rate (cm<sup>3</sup>/m<sup>2</sup>/day/barr)</b>	<b>Optical properties in visible spectrum</b>
PET (polyester)	28	78	transparent
Teflon	5.0		transparent
Parylene	3.3	112	transparent
Liquid crystal polymer (LCP)	0.2	1.1	Opaque

## Chemical resistance of LCP

Chemical Resistance , Rating: + Resistant –less than 2% change in weight and dimension, less than 5% change in mechanical properties.

Acetic acid (100%)	30 days/118°C	A950	+	Chlorine gas	180 days/23°C	A950	+	
						A130	+	
Acetone	180 days/56°C	A950	+			A625	+	
		A130	+	Chlorine/water	180 days/23°C	A950	+	
		A625	+	(saturated solution)			A130	+
Acetonitrile	120 days/23°C	A625	+			A625	+	
Brake fluid	30 days/121°C	A130	o	Chromic acid (50%)	90 days/50°C	A625	+	
(Castrol® TLX 988C)		A950	+		180 days/50°C	A950	+	
		B950	+			A130	o	
		C950	+			A625	o	
	90 days/121°C	A130	–		30 days/70°C	A950	+	
Brake fluid	90 days/121°C	A130	o			A130	+	
(NAPA® brand DOT-3)				Chromic acid (70%)	30 days/88°C	A950	+	
Caustic soda solution (5%)	90 days/23°C	A130	+			A130	o	
		A625	+			A625	o	
	180 days/23°C	A950	+	Dimethyl formamide	180 days/66°C	A950	+	
		A130	o			A130	+	
		A625	o			A625	+	
		A515	+	Diphenylamine	180 days/66°C	A950	+	
Caustic soda solution (10%)	180 days/23°C	A950	+			A130	+	
						A625	+	
		A130	+					
		A625	o			C130	+	
		A515	+			A950	+	
	30 days/88°C	A950	o			A950	+	
		A130	–			A950	+	
						A130	+	

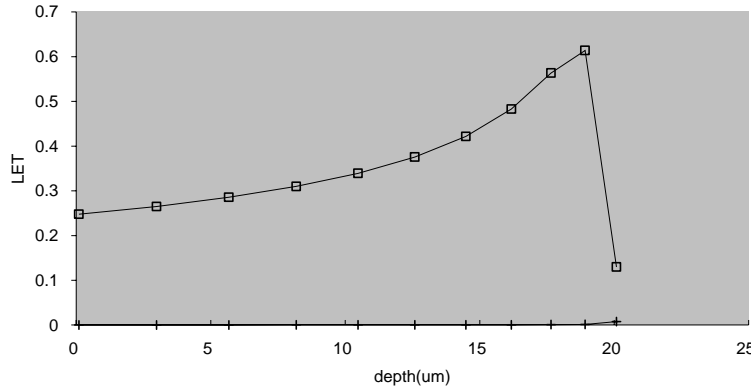
**Chemical Resistance , Rating: + Resistant –less than 2% change in weight and dimension, less than 5% change in mechanical properties.**

Ethylene diamine	30 days/100°C	A950	–		Lead free gasoline (petrol) + 10% methanol	30 days/121°C	A950	o				
	180 days/23°C	A950	+				B950	o				
		A130	o									
Ethylene glycol (50/50)		A625	+	30 days/50°C	A950	+	90 days/121°C	A130	–			
		A950	o				90 days/93°C	A130	o			
	30 days/121°C	B950	o					A625	+			
Fluorinert® FC-70	1 day/215°C	A950	+				Gasoline (petrol) w/70/30 heptane/toluene,	A950	+			
		A130	+					B950	+			
		C130	+									
Formic acid (80%)	30 days/104°C	A950	+				copper ion, t-butyl-hydro-peroxide					
	270 days/104°C	A625	+									
	455 days/104°C	A950	o									
Fuels: Fuel C (ASTM D471)	30 days/121°C	A950	+				H-FCKW 123	10 days/50°C	A130	+(1)		
		B950	+							C130	+(1)	
		C950	+							A530	+(1)	
50/50 iso-octane/toluene		A130	o							C150	+(1)	
	90 days/121°C	A130	o								C810	+(1)
		A230	o									
Fuel C + 20% methanol	125 days/60°C	A130	+									
Fuel C + 20% ethanol	125 days/60°C	A130	+									
		A230	o									
M-85 fuel	20 days/121°C	A130	–									
Lead free gasoline (petrol)	30 days/121°C	A950	+									
		B950	+									
	90 days/121°C	A130	+									

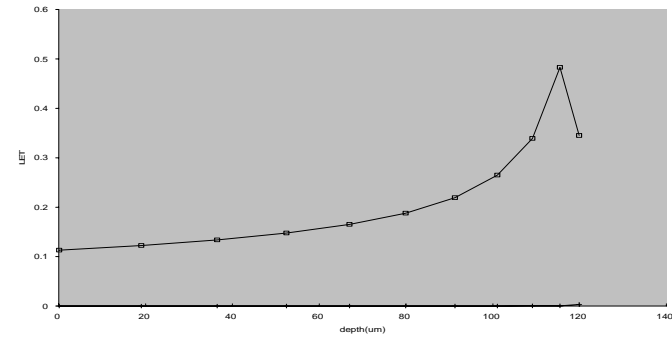
# **Radiation Tolerance and Shielding**

## **Properties of Liquid Crystal Polymers (LCP)**

# Linear Energy Transfer (LET) of High Energy Protons in LCP

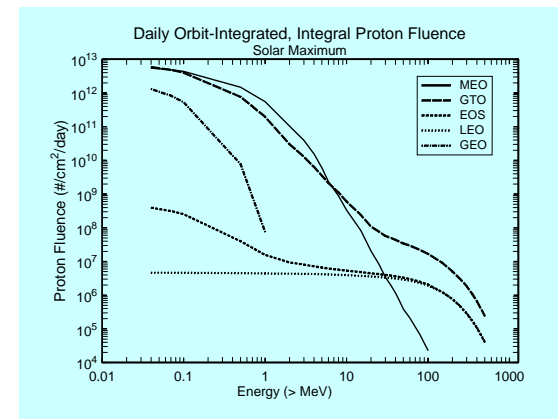


LET as a function of depth for 1 MeV protons in Vectra LCP.



LET as a function of depth for 3 MeV protons in Vectra LCP.

Proton Energy, MeV	Fluence in MEO (#/cm <sup>2</sup> /day, Barth, 1997)	Range in Vectra LCP (μm)	Range in Copper (μm)	Range in Aluminum (μm)	Range in PET (μm)
10	10 <sup>9</sup>	1640	468	1127	1574
5	10 <sup>10</sup>	468			
1	10 <sup>12</sup>	29			
0.1	10 <sup>13</sup>	1			

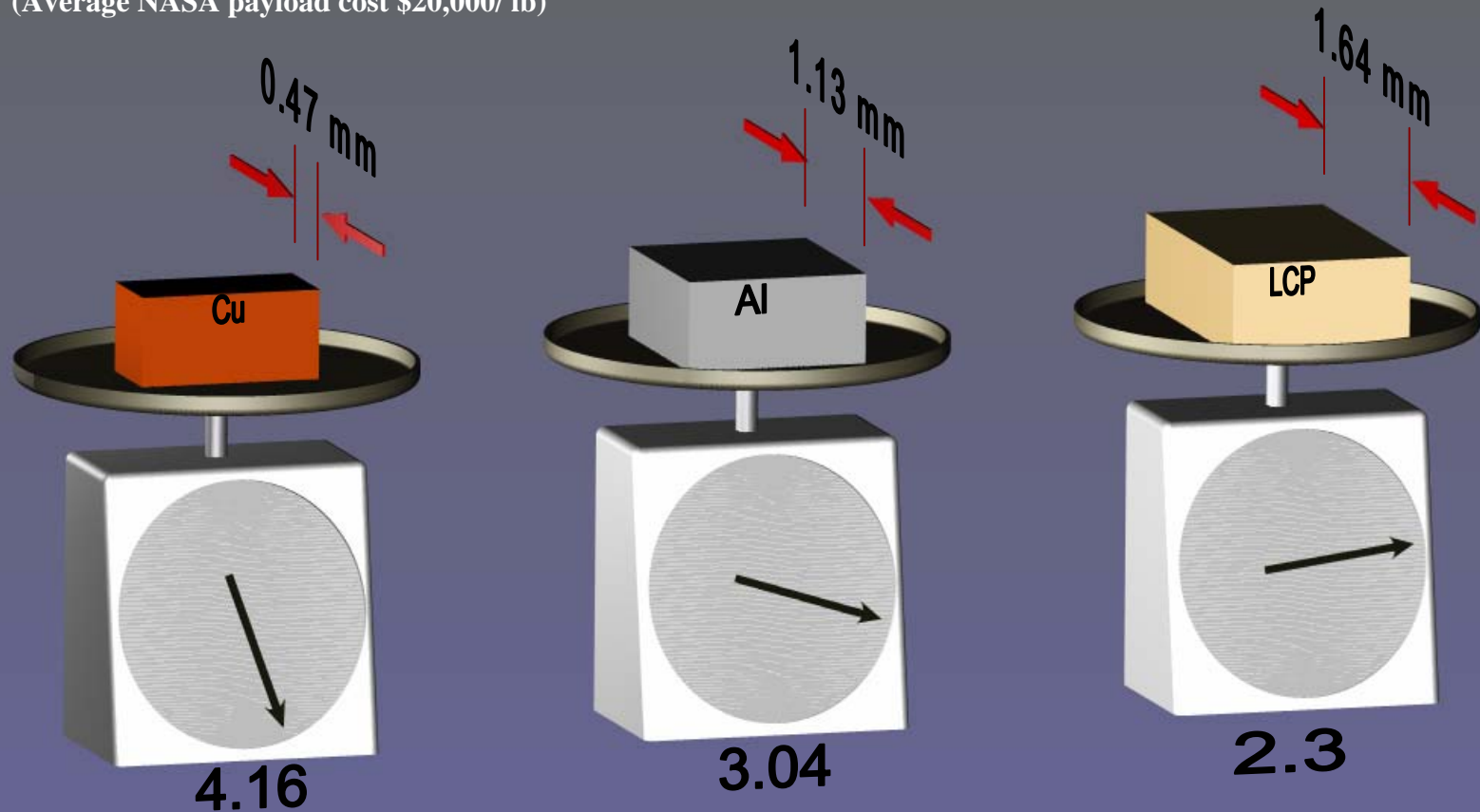


Source: Linden Photonics calculations using models developed by Dr. Barney Doyle, Sandia Laboratory.



## Range of 10 MeV Protons in Copper, Aluminum and LCP and relative weights for equivalent shielding power

(Average NASA payload cost \$20,000/lb)



Source: Linden calculations using models developed by Dr. Barney Doyle, Sandia Laboratory

**Tensile modulus and strength  
of LCP before and after exposure  
to 1 Mrad proton radiation**

Non-irradiated Sample	Young's modulus (psi)	Yield Stress (psi)	Area (sq in)
1	1006953	34651	0.00241
2	1059685	26121	0.001612
3	1146953	27002	0.00137
4	959259	39352	0.001512
5	1247600	47291	0.001827
<b>AVG</b>	<b>1084090</b>	<b>34883</b>	
Irradiated Sample	Young's modulus (psi)	Yield Stress (psi)	Area (sq in)
1	1351201	34123	0.001108
2	1376967	25358	0.001727
3	1614286	31718	0.001176
4	1642940	42163	0.001008
<b>AVG</b>	<b>1496348</b>	<b>33340</b>	

**Table 4.4.1 Cobalt 60 radiation  
Vectra A950 (% retention of properties)**

Radiation Dose	250 Mrads	1,000 Mrads	2,500 Mrads	5,000 Mrads
Tensile strength(1)	97	95	95	95
Tensile modulus(1)	100	100	106	106
Break elongation(1)		81	81	79
Flexural strength(2)	101	102	102	102
Flexural modulus(2)		108	108	116
HDT @ 1.82 MPa(3)	100	100	100	94
<i>(1) ASTM D638 (2) ASTM D790</i>		<i>(3) ASTM D648</i>		

**Table 4.4.1: Artificial weathering, 2000 hrs.(ASTM D2565 –  
xenon arc lamp, air temp. 125<sup>o</sup> C, water spray for 18 mins.  
Every 200 min.(% retention of properties)**

	Vectra A950	Vectra A130
Tensile strength(1)	95	95
Tensile modulus(1)	90	98
Flexural strength(2)	95	95
Flexural modulus(2)	95	95
HDT @ 1.82 MPa(3)	90	92
Notched Izod(4)	90	95

Source: Linden Photonics experiments at Sandia Laboratory as part of the Phase 1 effort

# Accelerated Lifetime of Thermal Bonds Between LCP and Glass

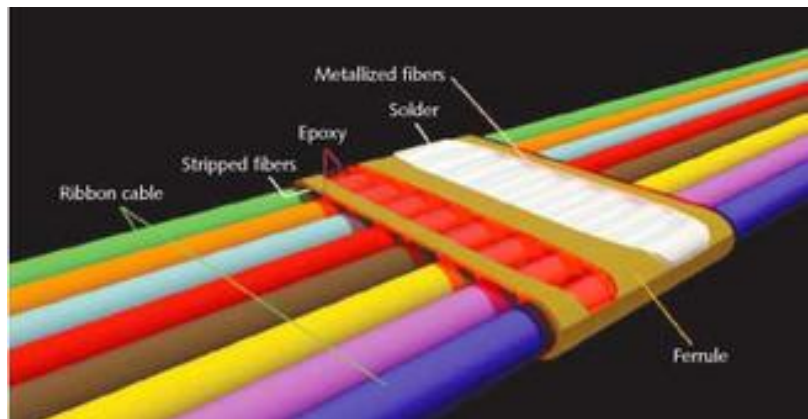
Sample #	Temperature ( $^{\circ}$ C)	Relative Humidity (%)	Life time, $T_N$ (hours.)
18	95	100	34
13	116	100	5.8
20 (surface treated)	116	100	10.0

**This yields an activation energy of 1.06 eV and a bond life at room temperature of 15 years**

Source: Linden Photonics Phase 1 experiments under ARMY STTR

# **Low Cost Manufacturing Technology for LCP Packaging**

# SMF 28 Fiber with LCP secondary buffer replaces metallized fiber.



Fiber feedthrough ferrules that use solder include the dual hermetic feedthrough in which the single fiber on the end is used for internal alignment and the second ferrule provides a hermetic seal.

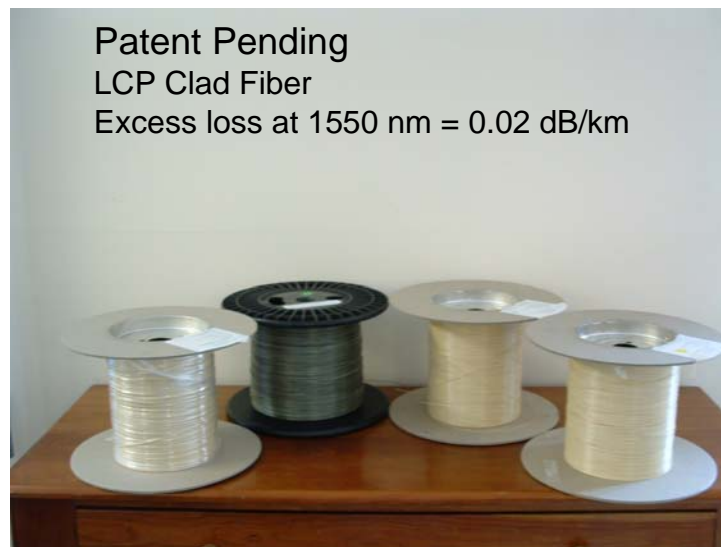
Commercial Optoelectronic Packaging is a \$2 billion market largely due to expensive hermetic packaging



Patent Pending

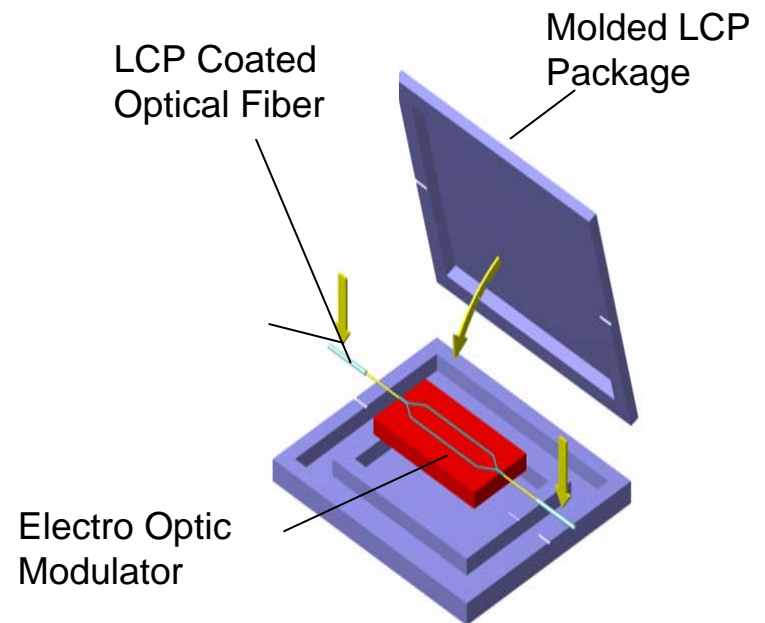
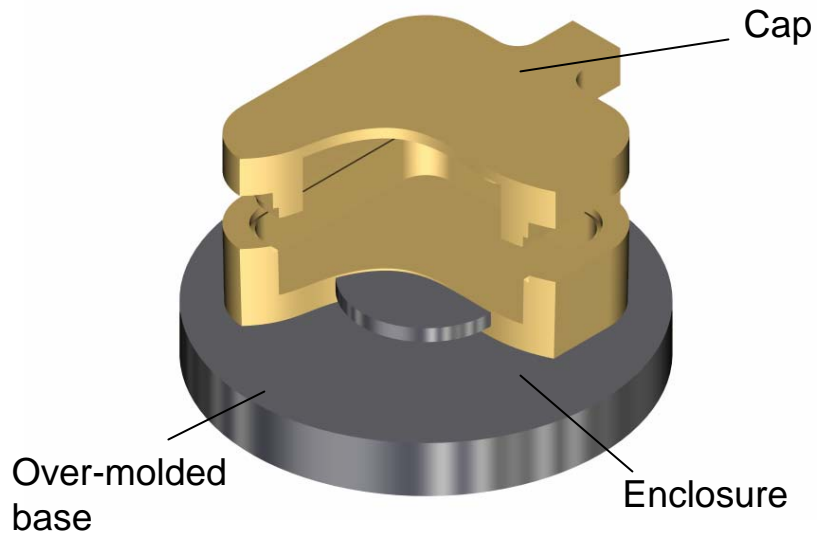
LCP Clad Fiber

Excess loss at 1550 nm = 0.02 dB/km

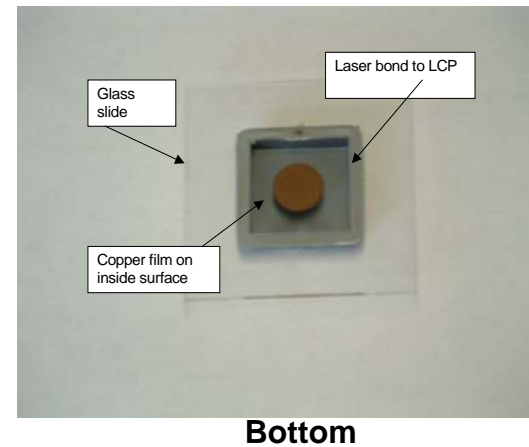
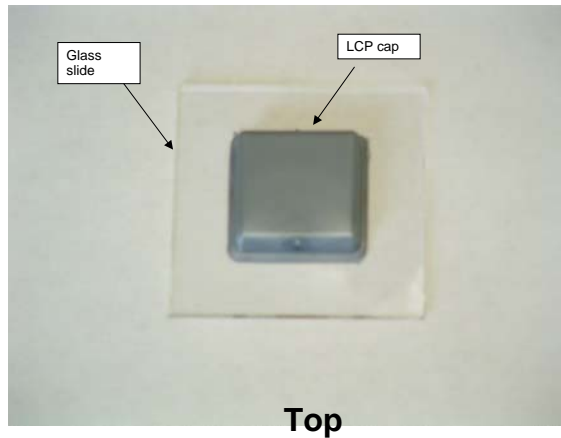


# Ultrasonically Bonded Package

Patent Pending



# Laser Bonding of LCP Cap



**Top view of LCP cap laser bonded to glass substrate**

Source: Laser bonding experiments by Speedline for Linden Photonics Phase 1 ARMY STTR.

# Partnerships

- Rockwell Scientific – Dr. Jeff DeNatale, Supply MEMS Devices
- Sandia National Laboratory - Dr. Barney Doyle, Radiation Testing
- Speedline Inc., Dr. Gerald Pham-Van, Develop LCP Laser Bonding Equipment
- University of Massachusetts – Professor Jayant Kumar, Intercalation Experiments



# Acknowledgements

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