Plastic Hermetic Packages for MEMS, MOEMS & Optoelectronic Devices?

Dr. Ken Gilleo
ET-Trends; gilleo@ieee.org

Introduction

The full hermetic package for electronics and optoelectronic (OE) devices was first developed in the 1800's and has served these industries well. The earliest optoelectronic devices, cathode ray tubes (CRT) demonstrated in the late 1800's, used a sealed glass vacuum enclosure. The Braun Tube, for example, was a scanning CRT display system that used a glass envelope to seal out the atmosphere and maintain the required vacuum. Later, electronic vacuum tubes were developed, starting with the Fleming diode that also used a glass envelope. A few years later, De Forest introduced the triode (Audion) that was able to amplify, making it the first active electronic device. Many of the early OE and electronic devices required a vacuum to operate because the flow of electrons through free space was part of the mechanism. Today, only a small minority of products requires a vacuum. Yet, the century-old tradition of the full-hermetic sealed enclosure has continued for many products. Figure 1 shows an early hermetic package used for one of the first electronic devices.

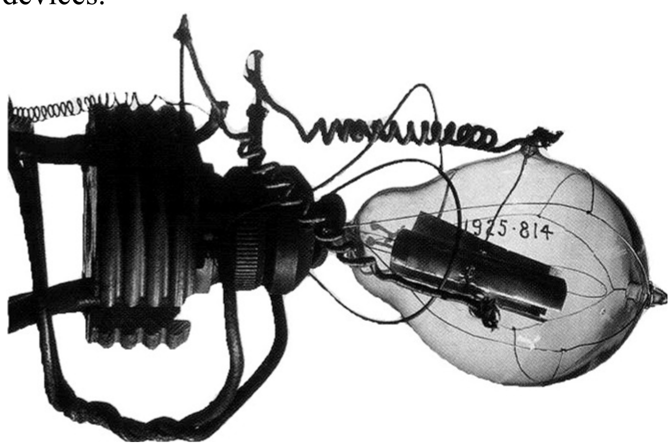

Figure 1 – Fleming Vacuum Tube

The Chemistry of Packaging

Chemists endeavor to produce, and even accelerate, chemical reactions. But packaging technologists work just as hard to prevent, or at least retard, reactions inside the package. Production reactions like polymerization of encapsulant are highly desirable, of course. But chemistry occurring inside an electronic or OE package is generally bad for the device and connections. Ambient atmospheric gasses and contaminants can also damage ordinary electronic devices, but these are less sensitive because of design, materials and passivation that provide sufficient reliability even with non-hermetic packages.

MEMS devices are difficult to passivate since they often have moving elements. Coating MEMS devices with passivation materials could change the characteristics of sensors or even prevent motion of parts. Optoelectronics devices are also challenging since they are typically constructed from compound semiconductors that are more reactive and sensitive to a broader range of contaminants. OE systems for telecom may have a 20-year life assurance requirement making it difficult to evaluate new packaging concepts. Optical devices could also be degraded or altered by passivation that changes any of the optical properties including the refractive index. The *de facto* packaging strategy for MEMS, MOEMS and OE products has therefore been the use of full hermetic package designs. Is the traditional hermetic package really essential here, or costly overkill?

The "Modern" Hermetic Package?

One of the most critical issues facing this trio of specialty devices is packaging. While electronic packaging and assembly have undergone a steady evolution to deliver low cost and high-level automation, hermetic systems have not really changed that much. Glass has given way to ceramic and metal, but cost has actually increased. Certainly, the full hermetic package provides assured reliability, but it delivers it with hefty penalties. These include significant cost, low degree of standardization, and many non-SMT styles that preclude automated assembly. While the plastic electronic package accounts for only 4% to 5% of total component cost, the percentage is much higher for hermetic packages and is often the largest single cost component. How can we determine if this package class is really needed?

The question takes us back to the chemistry of the MEMS, MOEMS, and OE devices. Can some atmospheric gases be tolerated? If the answer is "yes", or even "maybe", then it's time to look at alternative packaging since this could have as great a positive impact on these specialty devices as its had for standard electronics. We tend to ignore how important the role of packaging has been on affordable electronics. We take molded plastic packages and automated Surface Mount Technology (SMT) for granted, but they are essential to the electronics industry. Consider that if we applied today's "modern" optoelectronic designs and methods to electronic devices and packaging, the laptop computer would weigh tons, require a truck for transport, and cost millions of dollars. Let's explore plastic packaging.

Selecting a Packaging Material

Our first choice for cost-reduction is plastics because simple and highly automated processing makes them unbeatable in value. Although engineering plastics can cost more per kilo than metal, the plastic package can be orders of magnitude cheaper than a metal type. The cost for the process is more critical than cost of materials. Plastic parts can be molded by the dozens or even hundreds during each rapid injection molding cycle using multi-cavity molds – and all automatically. The next selection choice is what type of plastic; thermoset or thermoplastic? Although the workhorse plastic for packaging is thermoset epoxy, thermoplastics are a better choice here. First, a few of the many thousands of thermoplastics have the best barrier properties of any polymers. At least one plastic has about 10 times better barrier properties than epoxy packaging materials. In fact, the best polymers equal the barrier properties of glass. But thermoplastics can be remelting and this provides two key benefits. Thermoplastic resin can be molded into a precise shape including a cap or a cavity that would be needed for the devices that need free-space for movement (MEMS) or a window/port for light transmission (MOEMS and OE). There is one more important attribute that accrues from the remelt property and that is sealability. Thermoplastic packaging can be selectively heated to their melting point to permit a lid, glass window, or fiber to be sealed.

What thermoplastic is optimum? The first criterion must be high thermal stability. The melting point should be well above the processing temperature of solder, including lead-free types. We have set the lower limit at 300^{o}C. The next criterion that we used was high gas barrier, especially moisture. Other desirable properties are low outgassing, low dielectric constant, platability, and reasonable economics. Once again, cost per unit weight is less significant if manufacturing is efficient. Plastics have a density of about 1 compared to metals that are about an order of magnitude higher. This means that a kilogram of plastic resin can make about 10 times as many parts as metal. It also means that plastic packaging is lighter. We concluded, as have several others, that the liquid crystal polymer (LCP) class best met all criteria. The flexible circuit industry has started to adopt LCP laminates for many of the same reasons although low moisture absorption is important rather than moisture barrier, but the two properties tend to go together. Experience in LCP circuitry can be applied to packaging in the future. Table 1 shows properties of LCP films as reported by suppliers while Table 2 gives moisture barrier properties from Auburn University.

PROPERTY	PI 1	PI 2	LCP	Test
Tensile strength (kpsi)	50	42	15	D882, 64T
Elongation %	60	40	15	D882, 64T
Young's Modulus (kpsi)	800	825	700	D882, 64T
Tear strength (gm)	26.2	17.5	15.4	D1922-00A
Heat Shrinkage % @ 200$_o$C	.08	0.04	0.04	D2732
CTE (ppm/deg.C)	13	14	18	D696, 44
Moisture absorption %	2.4	2.0	0.1	D570, 63
CHE (ppm/%RH)	9	8	2	D570
Moisture Trans. Rate gm/sq/ cm/day	4.2	3.8	0.4	F1249
Dielectric Constant	3.3	3.1	3.0	D150
Dissipation factor	.005	.005	.003	D149

Tested on 2 mil commercial film – data from 3M Co. (typical)

Table 1 – LCP Film Data

Sample ID	WVTR (g/m² -day)	Permeability (g*mil/m²/day)	Diffusivity (cm²/sec)	Solubility (g/cc)
2L (2 mil)	0.1177	0.2354	2.589 x 10e-9	0.000268
2H (2 mil)	0.1373	0.2746	2.838 x 10e-9	0.000284
4L (4mil)	0.0678	0.2712	9.830 x 10e-10	0.000811

Test Conditions

- Conditions: 100% rh @ (55.3 mmHg)
- Carrier Gas: 100% Nitrogen, ambient pressure
- Temperature: 40°C

Auburn University

Table 2 – LCP Moisture Barrier Properties

Molding LCP Resins
LCP is a popular choice for OE connectors and many precision parts that require high dimensional stability. Resins are commercially available with high melting points; 300^{o}C to 340^{o}C. One of the most important attributes for high dimensional stability is low moisture absorption. This is because materials, including plastics, usually expand upon absorbing moisture; coefficient of hygroscopic expansion. Specialty molders therefore use, and have experience with, mold design and processing of LCP. This plastic can be molded into caps suitable for testing like the one shown in Figure 2 from Foster-Miller, Inc. (Waltham, MA). The cap can be made into an enclosure that can be hermetically tested by bonding a “lid”, a piece of glass in the initial work.

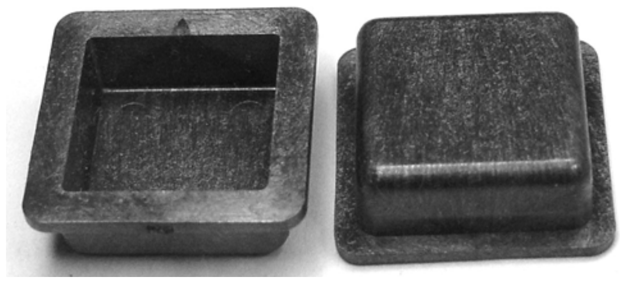

Figure 2 – LCP Molded Cap – Cookson Electronics

Sealing Processes
A variety of energy sources can be used to bring an LCP package to the melting point of slightly over 300^{o}C. These can be convection, direct, and radiant heating as well as mechanical methods that generate heat at the bond site, like ultrasonic bonding. We ruled out mass heating methods, like convection, since the molded part would soften and deform if everything were to be heated. Localized heating was the right choice and it will also prevent damage to MEMS or OE chips that can be thermally-sensitive.

Under a DARPA contract, Foster Miller, Inc. directed us to investigate laser heating while they explored ultrasonic methods. Initial testing showed that Near-Infrared (NIR) was a suitable energy source for sealing LCP to glass. Both IR and NIR readily travel through glass without appreciable loss. However, LCP does not absorb and convert IR/NIR to heat. We needed an energy absorber. LCP becomes a strong IR/NIR absorber when a small amount (>1% by weight) of carbon black is added. Carbon black is commonly used as an LCP filler and resin is commercially available that is compounded with carbon. IR/NIR dyes are available, but offer no advantage over low-cost and very inert carbon.

Equipment
We used a prototype diode laser-soldering machine from Electrovert designated as the DLS (Diode Laser Soldering). Although the 30-watt laser with output at 802 nm wavelength was designed for selective soldering, it worked well for plastic sealing. Figure 3 shows the machine system and the laser head. The laser energy is produced by a diode bar consisting of 19 lasers in a strip. Optics consolidates the “line of light” into a spot that is transmitted along a glass fiber to the head above. The head has optics that allows the circular beam to be focused and also to be observed with a camera. Motion is provided using a programmable X-Y table.

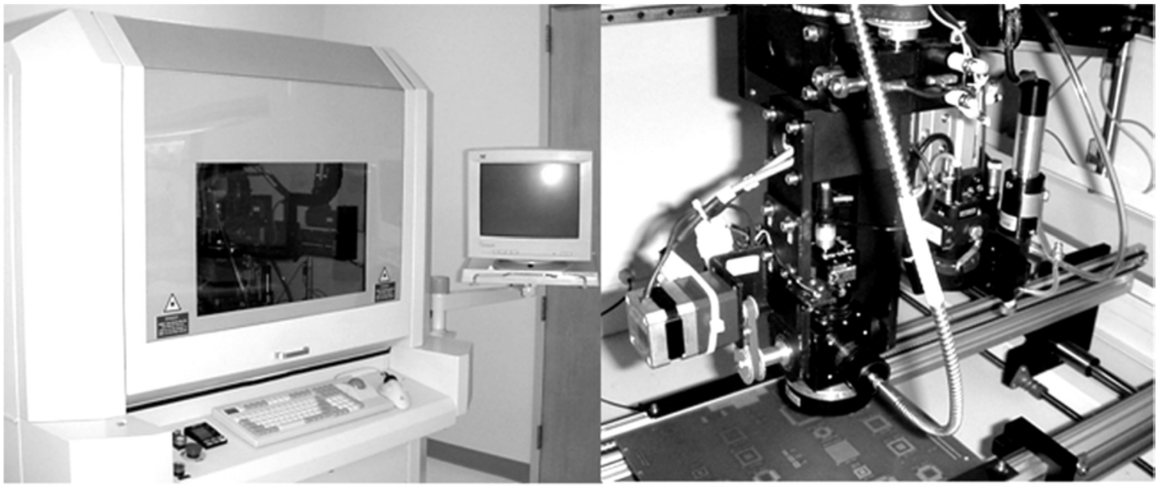

Figure 3 Laser Equipment

Experiments

Experiments done with Foster Miller, Inc., under their DARPA contract, began with LCP film but the company did not supply material with carbon. Later, molded caps with carbon black were provided to us for laser testing. No significant heating occurred unless carbon filler was used in the LCP. However, dark ceramic substrate could be bonded to unfilled LCP by sending the laser beam through the film and heating the ceramic. Carbon can be added directly by dissolving, or swelling, the surface of the LCP film with hexafluorobenzene, but this not considered more than a laboratory process at best. The laser beam was directed through glass placed on top of the molded LCP cap, and onto the plastic surface as shown in Figure 4. LCP surface melting occurred at 5 watts although 15 – 30 watts gave the most satisfactory results. The X-Y table was programmed so that the laser spot traveled along the perimeter of the cap so that a sealed enclosure was produced. The process appears to be robust giving a good seal unless energy is too low to melt the LCP, or so high that decomposition occurs (>450^{o}C). Excessive heating was quickly noted since the plastic darkened and produced gas bubbles. The resulting bubbles generated voids that were detected as leaks. Force must be applied to the lid for good sealing. The DSL does not have the ability to apply force and glass weights were used initially. Later, a laser optical bench with force application was set up at Cookson Electronics Equipment Group R&D in Franklin, MA.

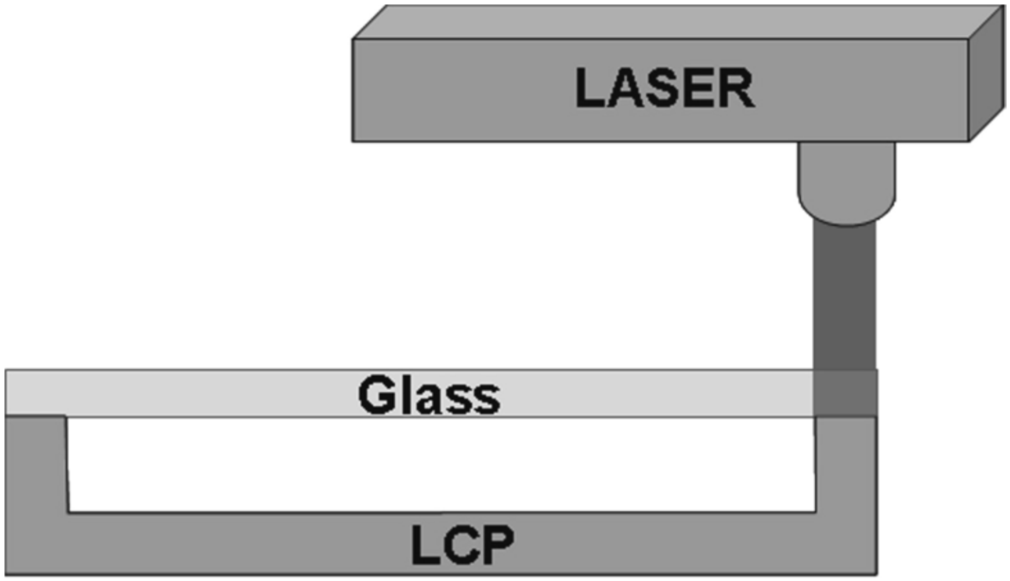

Figure 4 – Process Diagram

Bond strength tests gave values of about 100 PSI. Glass breakage and fracturing, leaving particles attached to the plastic, were the most common failure modes. The bond to glass was excellent and this may be due to a low polymer melt viscosity at the processing temperature of 400°C to 425°C as indicated by thermocouples. Samples of LCP caps with sealed glass lids were tested for hermeticity using the well-accepted helium leak method. Helium gas was introduced into a hole created in the plastic cap and the He detector measured leaking gas. The standard for hermeticity is a value < 1 x 10^{-8} cc/@ 1 atm. He. The team had hoped to achieve a value that approached this criteria but expected it to be much poorer. In fact, the project was first named NHP (Near-Hermetic Package). We were surprised when the independent test lab reported that the package simulator passed full hermeticity. Values for "good" samples were in the 10^{-9} range, the limit of the equipment. The "known bad" samples gave the expected poor results and served as a control. Those run at low power showed opens, but those sealed with excessive power, and visible degradation, ranged around 10^{-5}.

Design Concepts

The test vehicle was only designed to measure intrinsic characteristics of LCP and seals. There were no I/O paths. The laser-sealing concept can be applied to bonding glass lids to LCP housings for MOEMS, and perhaps certain OE products. An all-plastic BGA can also be envisioned where the laser is used to seal an LCP chip carrier platform to an LCP molded cap. Figure 5 shows how the laser beam could pass through the unfilled platform but generate sealing heat upon striking the carbon-filled cap. Wafer-level processes are also possible although chip I/Os would need to be routed to the back to produce a CSP or Flip Chip. However, several vertical rerouting processes have appeared in the literature. Figure 6 shows a wafer-level packaging (WLP) process.

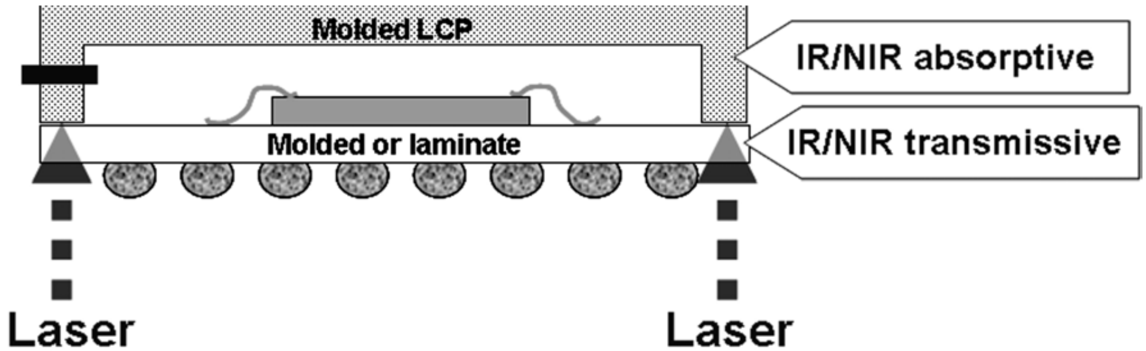

Figure 5 – Laser-Sealing of BGA

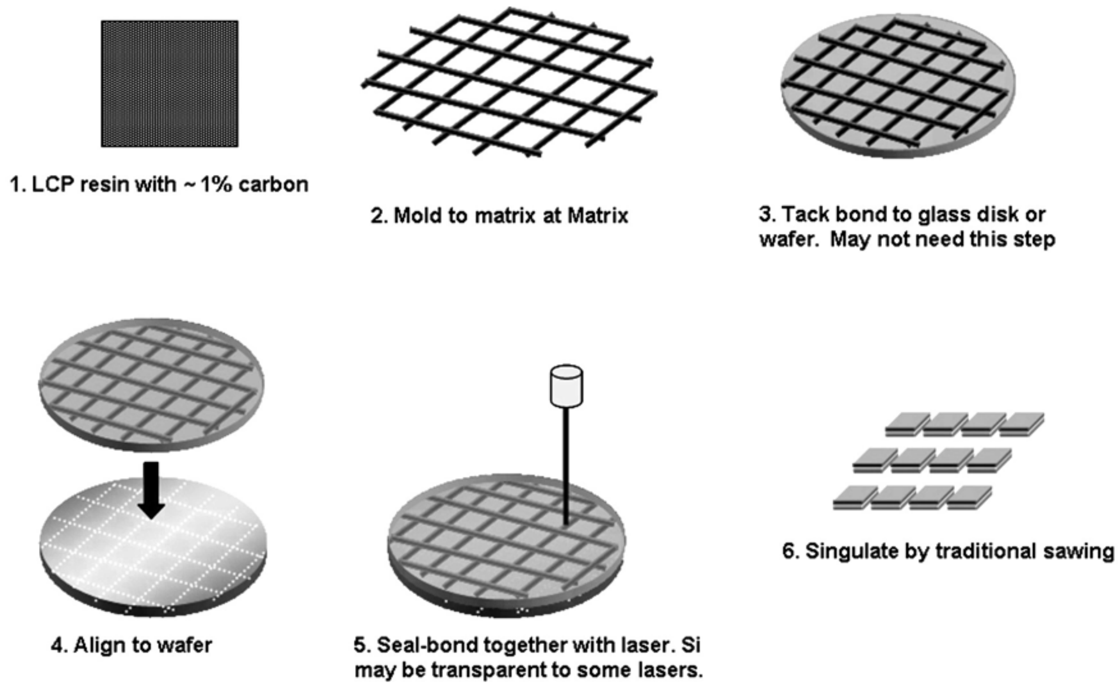

Figure 6 – WLP Laser Process

Plated LCP

We considered that a metal coating over the LCP caps might be necessary in the future and provided samples to Enthone for testing. First, a metal coating adds an additional barrier if we needed more protection than the LCP could offer. But the metal coating can also be used as an RF shield that could be required for RF-MEMS packaging. Enthone developed an electrolytic nickel-plating process as well as copper plating. The Ni coated had strong adhesion and could even be soldered without loss of adhesion. Enthone provided us with LCP caps with nickel and gold-over nickel and Figure 7 shows plated parts. No attempt was made to selectively plate the caps, but methods exist if this becomes desirable to provide a bare plastic edge for laser sealing. Alternately, a fully metallized cap could be sealed to a lid with solder to provide a high-level full hermetic package.

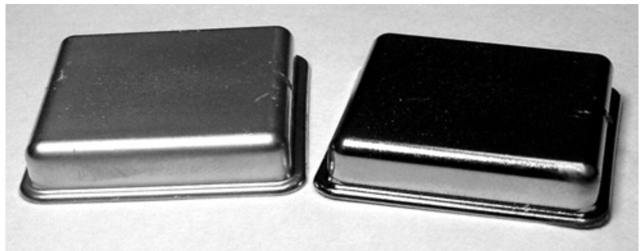

Figure 7 – Plated LCP Caps – Enthone (Polyclad)

Getters

We considered what could be done to boost plastic package performance if it became necessary. Since we did not expect to achieve such high He leak rate values, we worked on parallel approaches to improving the package interior. Getters were an obvious consideration. They are chemical scavengers that extract contaminants from the inside atmosphere of the package. In the case of MEMS with moving parts that can wear, particulate can be generated that will interfere with movement. Particle getters, sticky polymers with low outgassing, can be used and are available. Moisture getters are also commercially available that could be useful. The high moisture barrier of LCP suggests that a moisture getter may not be required for typical applications. However, an OE requirement of 5 to 20 years could benefit from a moisture getter.

Conclusion

Preliminary testing on package simulators indicated that plastic packaging might be able to provide a good level of hermeticity. If this is borne out in more extensive testing, then plastic packaging could be suitable for MEMS and MOEMS devices. The very long-term lifetime requirements for telecom optoelectronics do not allow us to extrapolate our conclusion to this class. The helium leak test, while generally accepted for metal and ceramic packages, may not be suitable for plastic. Plastic packaging of real devices, followed by extensive testing appears warranted on the basis of the preliminary data.

Acknowledgements

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Matrix Corp. (E. Providence, RI) produced the LCP caps.