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Opto-mechanical details in injection-molded assemblies

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ABSTRACT

With the advent of low-cost electro-optic components such as LEDs, laser diodes and CCD imaging devices, the cost and performance demands now fall upon the optical subsystems in order to achieve realistic marketing targets for many emerging commercial and consumer products.

One of the many benefits of injection-molded plastic optics is the diversity of features that are available to the design team. Once designed and incorporated into the tooling, many features are virtually free in high-volume production. These features can include mechanical details as well as optical functions. Registration features can be included for precisely positioning optical elements to one another or to other assemblies such as printed circuit boards or housings. Snaps, compression features, spring-loading elements, standoffs, self-tapping screws or ultrasonically weldable features can greatly facilitate ease of assembly.

Keywords: plastic optics, opto-mechanical, injection-molding, plastics characteristics

1. A REVIEW OF THE PLASTIC INJECTION-MOLDING PROCESS

In order to appreciate the design and integration of mechanical features into an optical component, a brief review of the injection-molding process is appropriate.

Injection molding is accomplished in a press that injects liquefied plastic resin into a custom tooling cavity representing the negative volume of the component to be manufactured. The press controls temperatures, pressures, and cycle times by computer control, as appropriate to the component and the characteristics of the chosen plastic resin. Once the press appropriately cools the component to a stable solid state, the press pulls the tool apart and ejects the component.

Figure 1 illustrates the basic functions of an injection molding press. Dried plastic resin beads are placed into the hopper. Upon demand, the beads are fed into the injection screw to form a melt that is delivered to the tool. The temperature of the melt is specific to the material and the appropriate melt flow requirements for the particular component. The thermal profile of the melt along the injection path is precisely controlled by the heater bands.

The mold tool consists of a mold base and custom plates and/or inserts machined to the requirements of the component design. A typical tooling plate is illustrated in Figure 2. Tool-grade stainless steel is used to accommodate the extreme pressures of the molding process without distorting. The mold is designed to take shrinkage of the selected resin into account. The component is designed with appropriate draft angles and a defined parting line. Details on one side of the parting line are formed by the stationary tooling plate while details on the other side are formed by the movable tooling plate (for example, the two sides of a lens). Non critical areas on the moveable side of the component are defined for contact by the ejector pins, which push the part out of the mold after cooling (for example, the bezel of a lens). A number of ejectors are placed so that they will not warp the component. But they often leaves marks on the component. The tool also includes venting to allow the escape of air displaced by the plastic, and heating and cooling channels for temperature control. More than one component can be molded at a time in a tool. This is called a multi-cavity tool, which increases production volume and reduces the cost of the component.

The optical surfaces and many of the intricate mechanical features in a tool are formed on inserts that are then mated and locked into the tool. Plano and spherical inserts (or pins) are generally formed with familiar grinding and polishing techniques. Aspherics and toroids are generally diamond-turned. Tooling will typically cost about $10,000 for a simple single-cavity lens, on up.

The clamp cylinder parts and joins the tool halves, and determines the size of the press in tonnage determined by the area of the component and its runners projected into the plane of the parting line times the injection pressure required for the particular resin. (For example, a 3 sq. inch lens x 18,000 psi = 27 ton clamping.) When the press and the material have reached a thermal equilibrium, the clamp cylinder joins the tool, the screw drives the melt into the tool through the nozzle. The melt channels in the tool through the sprue, runner and gate into the component cavity. (These features are visible in Figure 2.) The cooling cycle allows the resin to solidify to the point where it will not warp upon ejection, and in conjunction with pressure and temperature cycle profiles, it determines the precision of the component. The thicker and more precise the component, the longer the cycle time. Cycle time is the predominant factor that determines the production cost of the component.

A gating area must be defined on the component when it is designed. As shown in Figure 3, a fan gate is most common to optical components. A diaphragm gate provides excellent distribution of the melt if the component can tolerate a hole in the middle. The location of the gate should be chosen to allow the most laminar flow of the melt in the regions of the most critical surfaces. The size of the gate will have an impact on surface quality, and some room should be left for its enlargement if required for the process to achieve the desired quality. Small gates can be automatically removed (degated, with the runner and sprue stub) from the component after molding. Larger gates will have to be removed by secondary operations ranging from manual breaking or cutting to sawing or machining.

The process for optics is much more refined than for conventional mechanical components. Each vendor has his own proprietary techniques to improve the process. Specialties and costs vary significantly. A design should be "shopped around" before it is finalized since each vendor will have various suggestions on component design features that will improve quality and reduce costs in their specific operations environment.

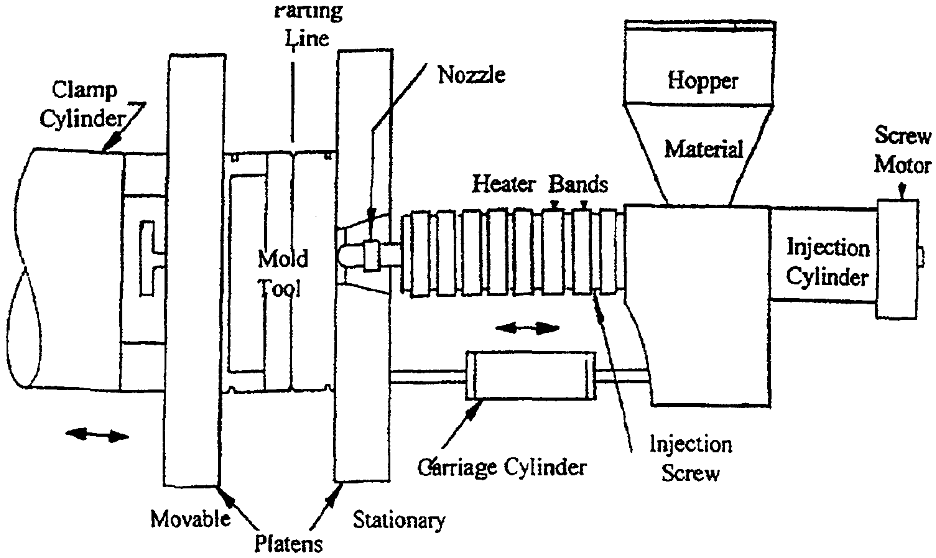


Figure 1- Elements of an Injection Molding Press

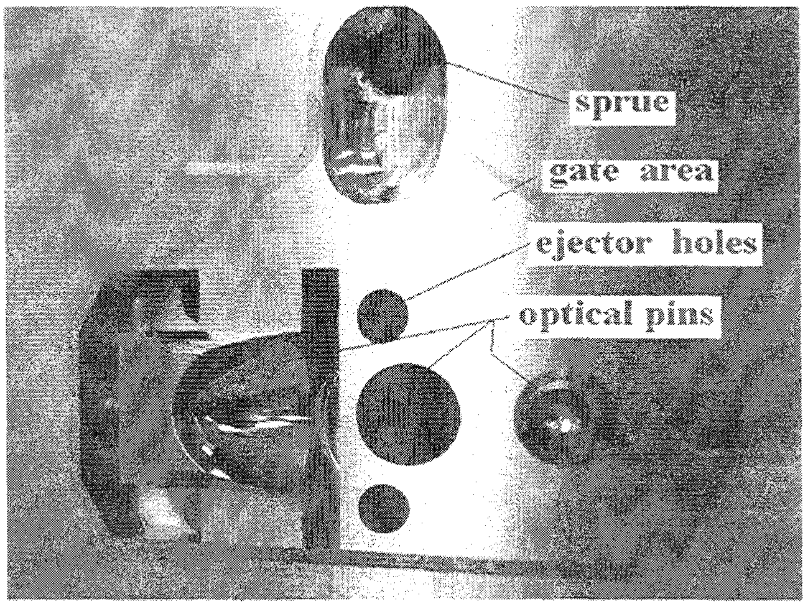
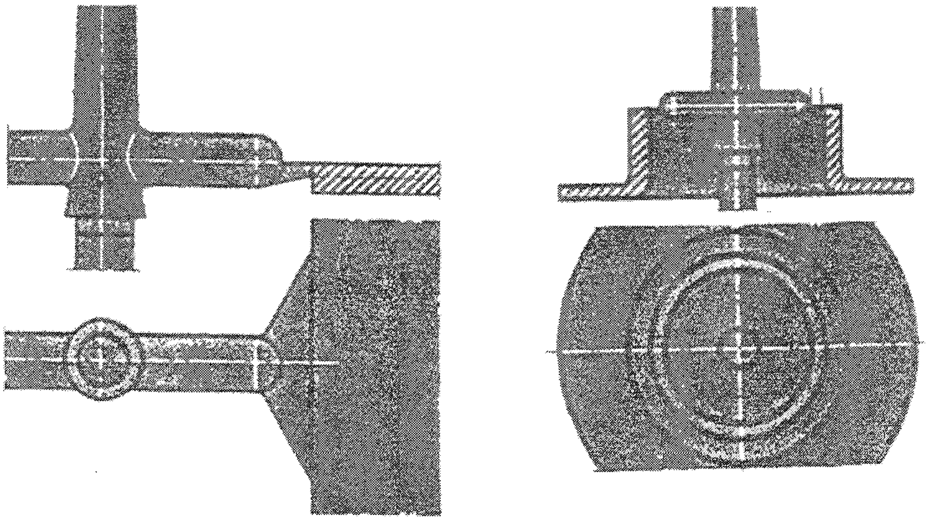


Figure 2- Typical Tooling Plate Details



FAN GATE **DIAPHRAGM GATE**

Figure 3- Common Gate Configurations for Melt Flow into the Component

2. SELECTION OF A PLASTIC MATERIAL

The optical and mechanical characteristics of common optical plastics are tabulated on the following page, as well as characteristics of BK-7, aluminum and steel for comparison.

Of these materials, acrylic, polycarbonate and polystyrene are the primary optical injection molding materials in that they are best characterized and most repeatable. Obviously, there are considerable differences in both mechanical and optical characteristics, and the choice of resin must best fit both aspects of the application.

Some of the most significant mechanical differences are in the areas of service temperature, impact resistance and abrasion resistance.

Plastic resin vendors offer many design aids in the form of in-depth materials specifications, molding parameters and mechanical design guidelines.[1,2]

3. DESIGN EXAMPLES

Of course, the variety of moldable optical and mechanical features is limitless. We will simply present a few examples to inspire your imagination.

Figure 4 is an example of the detail that can be placed into the bezel of a lens. A bezel on a lens has a number of benefits to a molded component. It can provide stiffness to the

MATERIAL:	Acrylic (PMMA)	Polycarb	Ultem 1000 (GE)	Polystyrene	Styr. Acrylonitrile (SAN)	Copolymer (NAS)	Copolymer (Cyc.Olefin)	Casting Resin (CR-39)	ABS	BK-7 (Glass)	Alum	Steel
Refractive Index n_f (486 nm)	1.496	1.600	1.687	1.604	1.578	1.575		1.510		1.522		
n_d (589 nm)	1.491	1.586	1.660	1.590	1.569	1.563	1.53	1.504	1.538	1.517		
n_c (656 nm)	1.488	1.580	1.651	1.584	1.563	1.558		1.501		1.514		
n_s (852 nm)	1.485	1.572		1.576	1.555							
Bandpass (nm)	Typ 390 to 1620, 1750 to 2100											
Abbe Value ($v=(n_d-1)/(n_f-n_c)$)	61.4	27.0	18.3	30.8	37.8	34.7	58	56		64.6		
dn/dt ($x10^{-6}$/°F)	-47	-79		-67		-78		-79		+1.67		
Haze (%)	2	3		3	3	3			12			
Luminous Transmission (%/.125")	92	89		88	88	90	91	93	85	92		
Critical Angle @ 589 nm	42.1	39.1	37.0	39.0	39.6	39.8	40.8	41.7	40.6	41.2		
Relative Birefringence (0 to 10)	4	7		10				2				
Relative Cost (0 to 10)	5	7		2		4			1	10		
Density (lb./cu. in.)	.043	.044	.043	.039	.039	.039	.037		.038	.091	.098	.28
Max Service Temp (°F)	170	240	340	175	175	175		210	170	-		
Deflection Temp (°F, 264 psi)	190	265	390		215		170-340		200			
Molding Temp. (°F)	450	500	700				400-600					
Therml Coeff (in/in/°F $x10^{-6}$)	40	38	31	35	40	36	33	68	48	4	12	7
Thermal Conductivity (K)	1.2	1.1	.85	.25	.70	1.1		1.2	1.4	7	1560	320
Mold Shrinkage (%)	.4	.7	.7	.4	.4	.2	.7	14	.5			
Izod Impact (ft.lb./in.)	.4	15	1	.4		.3			5	.1		
Abrasion Resistance (0 to 10)	10	2	2	4		6				3000		
Water Absorption (% wght)	.3	.15	.25	.2	.3	.15	<.01	.2				

lens for better surface quality. It can provide a buffer zone between the optical clear aperture and the gate stresses. And it can provide registration detail between its lens and other elements. In this case, it also provides an 'O'-ring seat to seal an air-spaced doublet.

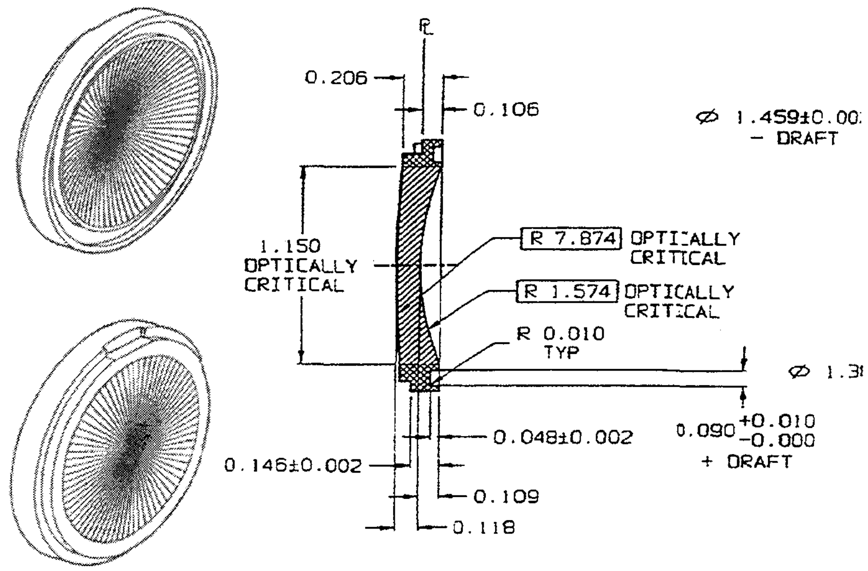


Figure 4- Lens Bezel Example with 'O'-Ring Seal

Another example is presented in Figures 5 through 7 in the form of an omnidirectional barcode scanner incorporating all-plastic optics. This design employs nine plastic components; six of which include optical as well as mechanical functions. These components utilize mechanical features which compress, snap and slide into one another to minimize assembly tasks and tolerance buildups. The scanner cone is an example of a diaphragm-gated component. The snap feature retains the inner glazing; the spring feature registers an outer glazing for OEM-customized silkscreening; and the swage connect is a hexagon hole/round pin press-on feature to integrate the cone into the molded housing.

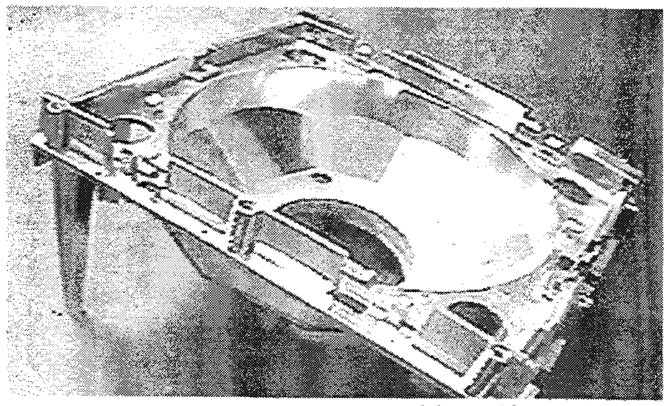


Figure 5- Scanner Cone with 11 Flat Facets

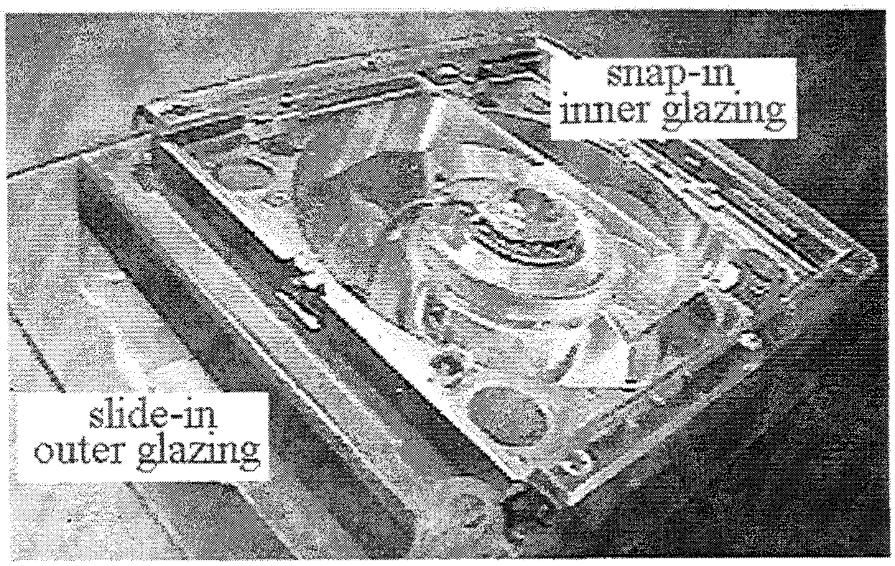


Figure 6- Scanner Assembly

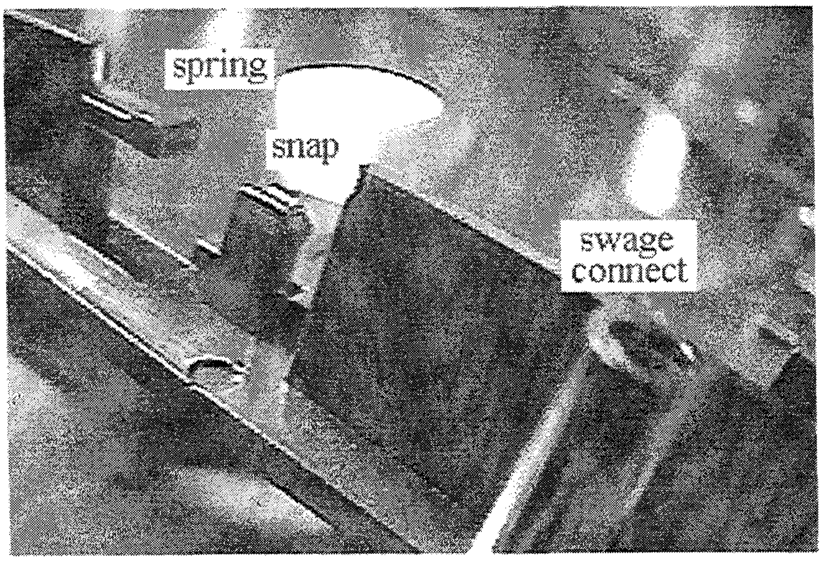


Figure 7- Mechanical Assembly Features on Cone

Finally, an example of mechanically configuring multiple off-axis optical elements into an internally-reflective waveguide structure for fingerprint imaging is presented elsewhere in this conference[3].

4. CONCLUSIONS

The flexibility of injection-molded plastic optics has been illustrated in terms of optical and mechanical detail. The injection molding process, tooling and available materials have been briefly reviewed as they relate to the implementation of these details.

The inclusion of mechanical detail into an optical injection mold clearly offers a number of advantages in terms of precision alignment and ease of assembly. In general, the optical surfaces must be given first priority in a design process in order to hold surface tolerances. Uniformity and continuity of melt flow, and relative isolation of stress-forming features are important to the optical surfaces.

Selection of an injection molding vendor is an important step in the early design phase of a product in order to benefit from their process-specific experience.

5. REFERENCES

1. G.E. Plastics, "Lexan® Design Guide", General Electric Company,One Plastics Ave, Pittsfield, MA 01201

2. Plastics Technology Center, AtoHaas, 215-785-8290

3. R.T. Hebert,."Off-axis optical elements in integrated, injection-molded assemblies", paper 2600-19 elsewhere in this publication.