Optomechanical Aspects of Plastic Optics

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Compared to glass-based optics plastic optics shows quite different optomechanical properties. Consequently several aspects such as i.e. wavefront error budgeting, or functional integration or fabrication related issues have to be adapted to these properties. The paper discusses optomechanical figures of merit and shows examples of plastic optics with high functional integration and discusses.

1 Introduction

Plastic optic elements offer a large variety of advantages such as: more than two times lighter than glass, cost effective for high volumes, aspheric and diffractive surfaces can be created as easy as spherical surfaces, integration of optical mounts, shatter-resistant, and rapid molding cycles (30 – 600 sec.). However, on the other side disadvantages as for example: environmental sensitivity, few optical grade plastics, shrinking effects must be accounted for (0.1 – 0.8%), tooling expensive for low volume runs, coatings do not bond as well (low temp. used 35 – 40°C), difficult to clean and must be handled in clean environment [1-3].
Therefore in comparison to glass-based optical systems, aspects like functional integration, additional issues in a wave-front error budget and different optomechanical figures of merit have to be considered [4].

2 Optomechanical figures of merit

Since plastic optics not only allows the integration of optical but also mechanical, fabrication-related and assembly features the material choice plays an important role. Optomechanical figures of merit are defined as characteristic numbers for a certain material under a specific optomechanical influence. Figures of merit for a comparison of the vibrational, thermo-optical, and thermo-mechanical related material properties are listed in Tab. 1. It easily can be seen that, compared to aluminum or glass almost all plastic optical materials show one to two orders of magnitude different optomechanical figures of merit.

property		resonant frequency	refractive index change	steady-state distortion coefficient	transient distortion coefficient
figure of merit		$\sqrt{\frac{E}{\rho}}$	$\frac{dn}{dT}$	$\frac{\alpha}{k}$	$\frac{\alpha}{D}$
unit		$\left(10^{-6}\frac{\mathrm{Nm}}{\mathrm{kg}}\right)^{0.5}$	$10^{-6}\frac{1}{\mathrm{K}}$	$10^{-6}\frac{1}{\mathrm{K}}$	$\frac{\mathrm{s}}{\mathrm{m}^2\mathrm{K}}$
preferred		large	small	small	small
COC	Topas®	1.73	-10.4	394	-
PC	Lexan®	1.41	-14.3	346	500
PMMA	Plexiglas®	1.59	-8.5	344	573
glass	N-BK7	32.27	2.8	6.4	13.7
aluminum	AlMg1Si	25.92	-	0.13	0.33

***Tab. 1** Figures of merit for some typical optical plastics such as cyclic polyolefine (COC), polycarbonate (PC), poly-methylmetacrylate (PMMA) in comparison to glass and aluminium.*

3 Functional integration

By its totally different fabrication process injection-molded plastic optics offers a large variety of surface shapes and structures easily allows to implement several optical, mechanical and even electrical features. A fully optimized polymeric optical system can not only make use of aspheric technology and integrally molded features in the optical elements, but embodies an extension of this design philosophy into the lens housing concept and assembly strategy.

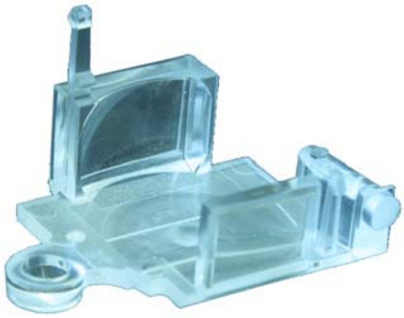

Fig. 1 *Monolithic view finder module of a single-use totally plastic camera. The module integrates several optical, mechanical, fabrication- and assembly-related features.*

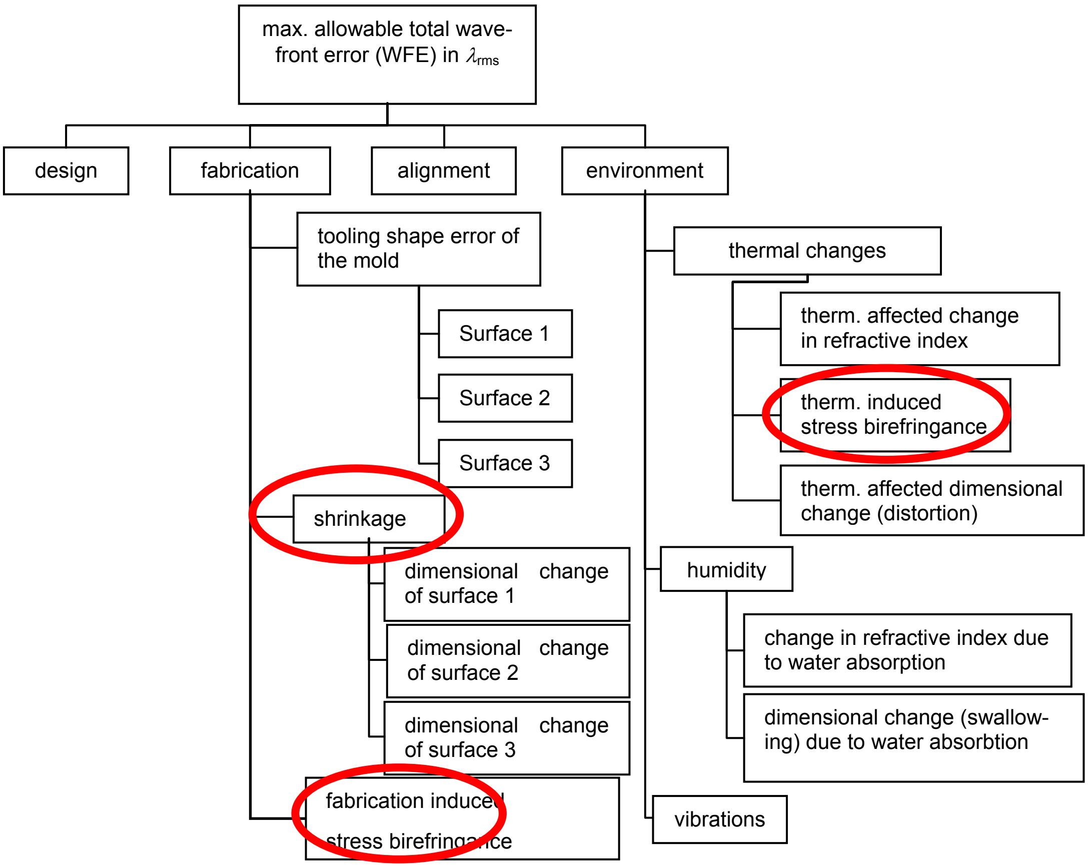

Fig. 2 *Wavefront error (WFE) budget for a polycarbonate monolithic 45° Prism with two spherical surfaces and integral mounting flange.*

The monolithic view finder module from a simple single-use plastic camera shows three optical features (view finder lens pair, exposure number magnified display and LED flash control display) and several mechanical features, such as a base-plate structure to hold all optical elements, snap-fit hooks and ridges to fix and position the module in a assembly suited manner (cf. Fig. 1).

4 Wavefront Error Budget

In order to achieve the performance requirements under any of the functional and environmental conditions a tolerance budget may help how to distribute the totally allowable wave-front error (WFE) among the many facets and tolerances of the system. With respect to plastic optical elements especially dimensional changes due to shrinkage, fabrication-induced and thermally-induced stress birefringence have to be considered. Furthermore contrary to glass-based elements moisture affects dimensionally changes (warping and swallowing) (cf. Fig. 2).

5 Conclusion and Outlook

From an optomechanical point of view further research has to be done concerning the following issues:

The current mold flow analysis tools for injection molded optics have to be improved both, with respect to optical precision and birefringance simulation. Especially for the latter, interfaces to determine the Jones Matrix from mold flow data has to be developed. A further issue to be investigated are plastic optical materials. Here, new materials, with high refractive index, low-birefringance, better environmental stability are required. Furthermore, research on moisture absorption and the optical impact on these materials have to be done.

References

[1] J.D. Lytle: “Polymer Optics ”, in *Handbook of Optics*, *by M. Bass*, *E. W. Van Stryland*, *Optical Society of America*, *D. R. Williams*, *William L. Wolfe* (eds.), 2nd ed., Vol.2, McGraw-Hill, New York, (1995).

[2] R.R. Willey and R.E. Parks: “Optical Fundamentals”, in *Handbook of Optomechanical Engineering*, A. Ahmad (ed., CRC Press, LLC, Boca Raton (1997).

[3] Corning Precision Lens Inc.:”The Handbook of Plastic optics“2nd Ed., Cincinnati (OH), (2000)

[4] M. Pfeffer: „Optomechanics of Plastic Optical Components“ in *Handbook of Plastic Optics*, S. Bäumer (Ed.), Wiley-VCH: 156-187 (2005).