5th International LED professional Symposium +Expo

LpS *2015* | Sept 22-24, 2015 | Bregenz

Sensitivity of the optical performance of LED illumination systems to manufacturing tolerances

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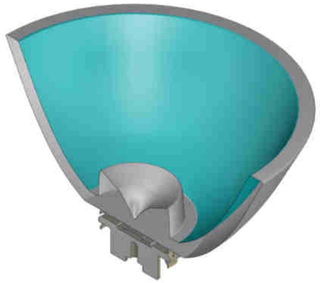
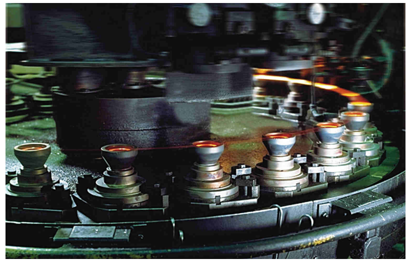
Auer Lighting GmbH

- German based Member of ADLT Group (US)
- Lighting expertise with R&D
- Complete tool shop in house
- Pressing capabilities (direct, injection molding, precision molding)
- Production of borosilicate glass (Suprax® 8488)
- Coating with sputtering and PICVD techniques





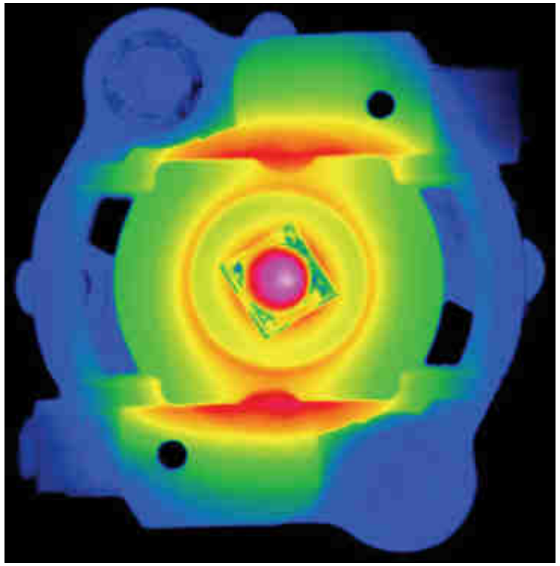
Overview

- ❑ Introduction
- ❑ Glass production techniques & challenges
- ❑ Optical development
  - ❑ Example 1: High-Bay free-form lens
  - ❑ Example 2: TIR collimator for general lighting
- ❑ Summary

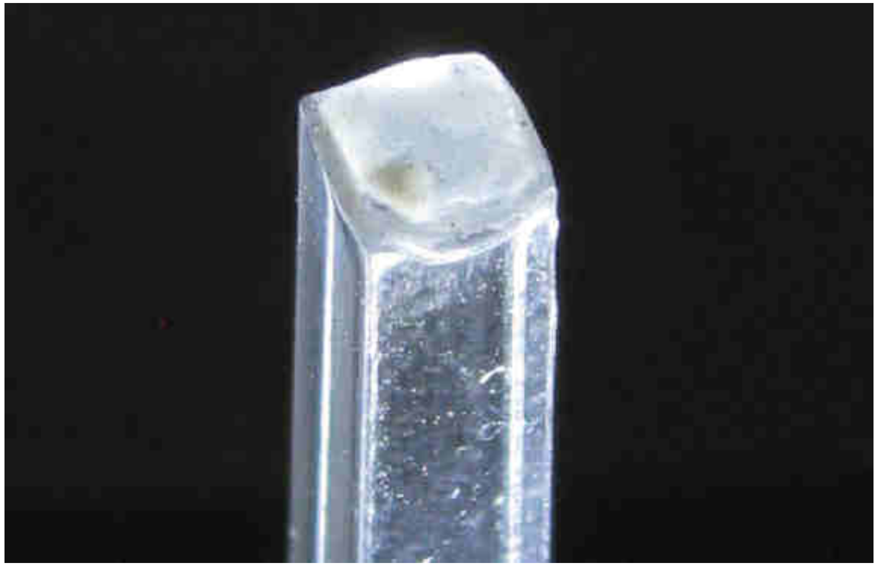
Introduction

- Remarkable market growth of high and super high power LED solutions
  → chip temperatures and luminous flux densities have increased
  → high demand for durable optics

- Increasing request for glass due to its superior properties (particularly its higher temperature stability) in the automotive and stage lighting industry + also benefits for general lighting applications (long-term stability)



Thermography image of a COB LED [Fraunhofer IWM].



PMMA light guide irreversibly damaged by moderate LED radiation.

Introduction

- Uncertainty among customers regarding the required surface accuracy of optics
  → to be on the safe side requirements are specified close to the technical limit
  → increase of the total cost of ownership without any benefit

- Discussion about typical manufacturing tolerances and their consequences on the optical performance

- Examples of two optical designs with direct implementation of manufacturing constraints and positioning tolerances

Glass production techniques

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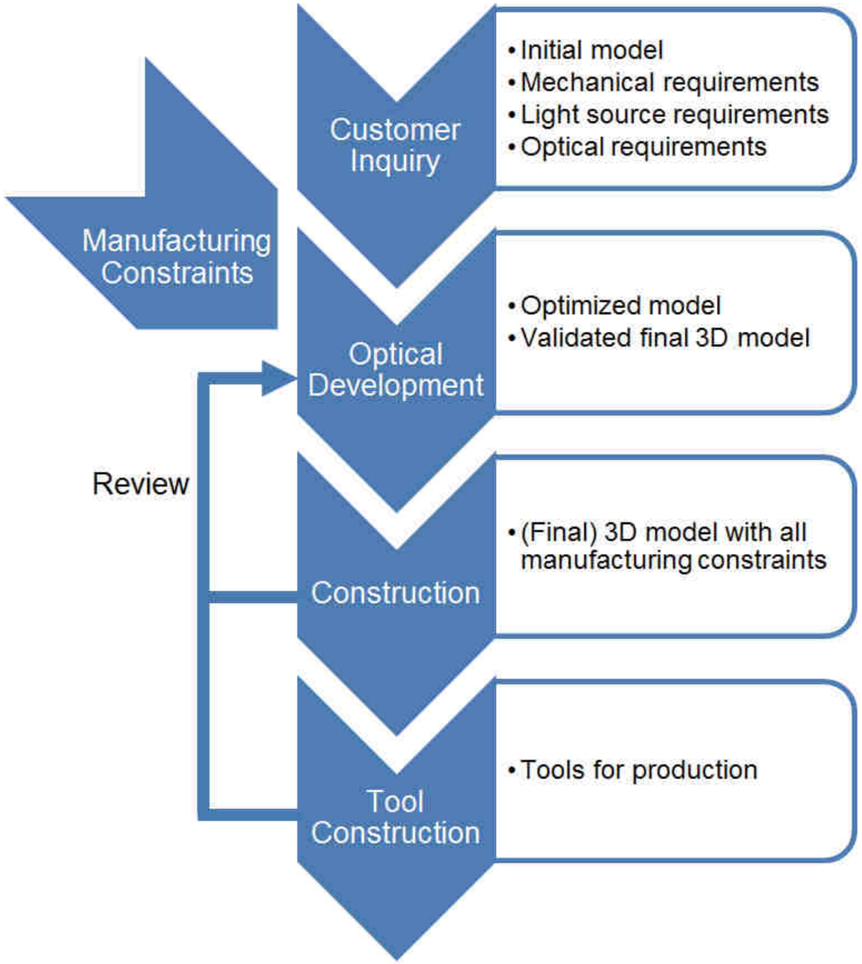
Available pressing techniques with respect to the specific application and requirements:

	Direct pressing	Precision molding	Injection molding
Characteristic	Cost efficient	Highest precision	Highest degree of geometrical freedom
Example products	 		
Method	Optics is pressed directly from the liquid phase	A glass preform (Gob) is heated to the softening point and then pressed	Liquid glass is pressed from a reservoir into the mold
Pros	• One process step only • Cycle time is in the order of seconds → high output, low costs • High quality surface and shape accuracy of about 50 µm	• Lower processing temperatures • Potentially highest precision • Deviations below 1 µm for imaging optics • No shear marks	• No shear marks • Undercuts possible • Optics with high aspect ratio (length/width) possible
Cons	• Shear marks and/or flow-lines in the glass possible • Glass shrinkage • Mechanical post-processing (polishing) can be necessary	• Long cycle times → low output, high costs • High quality gobs required	• Very precise molds required • Expensive press equipment

Optical development

- ❑ Potential surface irregularities and their influences on the optical performance can already be simulated during the early optical design stage
- ❑ Closed loop with tool shop
- ❑ Development cycle of LED optics:



Example 1: High-Bay free-form lens

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Inquiry

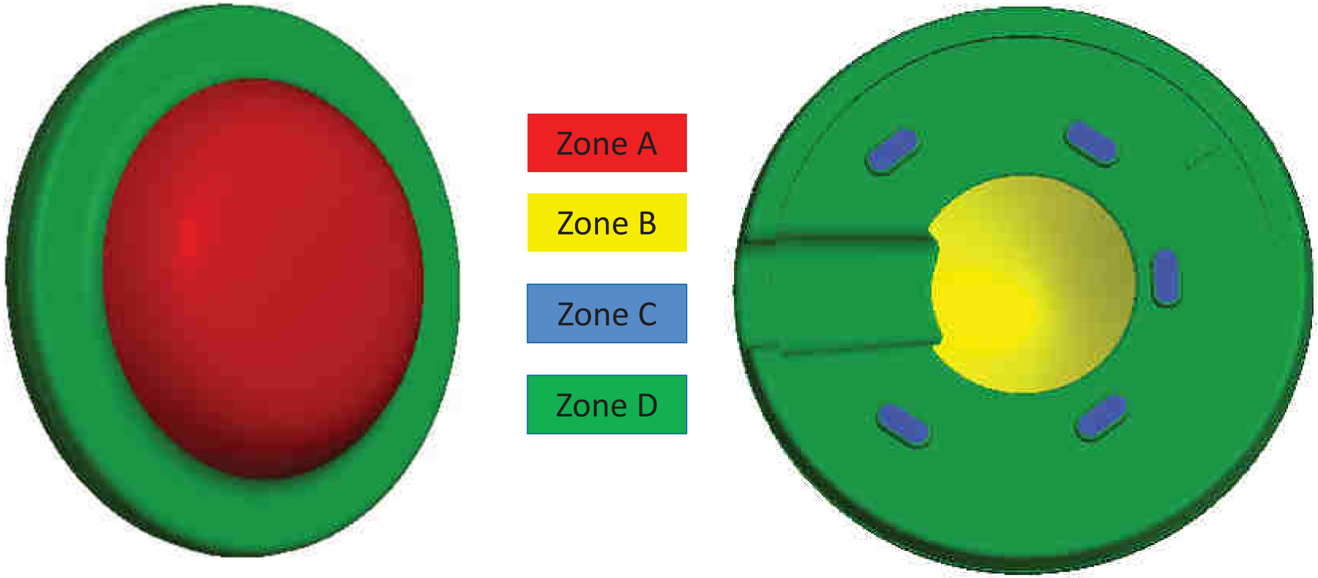
- **“Development of a family of interchangeable lenses for a high bay luminaire system”**
- Mechanical requirements: limited available space, geometrical positioning information
- Light source requirements: defined LED data consisting of a ray data set
- Optical requirements: Unique light distributions (max. lum. intensity @ ±60°)
- Pricing: target price as low as possible → direct pressing

Optical Development

- Ray-tracing optimizations
- During optimization characteristics of the hot forming process were implemented:
  - the variation of the material thickness was minimized for an minimized shrinkage
  - additional features, required for electrical connection and LED positioning

Example 1: High-Bay free-form lens

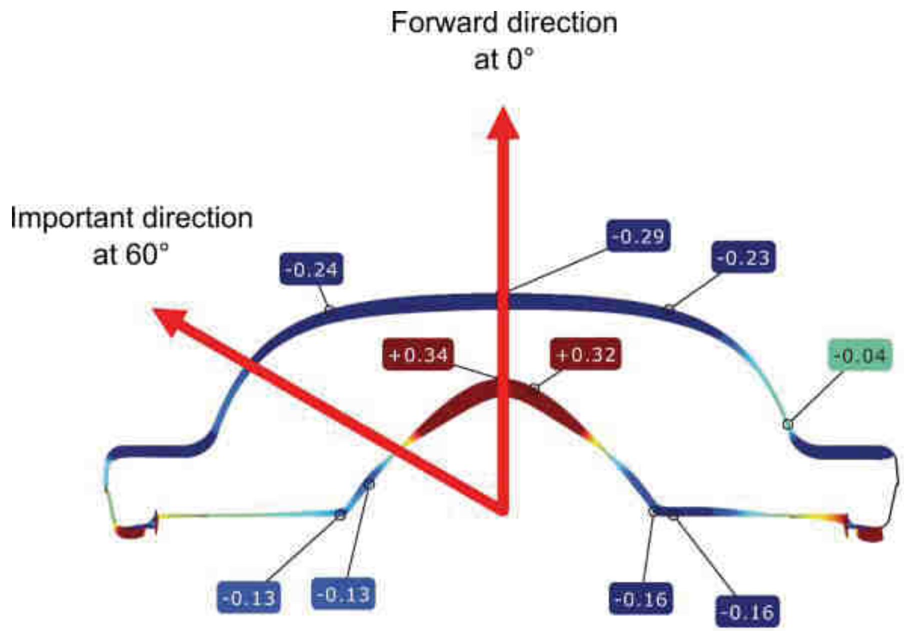
- Lens surface are subdivided into different zones of optical importance:



- Zones A and B: optical surfaces → require the highest precision
- Zone C: positioning elements for LED module → require only high accuracy in lateral direction → tolerance analysis of the LED position: maximum deviation should be ≤ 0.3 mm (in general no problem for the hot forming process)
- Zone D: non-optical surfaces → no special accuracy is needed as long as the geometrical dimensions required for the lens mounting are fulfilled

Example 1: High-Bay free-form lens

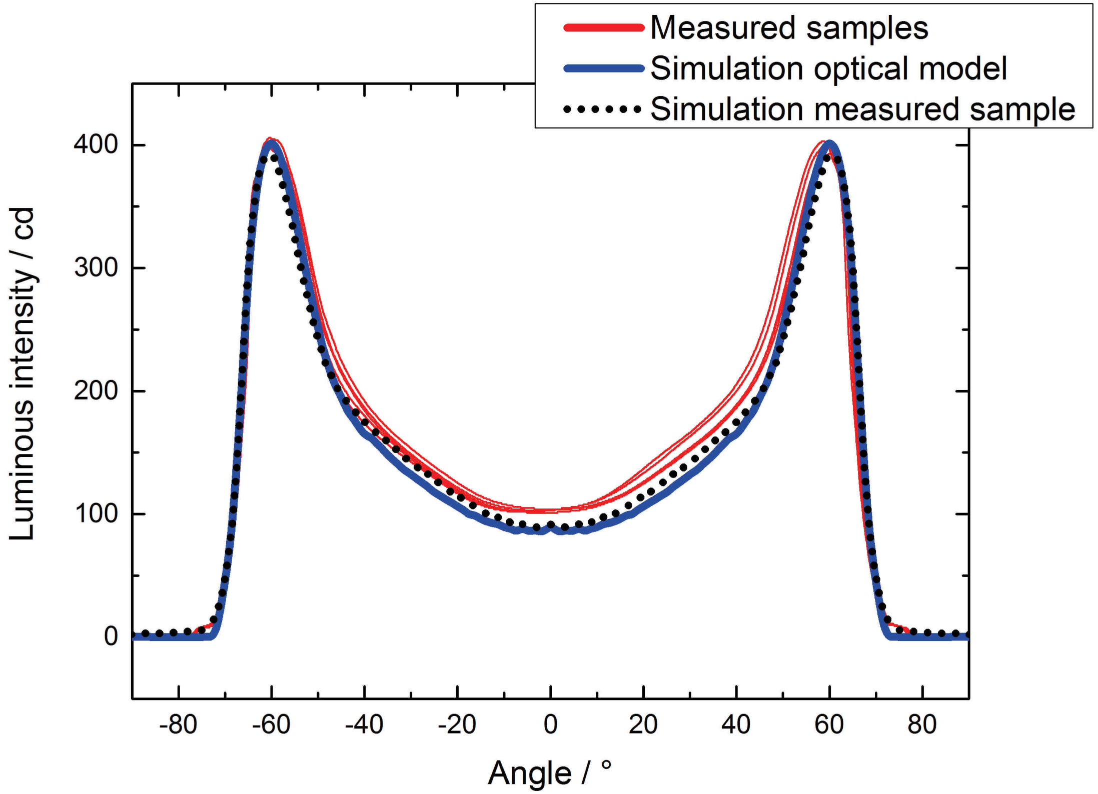
- After the initial sample production the lens was measured for dimensions and optical performance:



- The maximum deviation occurs in the center, which is only responsible for the on-axis emission

- The important fraction (for the 60° emission) of the optical surface has typical deviations of 0.1 mm

Example 1: High-Bay free-form lens



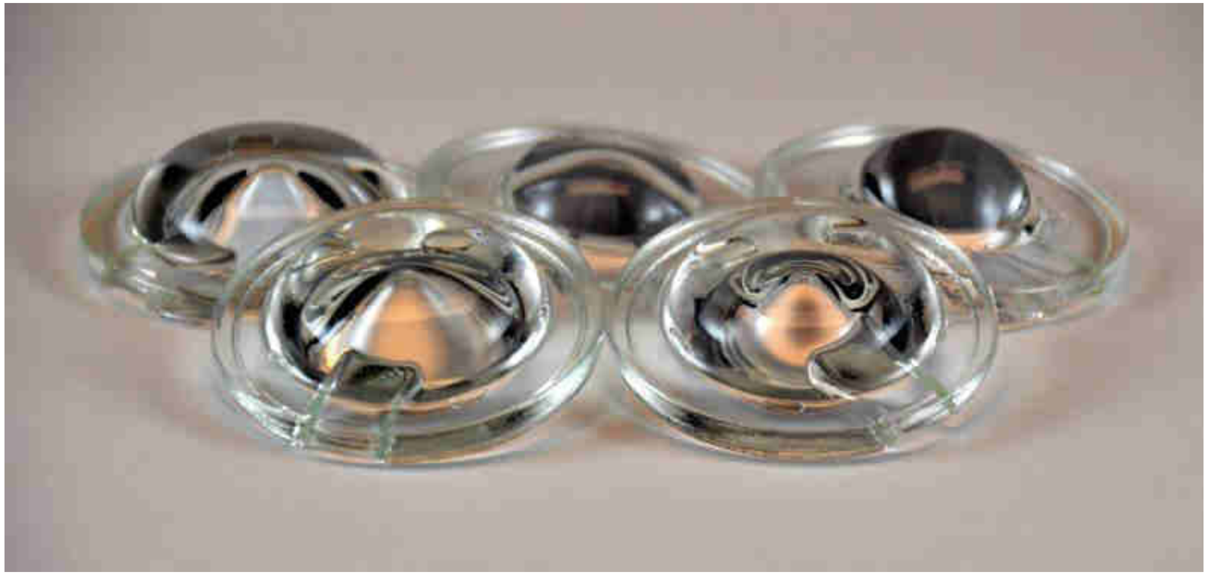
Light distributions of the optical target model and the measured contour are compared to the measured sample lenses.

- ❑ Development target is consistent with the measured light distribution
  → important features of the distribution at ± 60° are matching the requirements

- ❑ Remaining differences to the measured light distribution are primarily caused by a deviation between the real LED and the ray file used for the development

Example 1: High-Bay free-form lens

- The final product was produced in a direct glass pressing process
- No post processing was needed → cost-efficient product
- Both, the groove for the electrical contact of the LED and markers for the LED module positioning fulfill the customer’s requirements



Produced free-form lens family for LED high-bay applications.

Example 2: TIR collimator

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Inquiry

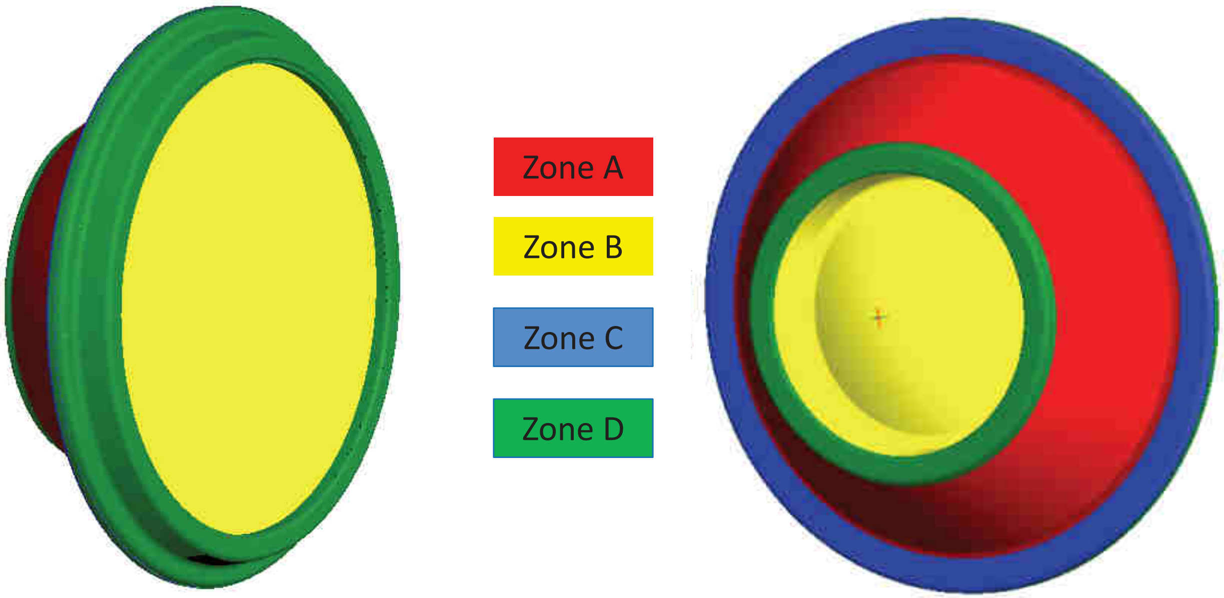
- **"Development of a collimator lens for a general lighting retrofit system"**
- Mechanical requirements: geometry restrictions: ∅ ≤ 51 mm
- Light source requirements: defined COB LED data consisting of a ray data set
- Optical requirements: 40° (±10%) beam angle, Maximum luminous flux on a wall in 3 m distance
- Pricing: target price as low as possible → direct pressing

Optical Development

- Ray-tracing optimizations
- During optimization characteristics of the hot forming process were implemented: Corner radius of the inlet lens

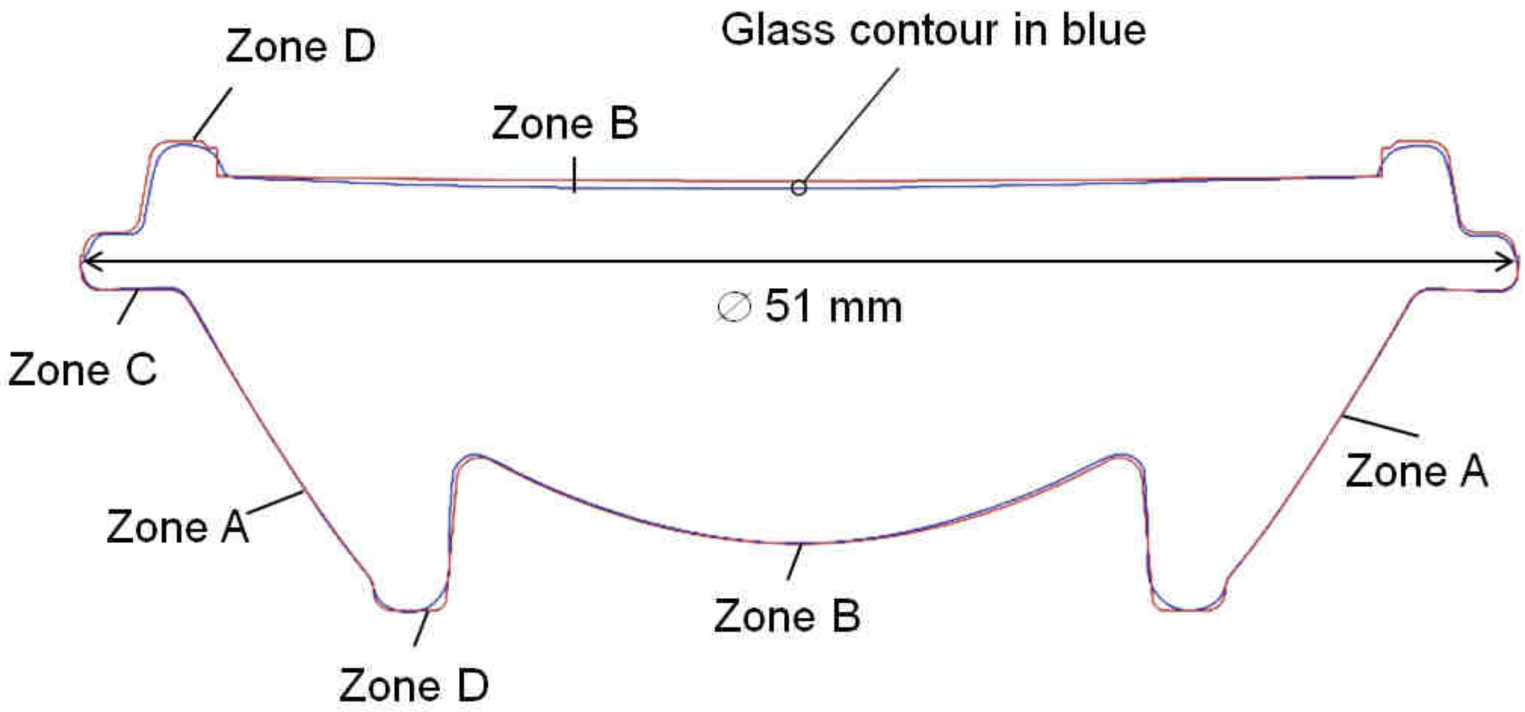
Example 2: TIR collimator

- All surfaces are subdivided into four zones of importance:



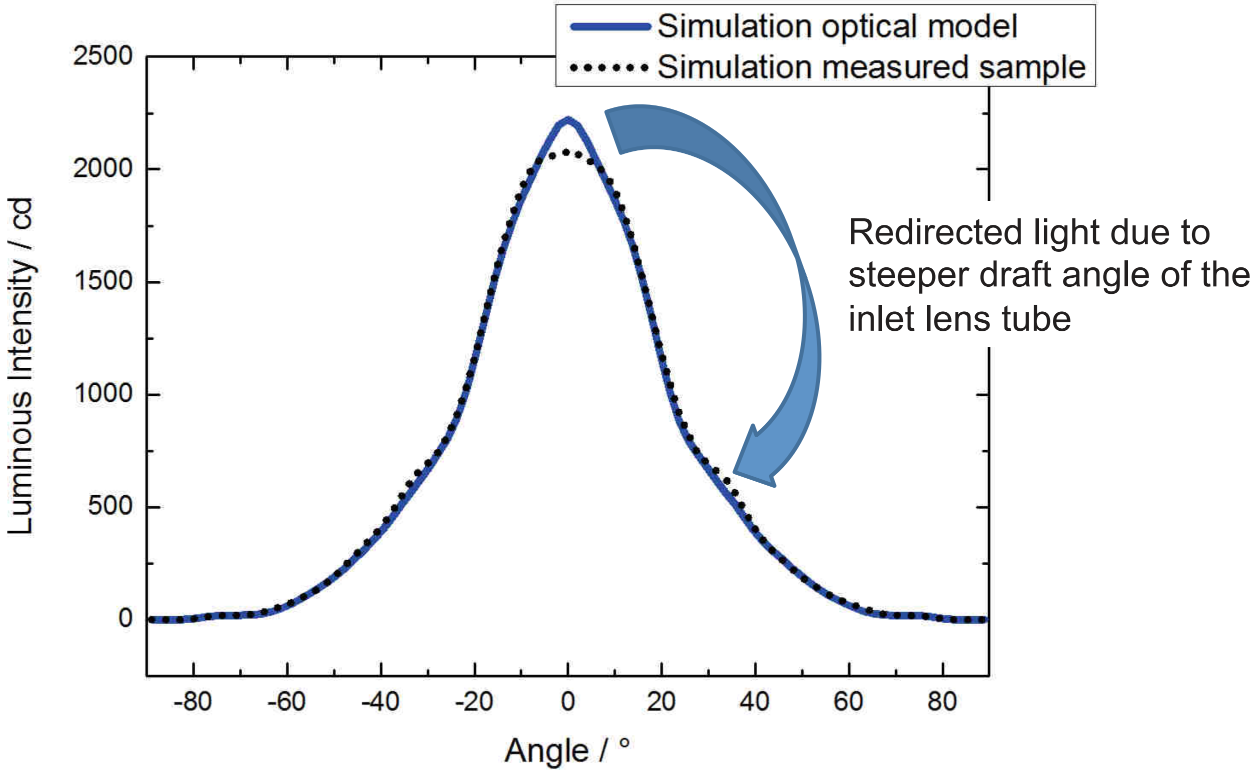
- Zone A: optical TIR surface → impact on the light collimation and beam angle
- Zone B: optical surfaces → responsible for the light refraction
- Zone C: positioning functions → geometrical tolerances should be as low as possible
- Zone D: non-optical surfaces

Example 2: TIR collimator



Contour control plot for a produced glass sample compared to the optical model.

Example 2: TIR collimator

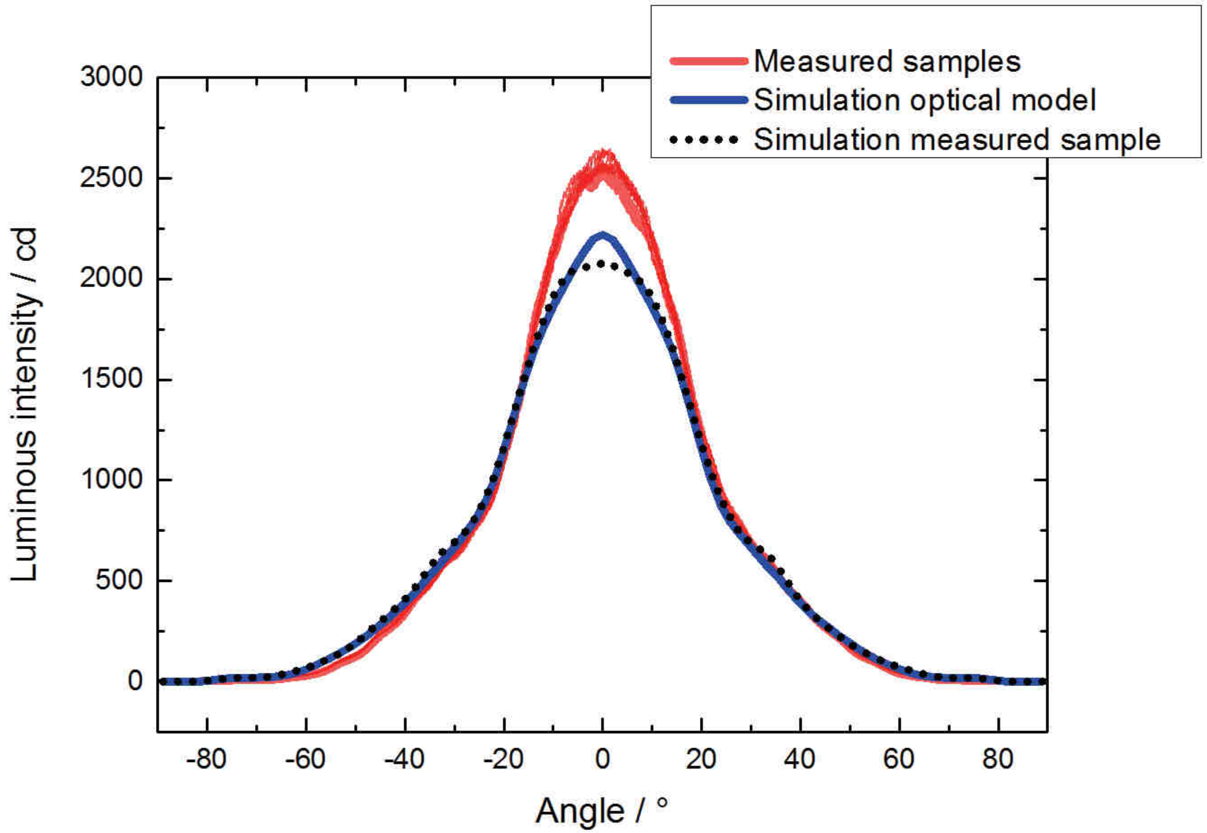


Comparison of the simulated luminous intensity distributions for the optical model and measured sample.

- Part of the center beam is directed into higher angles around 35° <> steeper draft angle of the inlet lens tube / shrinkage

- Beam angle is still within the specified 40° (±10%) window and the luminous flux remains almost unchanged

Example 2: TIR collimator

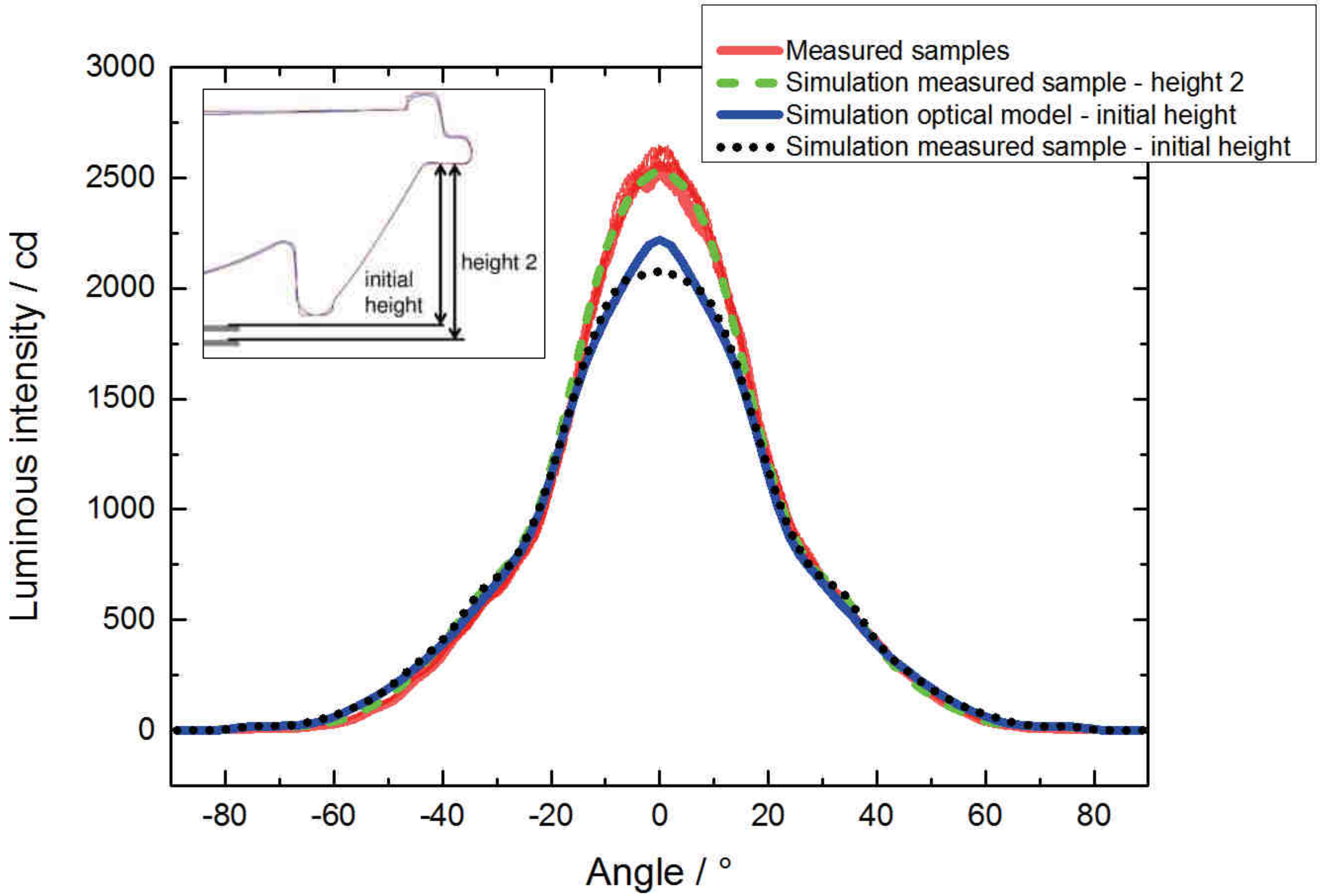


Comparison of the measured and simulated luminous intensity distributions.

- Measured samples in the retrofit module show a significantly higher maximum intensity, but loss in the optical efficiency / luminous flux on the wall

→ identifying cause via optical simulations

Example 2: TIR collimator



Optical simulation with lens shift to height 2.

- Simulations revealed a mounting height difference of 0.8 mm between the customer fixture and the initial simulation height

Example 2: TIR collimator

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- Maximum contour deviations are occurring at the exit lens in the order of 0.3 mm

  → almost no effect on the light distribution

- Most important TIR surface and entrance lens surface show typical deviations of 0.07 mm

- Measured beam angle shows a good agreement with the development target

- Comparison of measured and simulated light distributions reveals positioning inaccuracies between both optical setups

  → correct positioning of the optics and LED(s) in the fixture is essential and in own responsibility of the customer.

TIR collimator from Suprax® 8488

Summary

- A still common subject for discussion is the technical feasibility of very small features in illumination optics especially when made from glass

  → Overview of possible pressing technique characteristics and their early integration into the optical development

- Two lens examples have shown that the following points in particular can show a higher impact on the optical performance than typical lens contour deviations:

  - deviations between LED data provided by supplier and real LED distribution:
    - chip size and height are often specified with a 0.5 mm tolerance
    - color deviations over angle and deviations between real light distribution and ray file are observed on a regular basis

  - poorly positioned components in a lighting fixture:
    - compressibility of gaskets
    - processing tolerances

Summary

- LED tolerances and the later fixture assembly play a major role for deviations from a desired optical performance

- Usually no tolerance analysis of the whole lighting system is performed

  → expensive, overly precise optical surfaces and delicate features are requested to be on the safe side

- The day-to-day business of Auer Lighting GmbH shows that customers are very satisfied with the usage of glass in a wide array of applications and market segments

- Driving motivation for using glass optics or for exchanging limiting polymer parts in lighting fixtures:
  - high optical and long-lasting performance
  - temperature stability (mechanically & optically)
  - no yellowing / UV stability

Thanks for your attention.

Meet us at our booth A21.

Hybrid-reflector from non-glare line "Jupiter"

LED light guides for color mixing and beam shaping