Designing Light Guides for Illumination Systems

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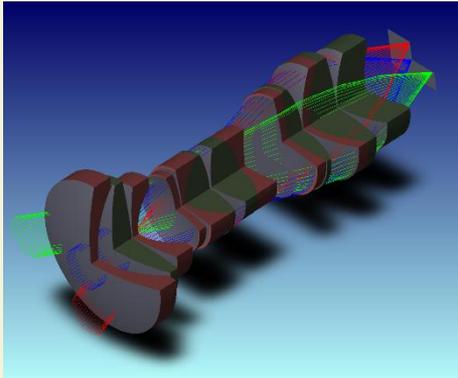
Keywords: optical design, illumination, consumer optics
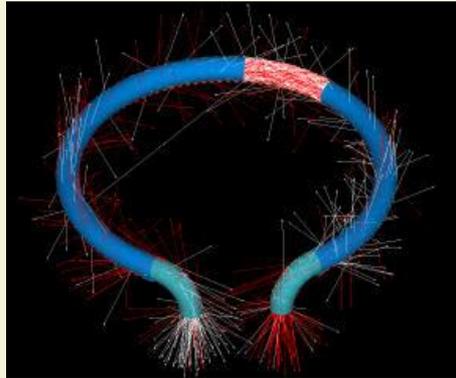
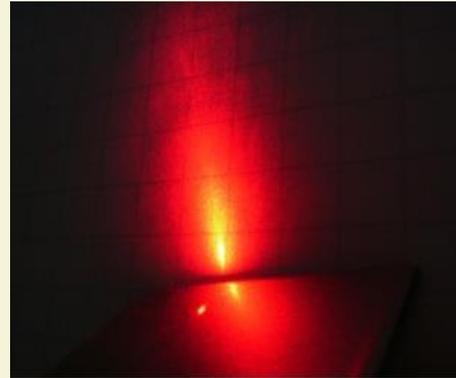Hembach **Photonik**
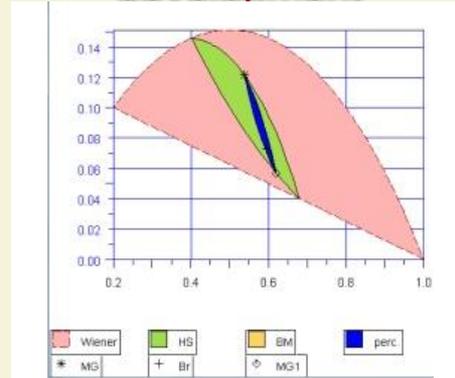
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Key areas

Imaging optics	Illumination optics	Straylight analysis	Software development

Small innovative company in Nürnberg Area, Germany
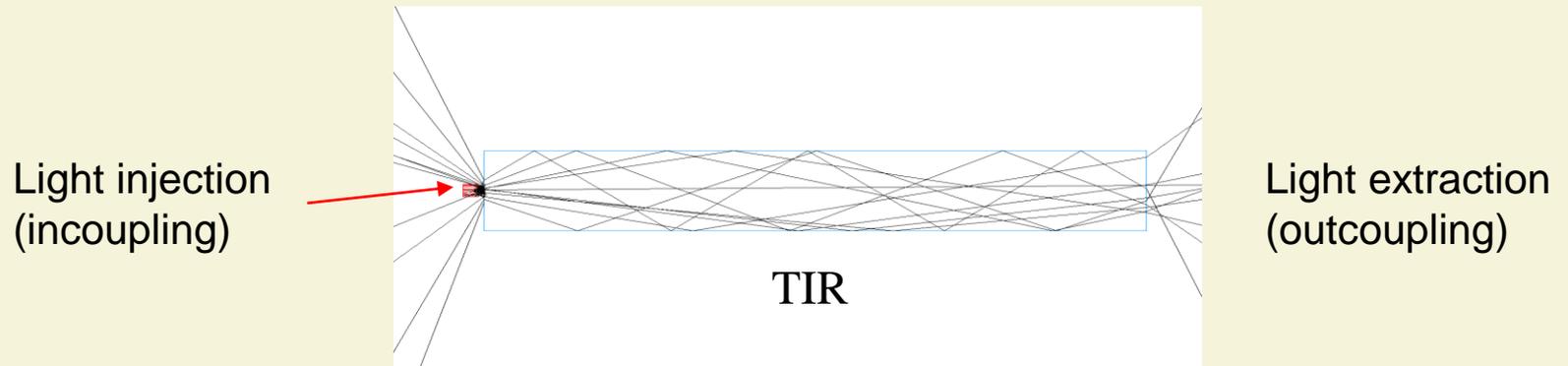
Currently 8 employees: physicists, mathematicians and engineers

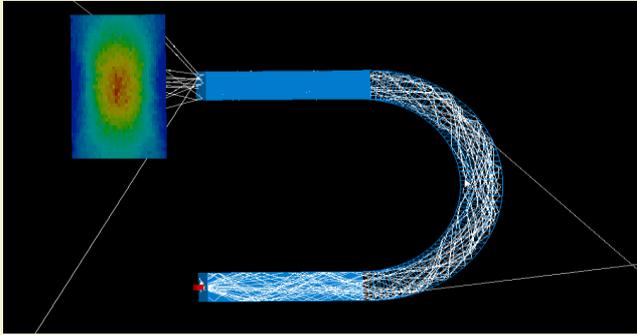Optical design & analysis; optical software
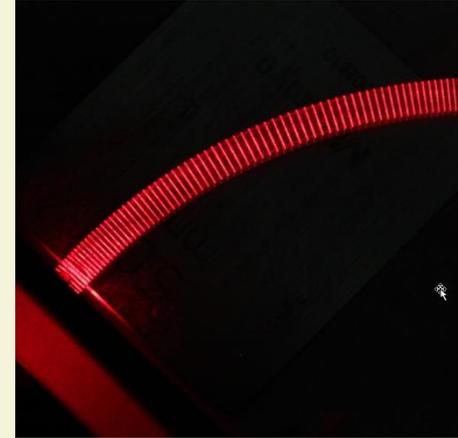
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What is a light guide?

Optical component transporting light by total internal reflection (TIR)

Light injection
(incoupling)

Light extraction
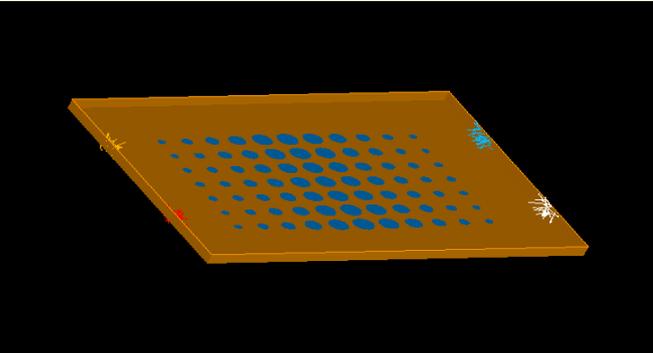(outcoupling)

TIR

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Light guide – Usage

Transporting
light from/to
locations that are
difficult to access/connect

Light diffusion
and
homogenization

Both transport and
homogenization

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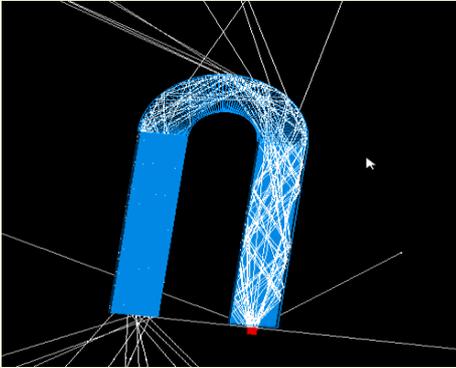
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Light guides – Some facts
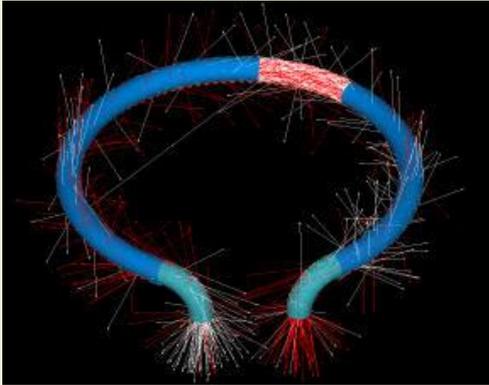
Ring light guide

- Most light guides are made of plastic materials such as PMMA or PC using injection molding
- TIR reflectivity close to 100%
- Very compact designs possible: essential for applications with limited available space
- Controlled and efficient light injection/extraction requires incoupling/outcoupling structures such as prisms, white dots etc.

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Light guides - Design limits

$$A\Omega \quad = \quad A'\Omega'$$

Etendue conservation

Minimum radius of curvature (relative to light guide thickness) required to prevent leaking

Etendue (phase space volume) is constant or increases within light guide;

Manufacturability:
- Minimum structure size typ. 50-100µm
- Compatibility with injection molding process

Material properties: absorption and scattering pose upper limit on size

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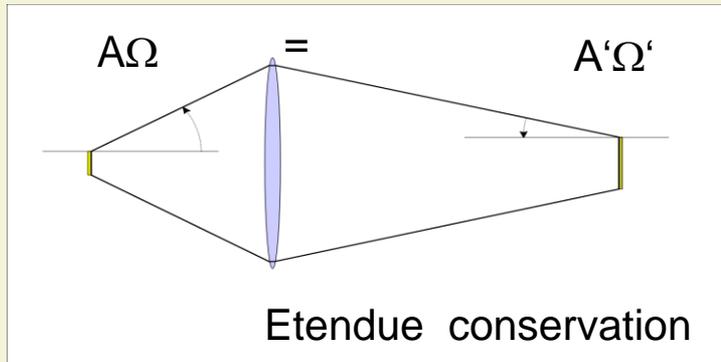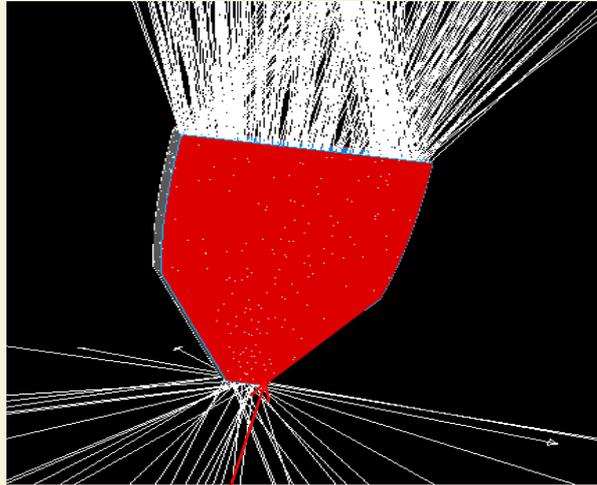
Optical design and simulation

Normal procedure:

- Define outer shape envelope
- Couple light into light guide and distribute it; reshape light guide if needed
- Design structures for light extraction
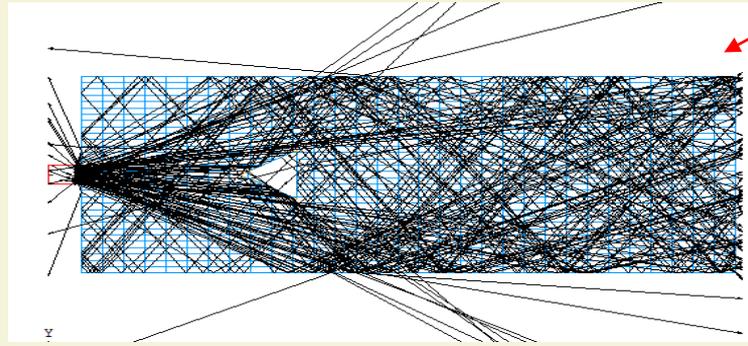- If needed: further homogenization of light by use of diffusers

Computation time:

- Luminance calculations are extremely time-consuming (hours, days, …) and thus can be used only for final design verification.
- Optimization requires fast calculations based on simplified merit function (homogeneous illuminance at exit surface etc.) that are fast to compute.

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Couple light into light guide and distribute it

Triangles to deflect light

Tailored design using curved surfaces

CPC or similar structures to „collimate" light.
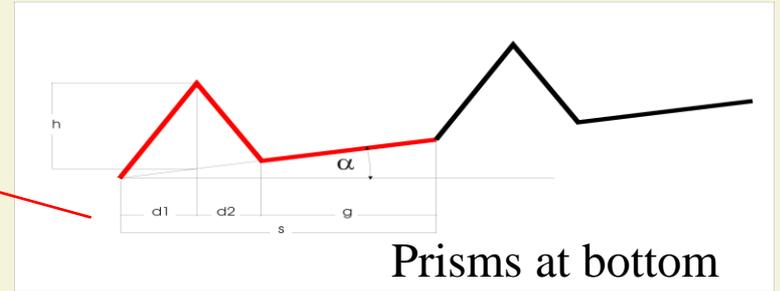
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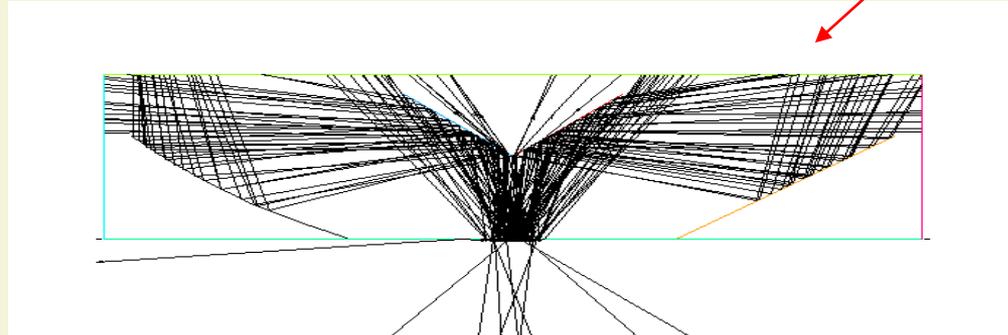
Light extraction: Example

Linear light guide to illuminate rectangle homogeneously with maximum efficiency
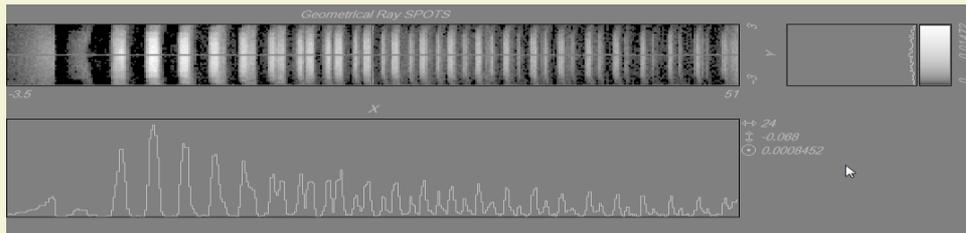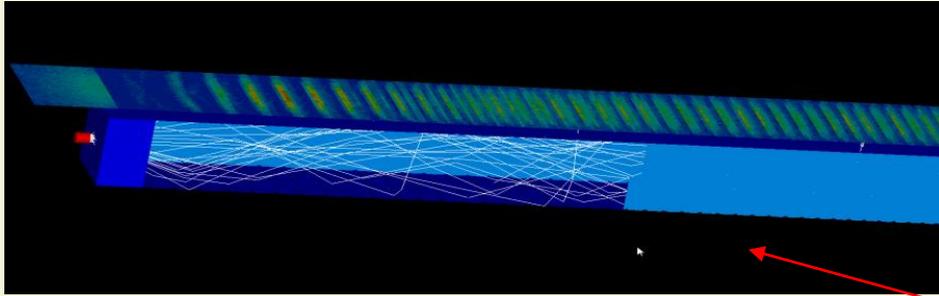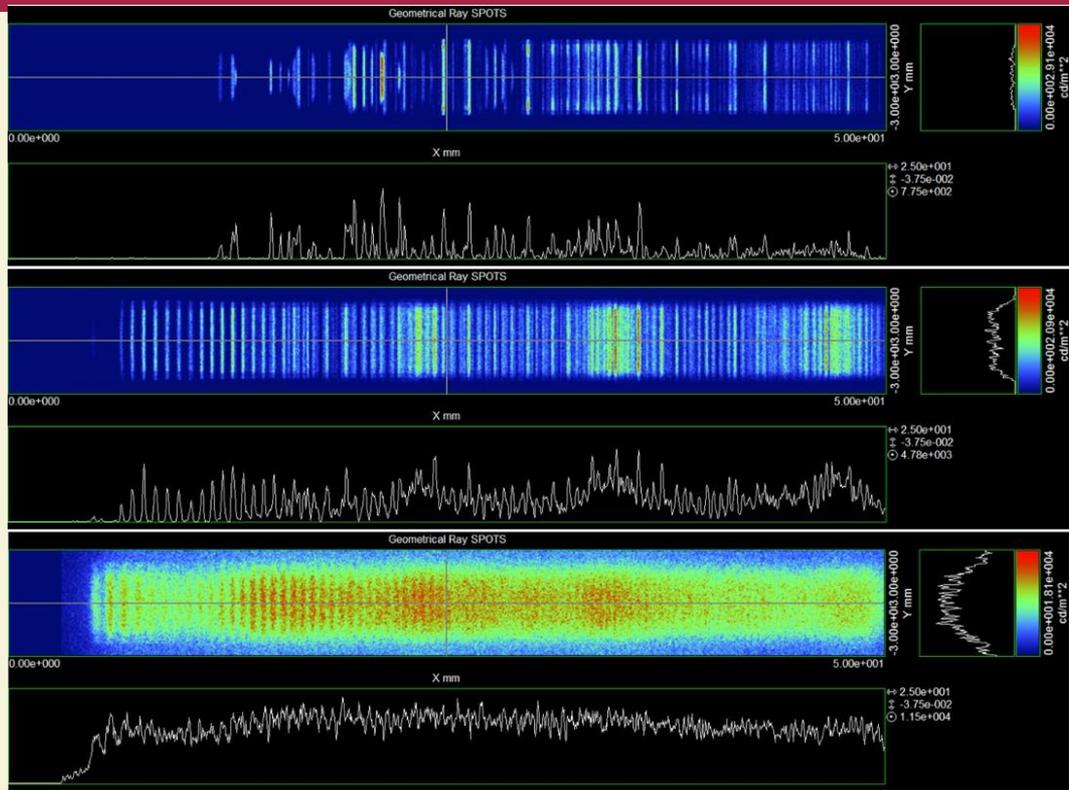

Detector surface to measure output luminance L

Prisms at bottom side for out-coupling

Output luminance (without diffuser)

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Optimizing light guide performance

- Manual or automatic
- Adjust prisms angles/spacings to improve homogeneity and efficiency

Further improvements:
- Reduce size of structures (manufacturing limits!)
- Use additional diffusor (costs!)

Improving homogeneity: surface scattering
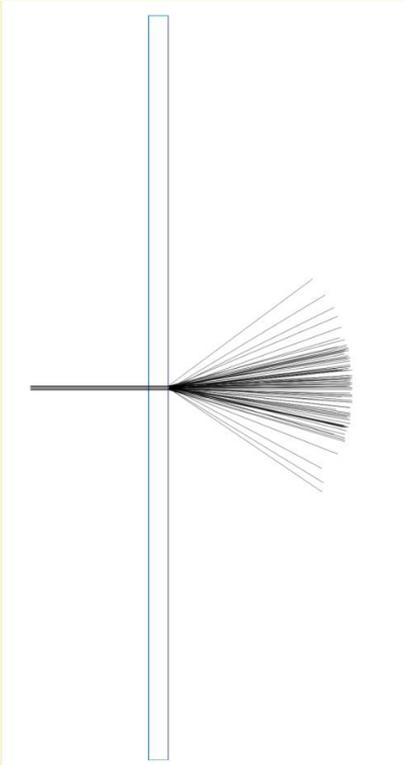
Surface scatterers homogenize the angular distribution of light

Implementation:
-   Separate diffuser sheets
-   Rough exit surface of light guide, e.g., eroded surfaces (standardized)

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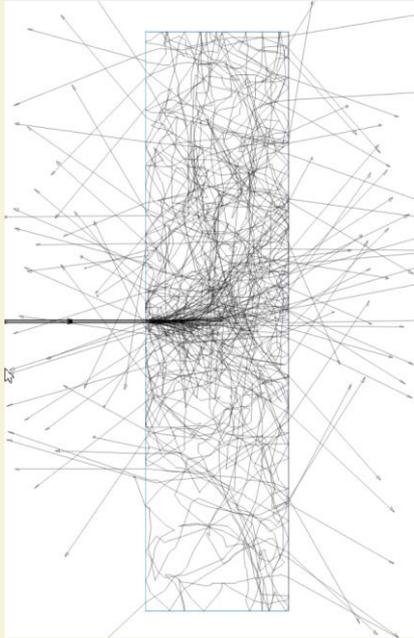# Improving homogeneity: volume scattering

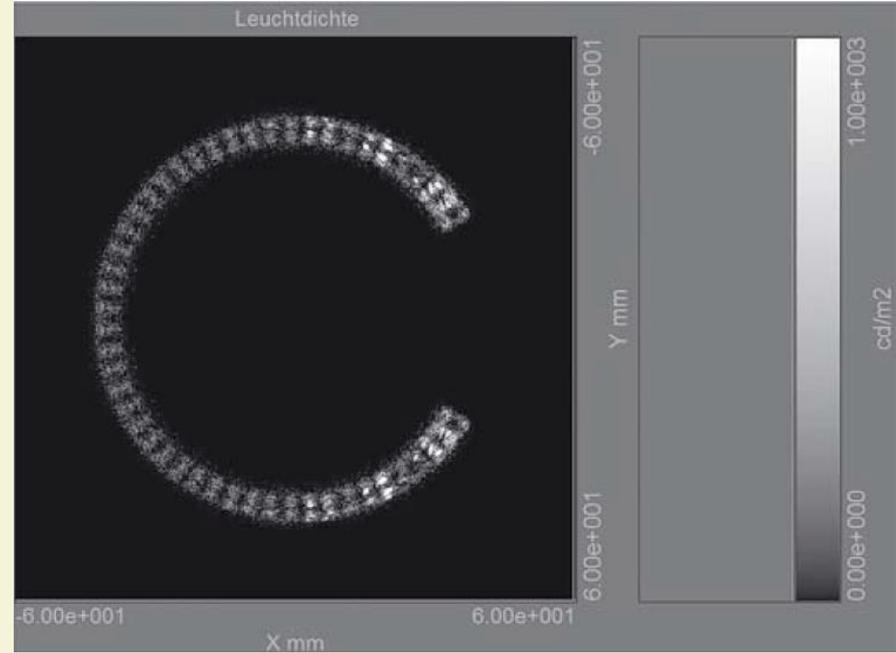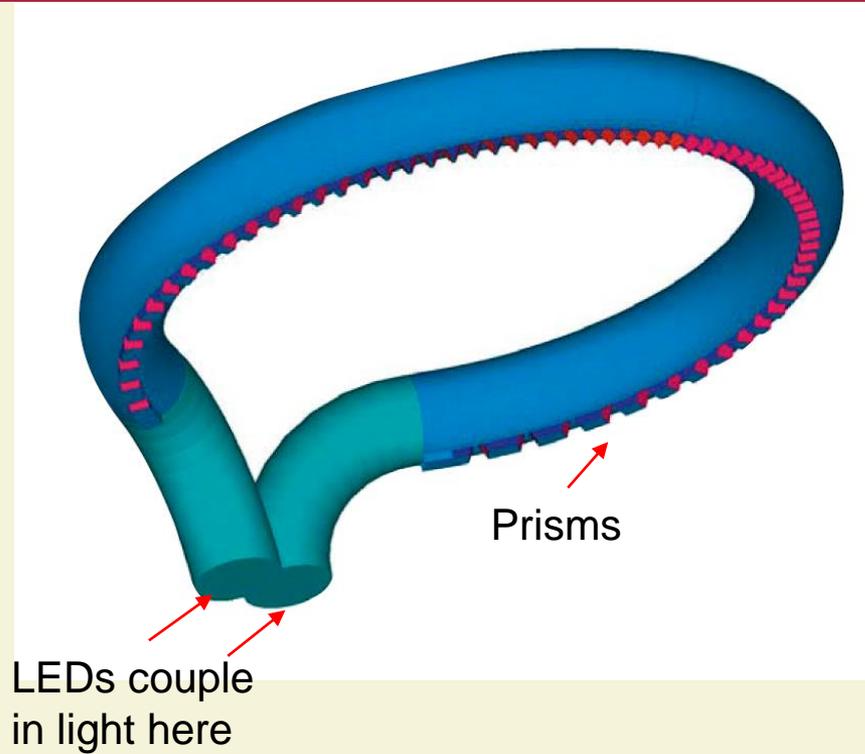Volume scatterers homogenize the angular and positional distribution of light

Implementation:
- Separate diffuser layer on top of light guide (separated by an air gap)
- Add nano particles to light guide material

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Example: Ring light guide (day driving light)

Prisms

LEDs couple
in light here

Output luminance

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Problems and challenges

Simulations very reliable for perfect light guides, but this is not the real world:

- – Surface roughness, sink marks, other shape deviations
- – Bulk scattering, bulk absorption, refractive index variations

Main problems:

- Many injections molders do not have a background in optics, and therefore do not „speak the same language" as optical designers; difficult to specify material imperfections and tolerances
- Optical properties depend on the process, the manufacturer and are often difficult to measure
- Often no optical metrology available; one has to rely on „good luck" and experience

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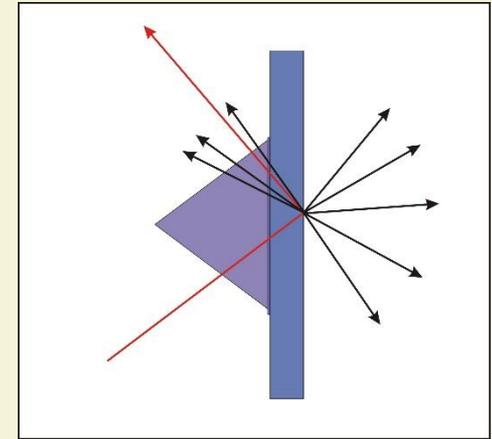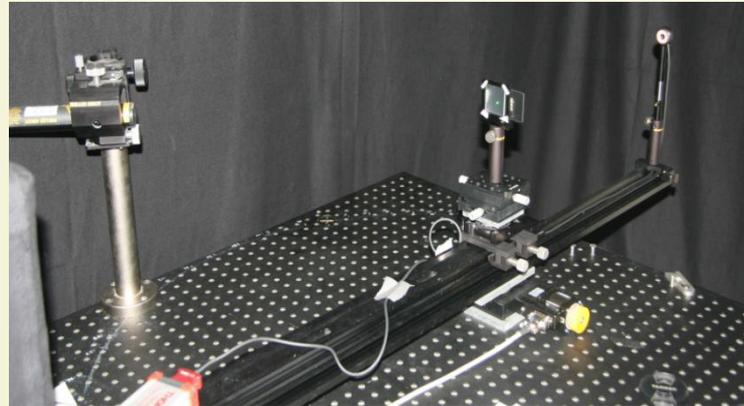
Suggestions for improvement

- More optical know-how/problem awareness needed among injection molders
- „Partnerships" – closer cooperation between designer and a few (or only one) manufacturer to learn from each other and gain experience
- Better standardization of interface between optical designer and manufacturers (like in optical industry)
- Data sheets of material suppliers should contain relevant optical data (bulk absorption spectrum etc.)
- More and better optical metrology

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Example for material characterization – surface scattering measurement
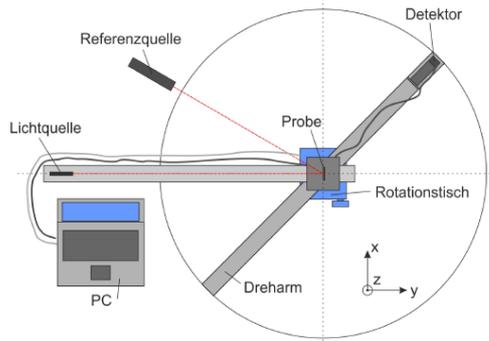
Goniometer setup

Measurement of scattering from surface roughness:
Illumination with and without TIR condition

TIR-illumination

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Thank you for your attention!