Designing Light Guides for Illumination Systems

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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
What is a light guide?

Optical component transporting light by total internal reflection (TIR)

Light injection (incoupling)  Light extraction (outcoupling)
Light guide – Usage

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

Light diffusion and homogenization

Both transport and homogenization
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.
Light guides - Design limits

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
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.
Couple light into light guide and distribute it

CPC or similar structures to „collimate“ light.

Triangles to deflect light

Tailored design using curved surfaces
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)
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)
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
Example: Ring light guide (day driving light)

LEDs couple in light here

Prisms

Output luminance
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
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
Example for material characterization – surface scattering measurement

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

Goniometer setup

TIR-illumination
Thank you for your attention!