Plastic optical fiber coupling systems: a novel opto-mechanical modeling approach

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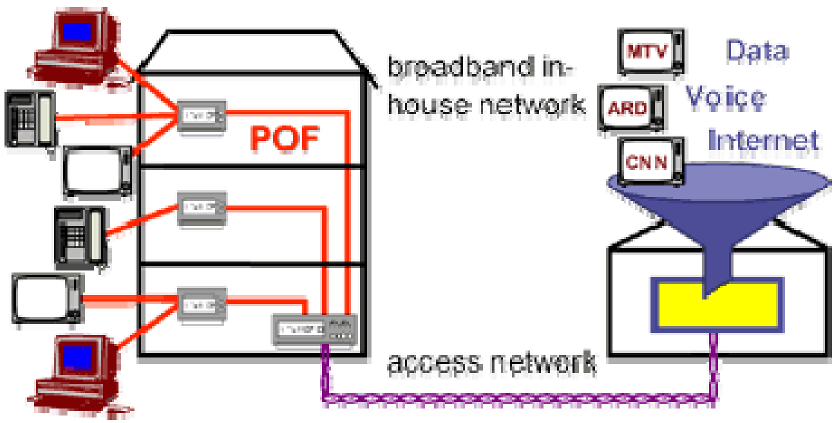
Today’s applications of POF



Data communication

Luminous textiles

Automotive

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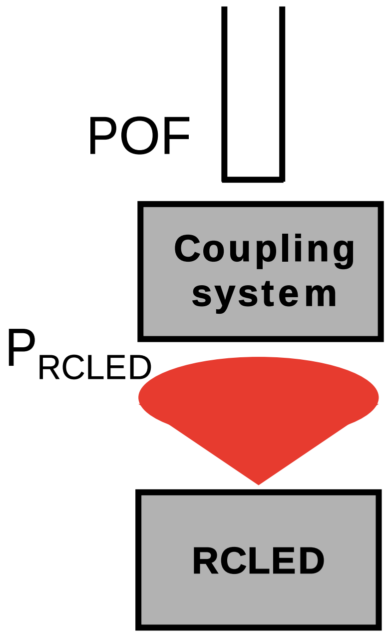
Introduction



Advantages of using POF:

- Lightweight
- Robust
- Low cost
- Easy to install
- Immune to electromagnetic interference

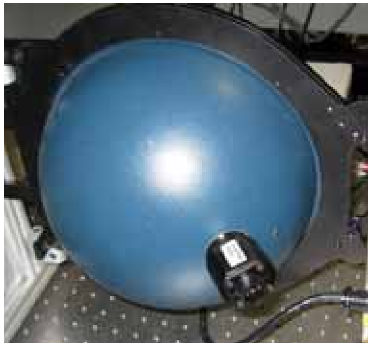
GOAL: Experimental characterization of RCLEDs → Design and modeling of coupling system → Tolerancing of coupling system

Characterization tools

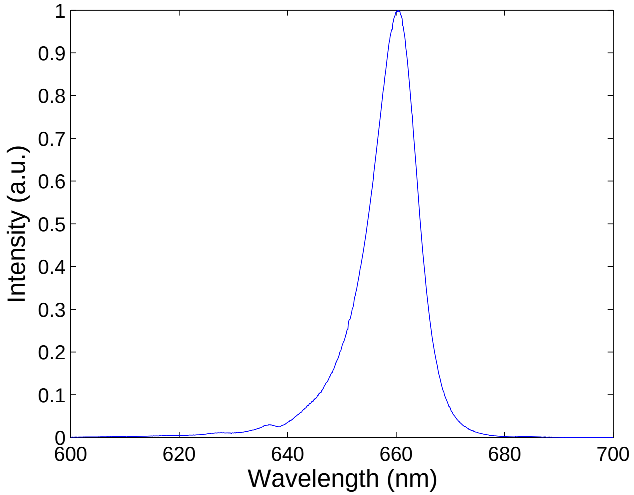
Spectrum analyzer

Goniometric radiometer

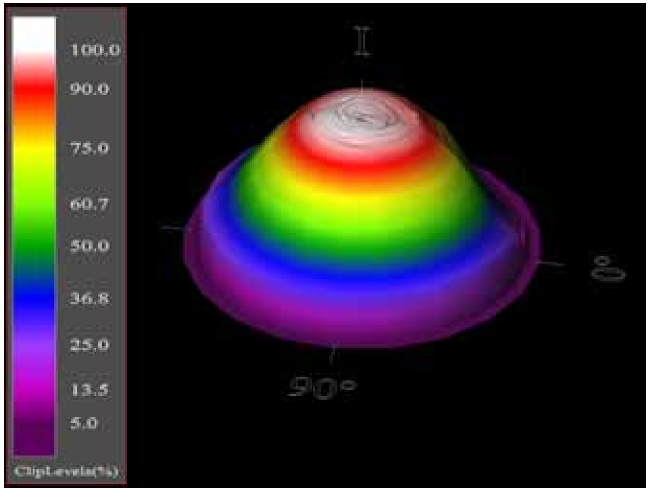
Integrating sphere



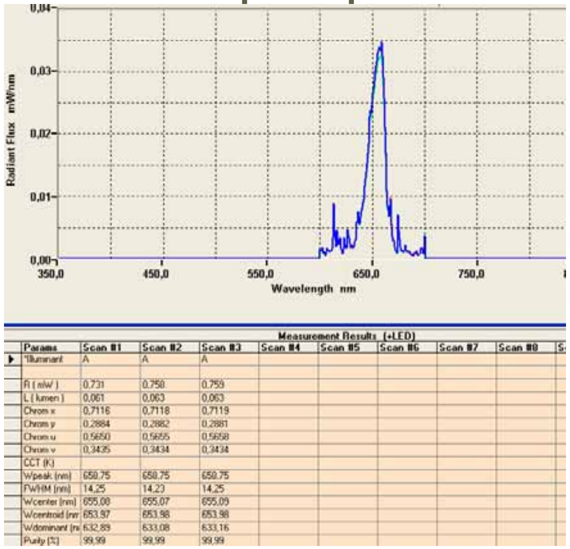
Optical spectrum



Far-field pattern



Total output power

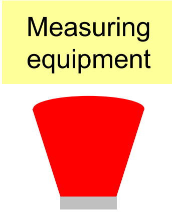


Measurement Results (+LED)

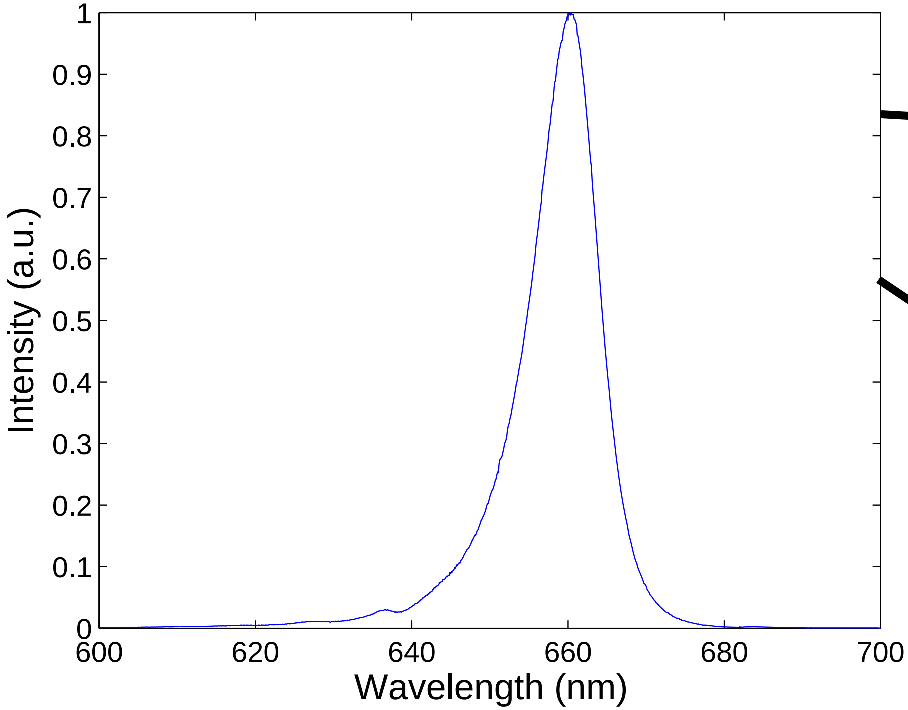
Params	Scan #1	Scan #2	Scan #3	Scan #4	Scan #5	Scan #6	Scan #7	Scan #8
*Illuminant	A	A	A					
R (mW)	0,731	0,750	0,759					
L (lumen)	0,061	0,063	0,063					
Chrom x	0,7116	0,7118	0,7119					
Chrom y	0,2884	0,2882	0,2881					
Chrom u	0,5650	0,5655	0,5658					
Chrom v	0,3435	0,3434	0,3434					
CCT (K)								
Wpeak (nm)	650,75	650,75	650,75					
FWHM (nm)	14,25	14,23	14,25					
Wcenter (nm)	655,08	655,07	655,09					
Wcentroid (nm	653,97	653,98	653,98					
Wdominant (n	632,89	633,08	633,16					
Purity (%)	99,99	99,99	99,99					

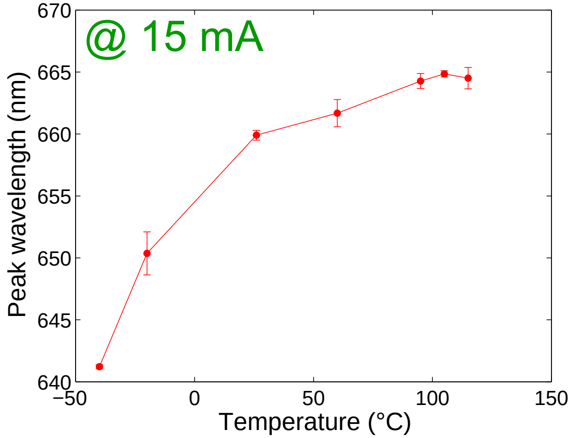
Spectral analysis of RCLEDs

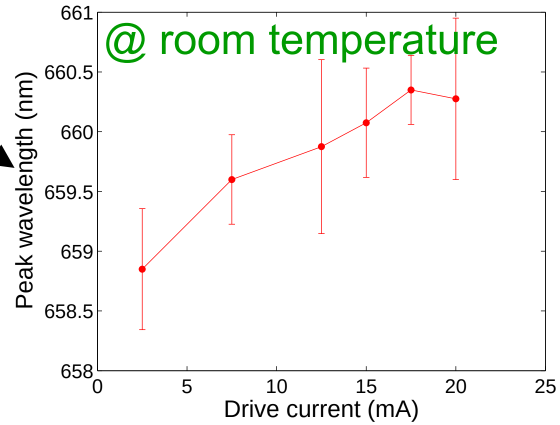
Influence of drive current (2.5 to 20 mA @ room temperature and 7.5 to 27.5 mA @ 115°C)
and temperature (-40 to 115°C) @ 15 mA on the spectrum



Example of 1 measurement



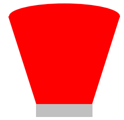


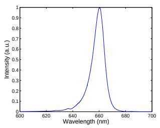


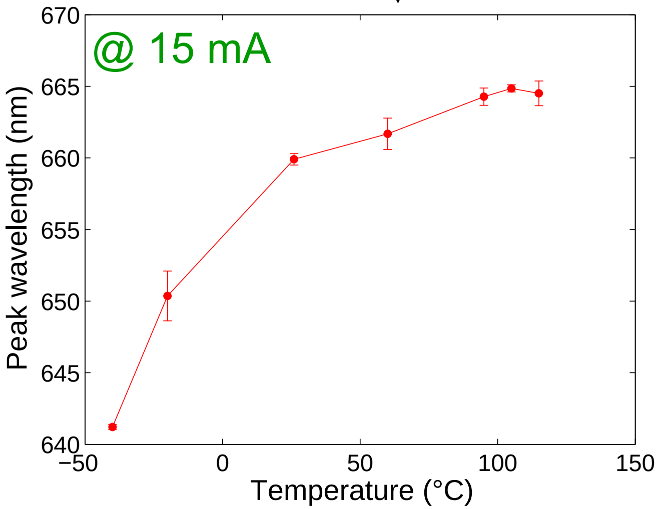
Spectral analysis of RCLEDs

Influence of drive current (2.5 to 20 mA @ room temperature and 7.5 to 27.5 mA @ 115°C) and temperature (-40 to 115°C) @ 15 mA on the spectrum

Measuring equipment

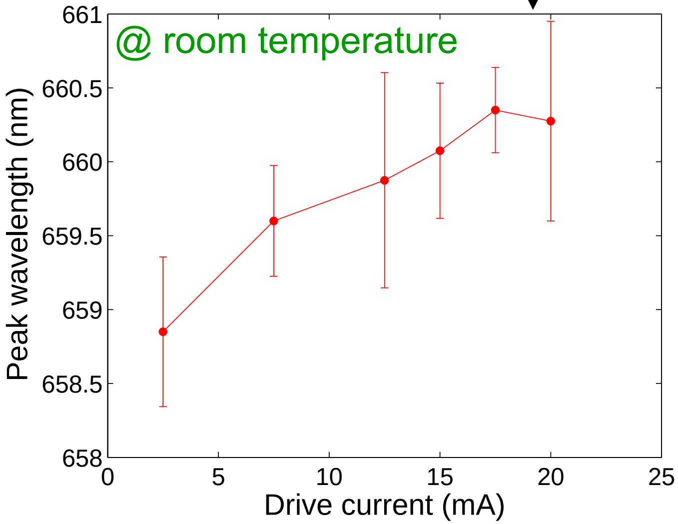






Shift in λ_{peak}: 23.3 nm OR (0.137±0.020) nm/°C
Literature: 0.11 nm/°C

(P. Sipilä, M. Saarinen, M. Guina, V. Vilokkinen, M. Toivoren, M. Pessa; *Temperature behavior of* ***resonant cavity light-emitting diodes at 650 nm***; **Semicond. Sci. Technol. 15 (2000), 418-421**)

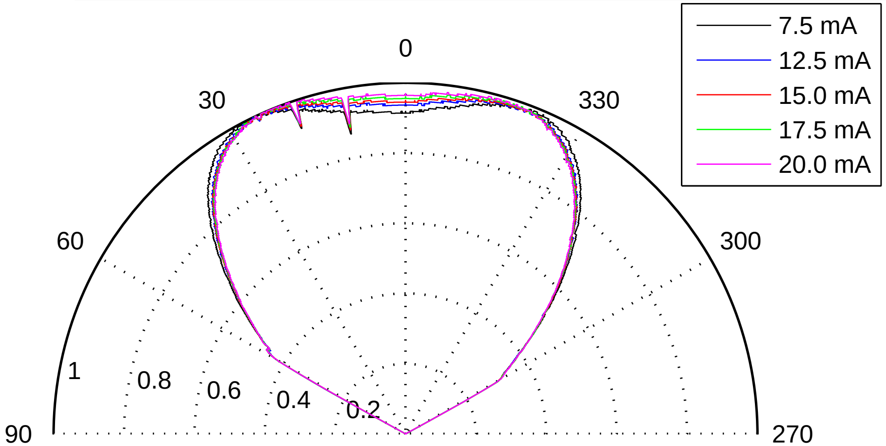


Shift in λ_{peak}: 1.42nm OR (0.054±0.043) nm/mA

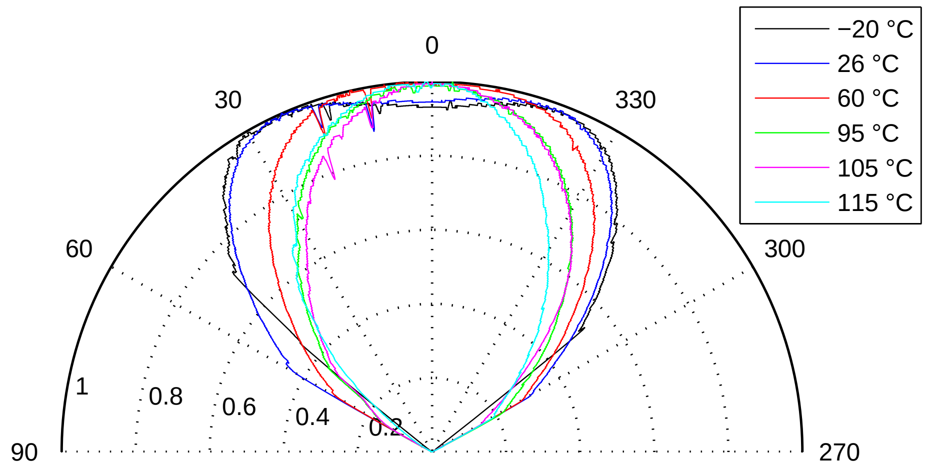
@ 115°C: 0.69nm OR (0.034±0.005) nm/mA

Far-field pattern of RCLEDs

Influence of drive current (7.5 to 20 mA)
and temperature (-20 to 115°C) on the far-field pattern

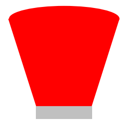


Drive current has no influence



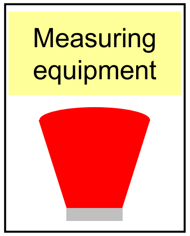
The far-field pattern is the broadest at room temperature

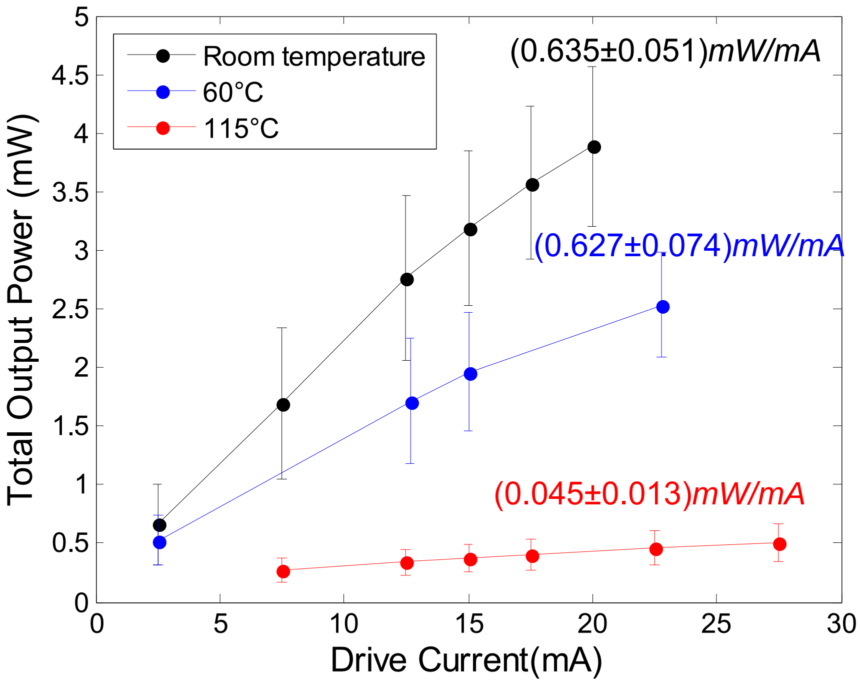
Measuring equipment

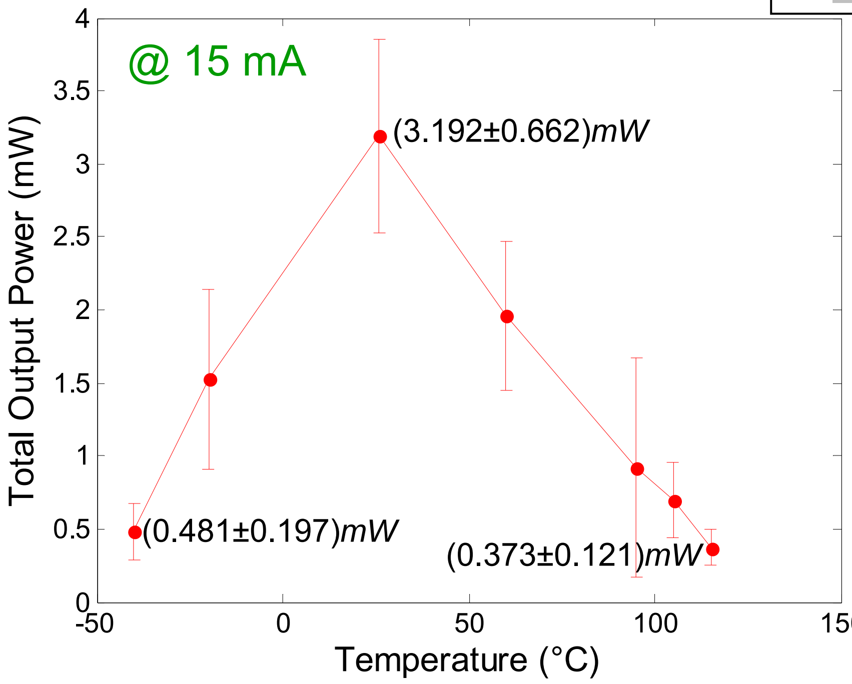


Total absolute output power

Influence of drive current (2.5 to 27.5 mA)
and temperature (-40 to 115 °C) on the total absolute output power



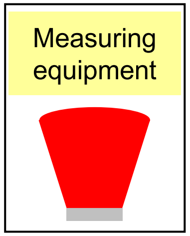




Increasing the drive current increases the total output power

Maximum total output power is reached near room temperature

Repeatability and reproducibility

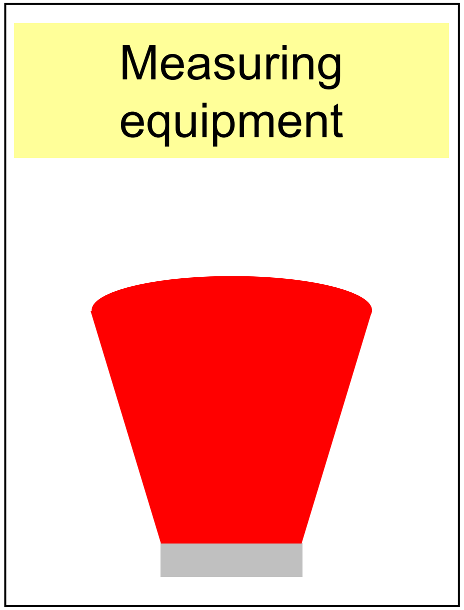


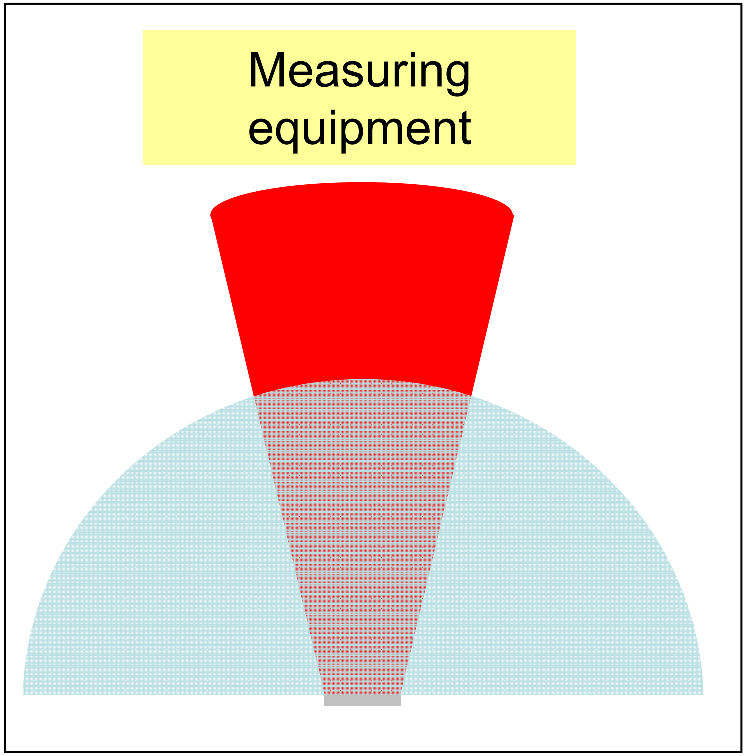
Repeatability and reproducibility of experiments performed to fully characterize the RCLEDs

	5 times on 1 day at room temperature	5 times on 1 day at 60°C	5 times on 5 consecutive days at room temperature
Spectrum analyzer	0.05%	0.06%	0.12%
Goniometric radiometer	0.5%	0.1%	8.7%
Integrating sphere	0.22%	1.57%	3.08%

- Spectrum analyzer: maximum difference in peak wavelength
- Goniometric radiometer: mean of maximum procentual difference between the measured far-field patterns over all the angles
- Integrating sphere: mean error on the measurements

Shift from air to epoxy medium in experimental characterization





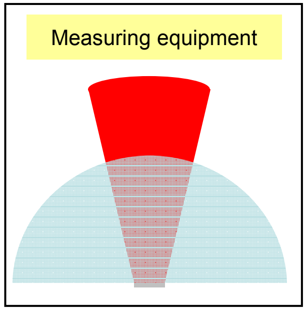
RCLED emitting in air

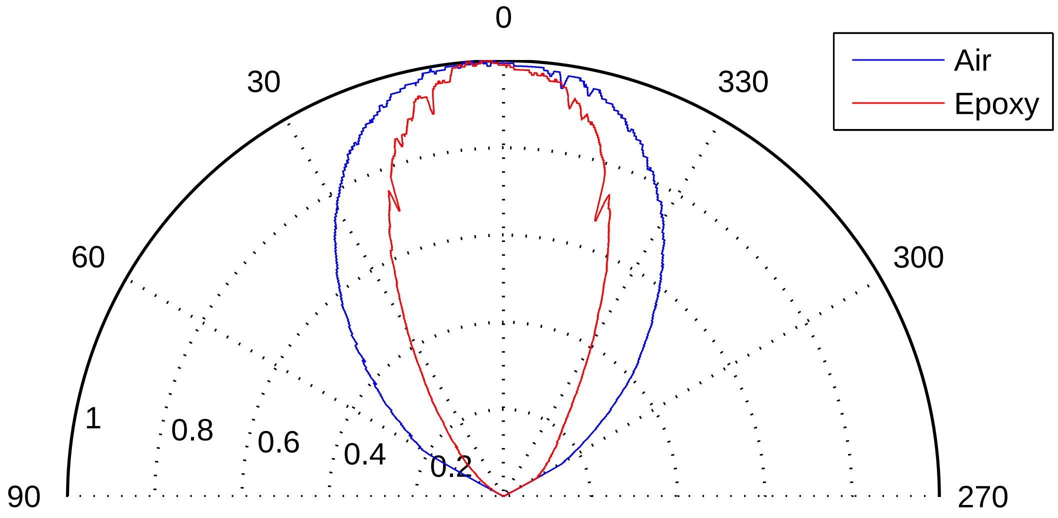
RCLED emitting in epoxy

The source model measured in epoxy will be implemented in the design and modeling

Shift from air to epoxy medium in experimental characterization

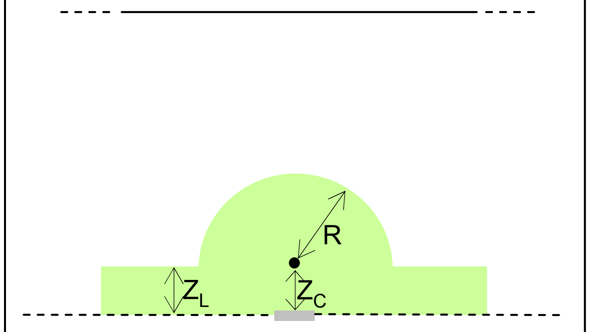
What happens with the total output power and the far-field pattern when the source emits in epoxy (room temperature and 15 mA)?



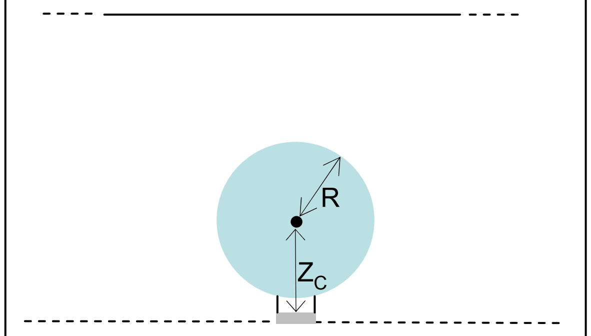


Far field pattern is 36.1±28.1% smaller than in air
Total output power is 19.9±11.6% higher than in air

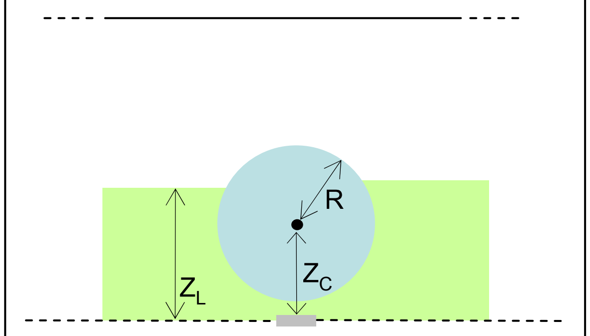
Possible configurations of fiber coupling unit



Overmolded lens in clear epoxy



Ball lens



Buried ball lens

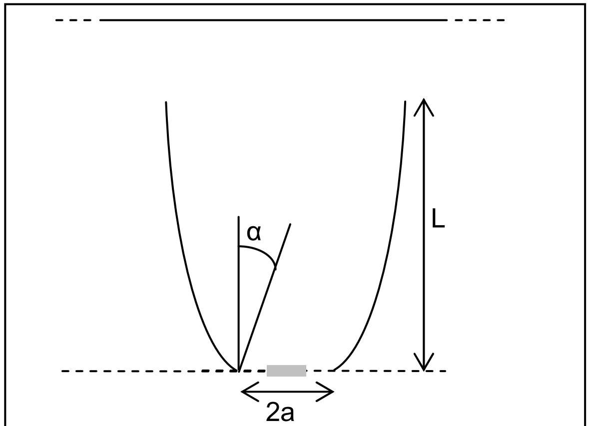
$D_{cladding}$ = 1000 µm

$n_{cladding}$ = 1.5

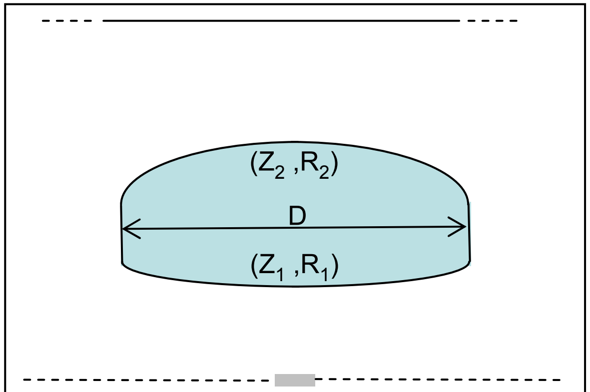
NA = 0.48

$D_{RCLED\ emitting\ surface}$ = 83 µm

$n_{mmersion\ material}$ = 1.5



Compound parabolic concentrator (CPC)



Mini lens

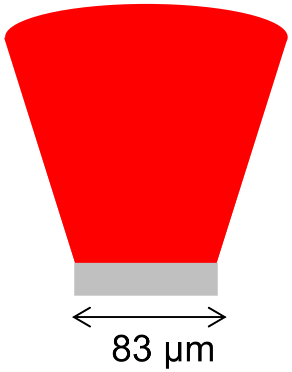
- Glass
- Epoxy
- RCLED aperture

Optimum coupling efficiencies

At 60°C and 105°C the optimum coupling efficiencies are determined.
Results obtained through raytracing (ASAP, Breault)

	60°C	105°C
Overmolded lens in clear epoxy	71%(-0.15dBm)	69%(-1.83dBm)
Ball lens	79%(-0.30dBm)	78%(-1.73dBm)
Buried ball lens	77%(+0.20dBm)	76%(-1.41dBm)
CPC	82%(-0.14dBm)	82%(-1.52dBm)
Mini lens	80%(-0.25dBm)	78%(-1.73dBm)

Uniformly emitting light source

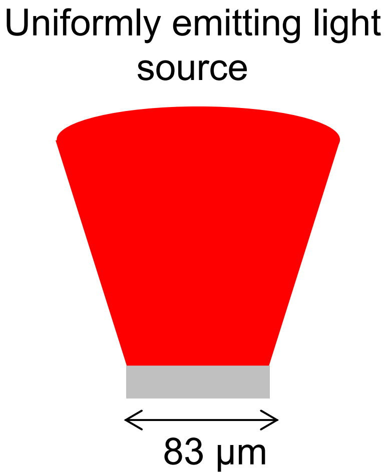


Coupling efficiencies are not affected a lot by temperature

Optimum coupling efficiencies

At 105°C the optimum coupling efficiencies are determined
after the lenses were AR coated.
Results obtained through raytracing (ASAP, Breault)

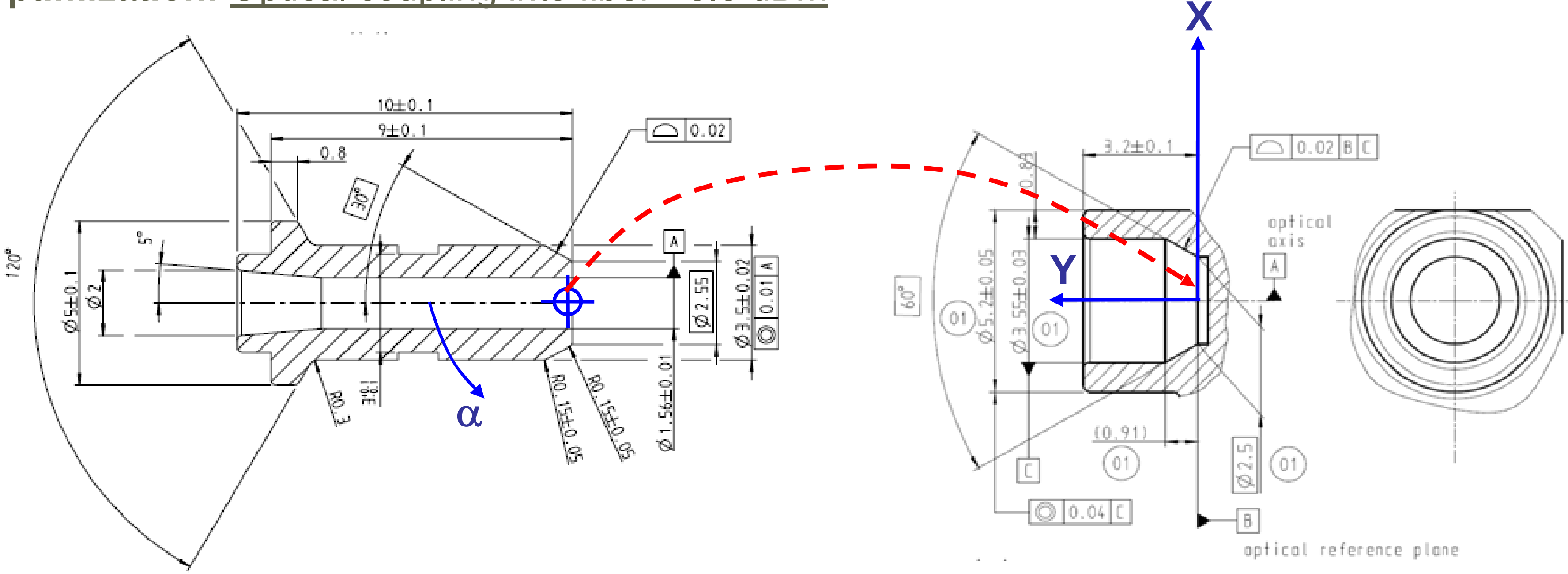
	No AR coating	AR coating
Overmolded lens in clear epoxy	69%	/
Ball lens	78%	91%
Buried ball lens	76%	82%
CPC	82%	/
Mini lens	78%	82%



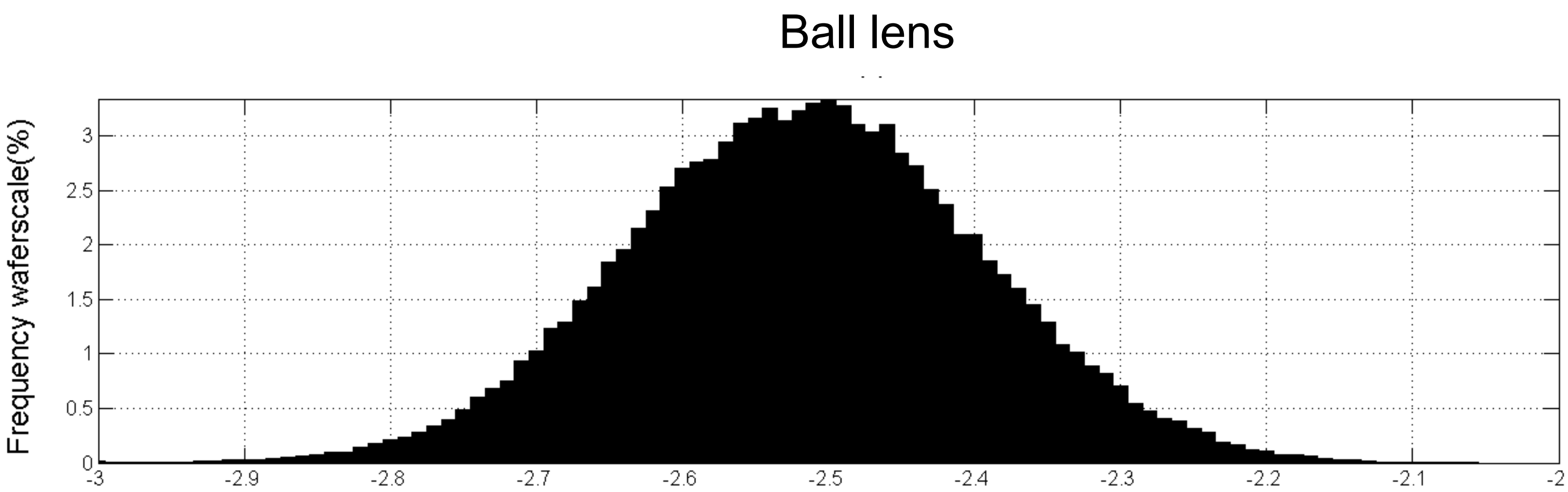
Coating the lenses increases the coupling efficiencies with a couple of percents.
The choice of the used coupling system will depend on fabrication possibilities and cost

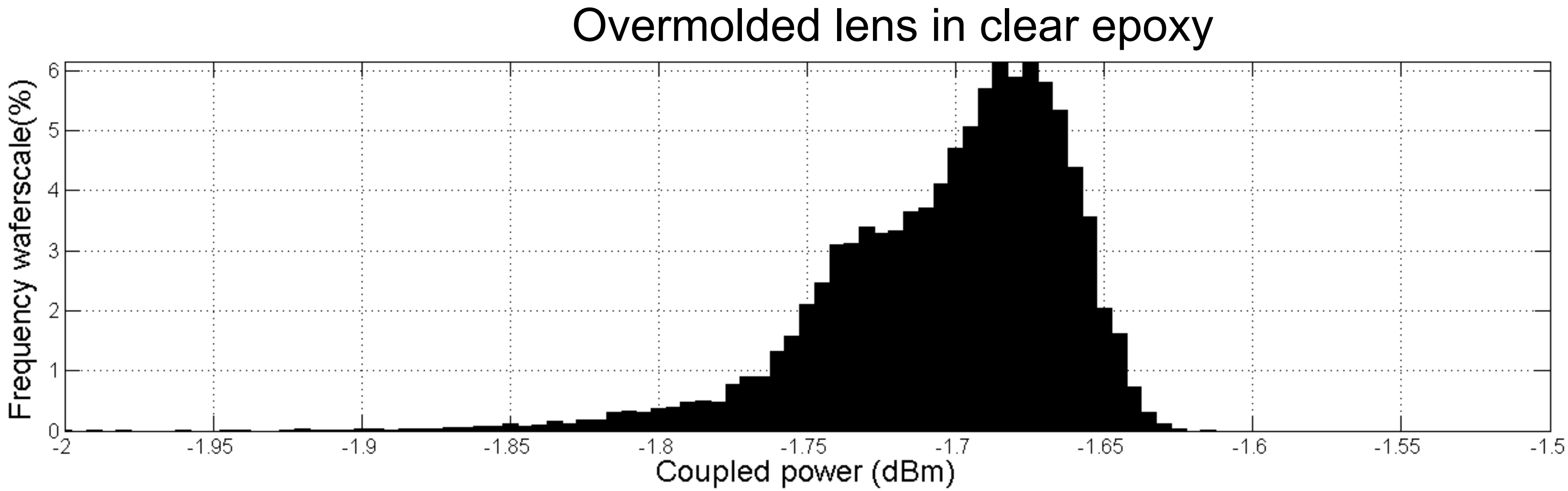
Tolerance study

Goal: Assessment of the optical coupling with respect to realistic errors
Start point: Dimensional and geometrical tolerances as per CAD drawings
Method: Polygon model of ferrule/package assembly in MatLab
Solver: Ferrule model position optimization in X, Y and α to minimize the contact distance between key datum points
Merit function: Optical coupling into fiber
Optimization: Optical coupling into fiber>-3.5 dBm



Tolerance study



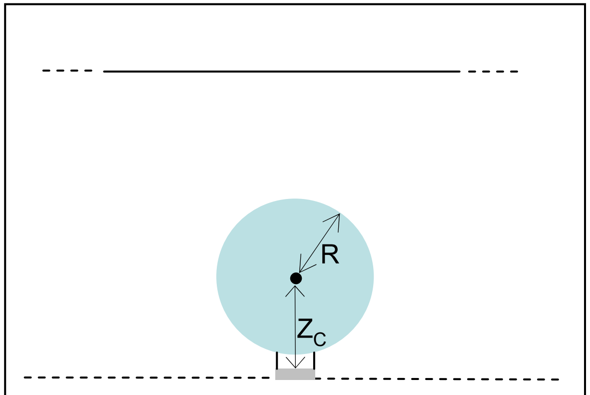


Tolerance study

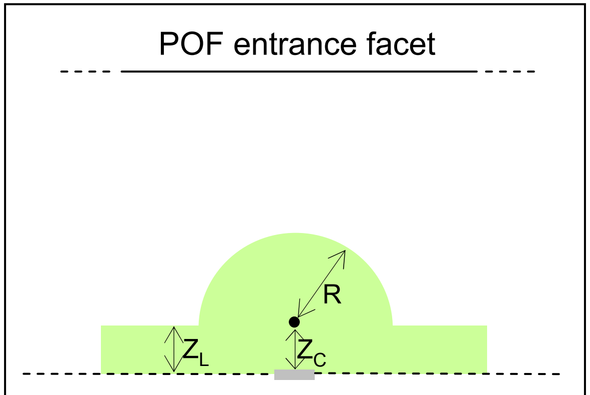
Predefined specification: at least -3.5 dBm over the complete temperature range.
Tolerancing on geometrical parameters

Parameter	Ball lens	Overmolded lens in clear epoxy
R_C	145±4.4µm	179±14.4µm
Z	138±5.1µm	167±8.8µm
Z_L	/	174±18.9µm

Ball lens configuration is more sensitive to fabrication and alignment errors



Ball lens



Overmolded lens in clear epoxy

Conclusions

This research work lead to

- A complete quantitative characterization of the RCLED both in air and in epoxy
- A novel approach to implement measurement data in a source model for the design
- A tolerance analysis to find the configurations which are technological feasible
- A way towards industrial realization of a low cost data communication system that is mass manufacturable