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Cylindrical multipass reflection cells for optical trace gas sensing

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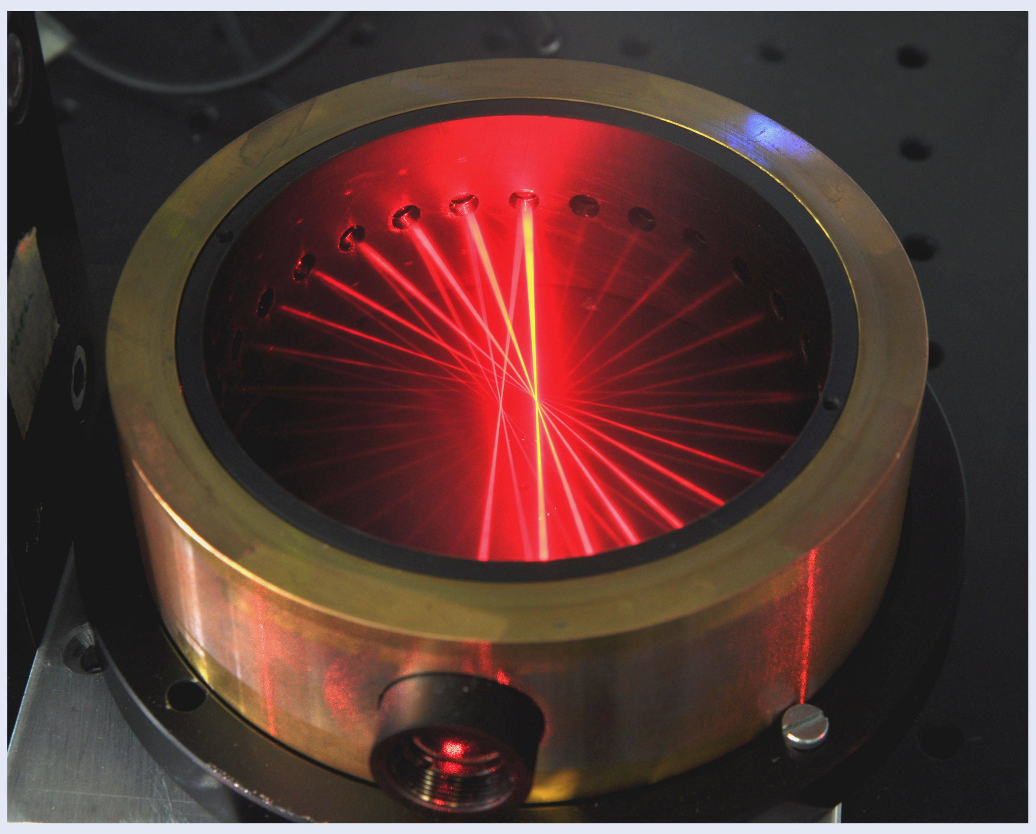
EMPA Materials Science & Technology

IRsweep Innovation in sensing

Concept - single piece multipass reflection cell with cylindrical cell body

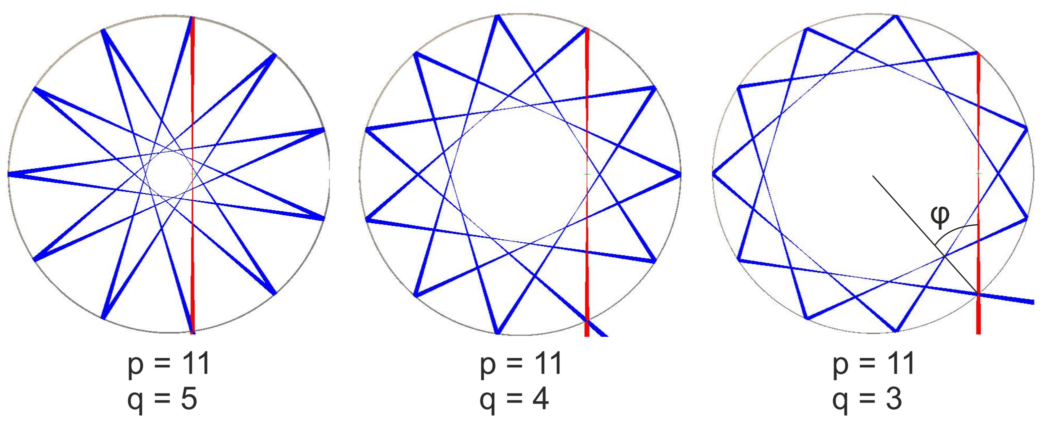
The optical path length through a gas sample is a decisive parameter in laser spectroscopy to achieve high instrumental sensitivity and analytical precision. Small absorption signals are usually compensated for by the use of multipass cells, the most widely known being those based on the design of White [1] or Herriott [2]. For more compact configurations, variations of a pair of cylindrical or astigmatic mirrors have been proposed [3,4]. Nevertheless, the footprint of such multipass cells generally ranges from about 0.2–1 m with volumes up to 5 L, which makes the optical cell often becoming the size-limiting element in laser spectroscopic trace gas analyzers.



Our new design for a compact multipass reflection cell for MIR laser spectroscopy combines the optical mirror with the cell body [5]. It consists of a single-piece, diamond turned cylinder. The cylinder has a single window serving as entrance and exit aperture. A light beam entering the cylinder propagates on a star-shaped pattern determined by the entrance angle. With proper design of the surface shape, the light beam is refocalized after each reflection. This leads to minimal aberration and reproducible propagation of the laser beam. The patented [6] absorption mask reduces interference fringes and enables highest accuracy trace gas analysis.

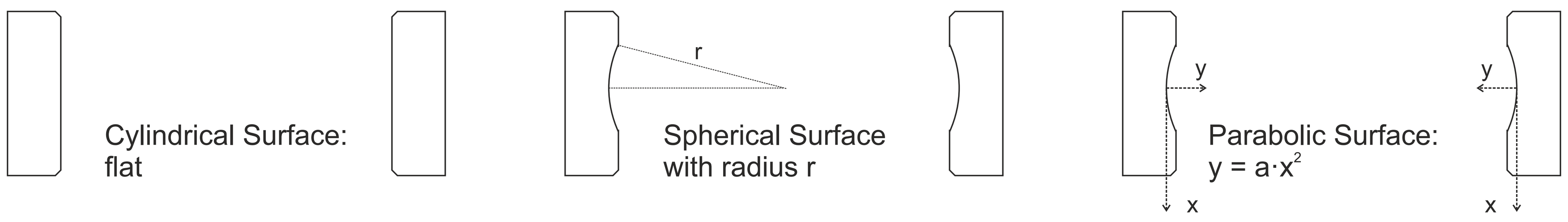
Design consideration I: (p/q)-star polygon

A star polygon is fully described by its number of spikes p and its density q. All (p/q) pairs with no common divisor describe a star that can be drawn in a single line.



Entrance angle $\varphi = 90° \cdot (1 - 2q/p)$

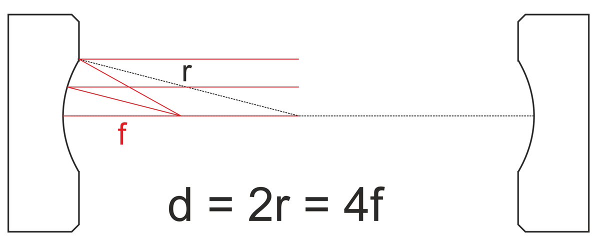
Design consideration II: Off-plane surface shape



While the circular surface shape in the in-plane direction is given by the cylindrical shape of the cell, the shape of the off-plane surface can be freely chosen.

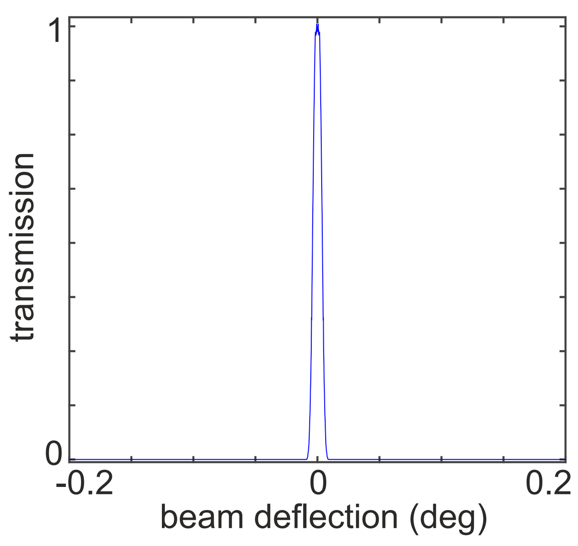
Spherical and parabolic surfaces are superior to a simple flat surface because they refocalize the beam after every reflection.

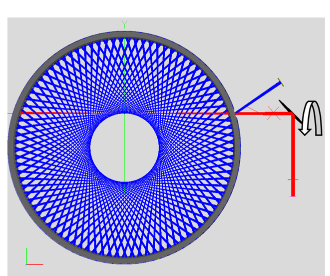
Design consideration III: respective mirror arrangement

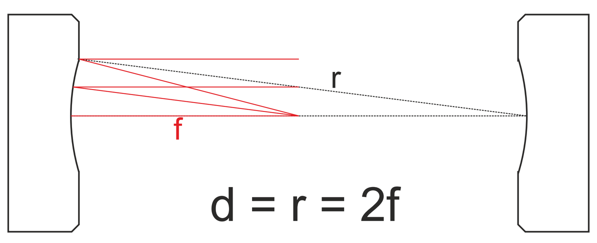


Concentric mirror arrangement:

- d/r = 2.
- beam focalized to center at every reflection.
- non-ideal beam diverges.
- sensitive to misalignment:

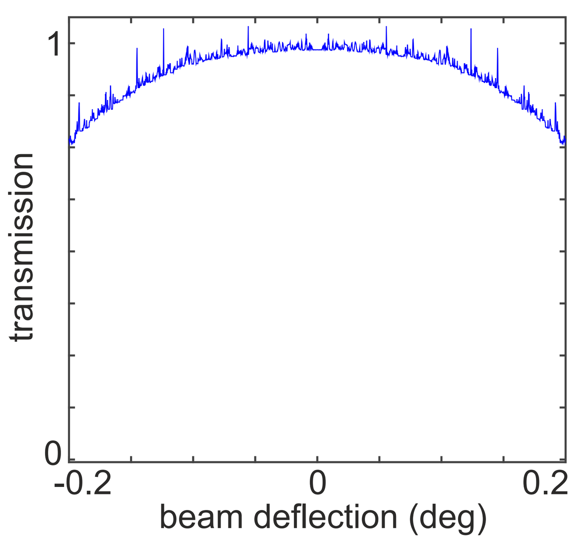




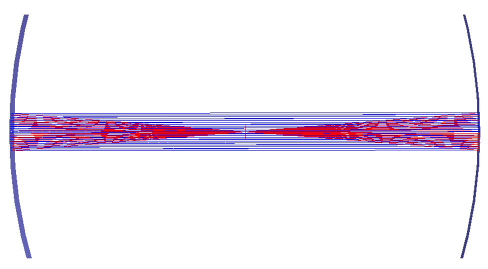


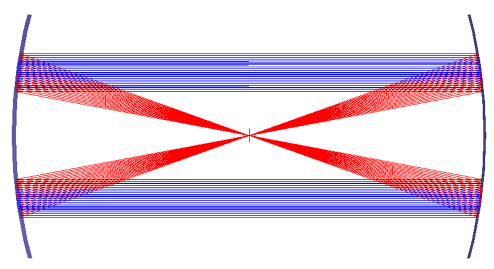
Confocal mirror arrangement:

- d/r = 1.
- beam is in turns focalized and collimated.
- non-ideal beam propagates stably.
- tolerant towards misalignment:



Design consideration IV: in-axis vs. off-axis illumination

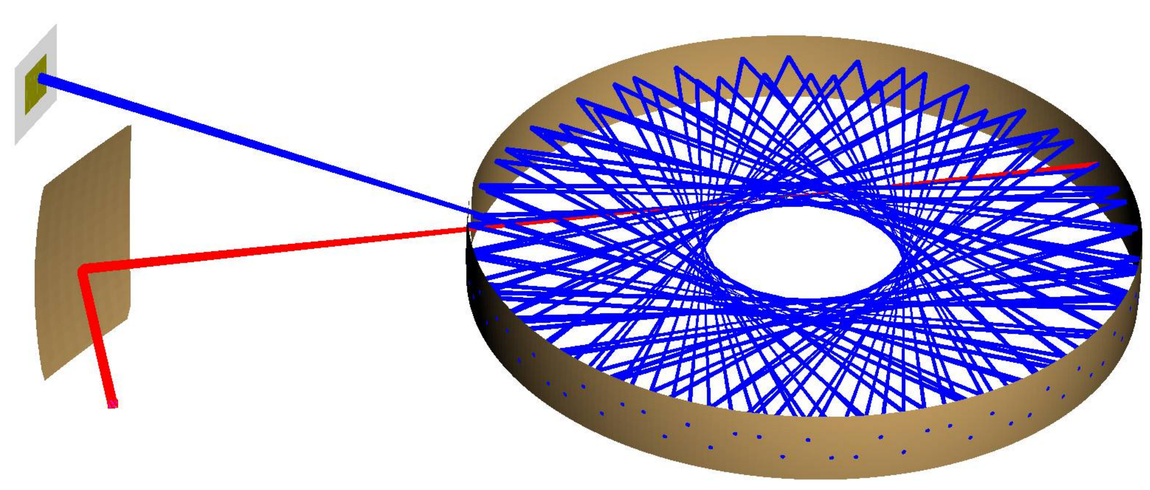




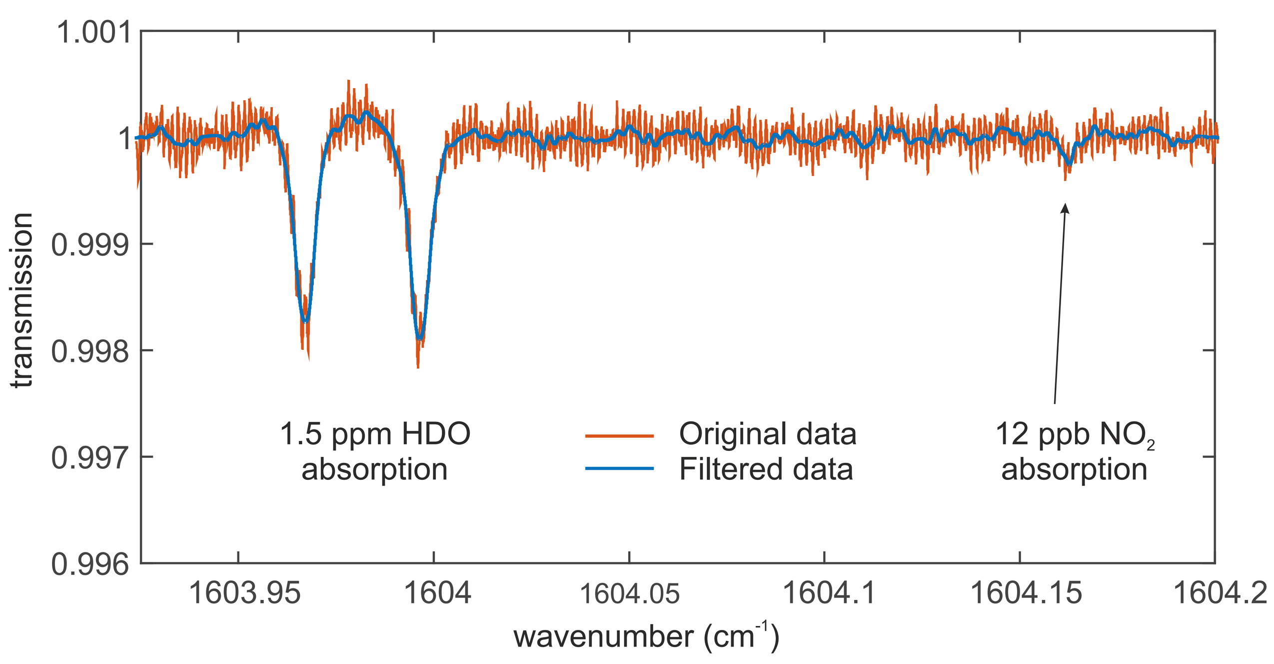
In a confocal, parabolic mirror arrangement, we can exploit the perfect focussing of a parabolic mirror under non-centric illumination to create off-axis illumination beam patterns. By this, we increase the distance between adjacent reflections and reduce the likelyhood of spill-over leading to interference fringes.

Final design parameters:
- r = 72 mm
- p = 89
- q = 36
- φ = 17.19 deg
- optical path = 1224 cm

- parabolic mirror shape
- confocal arrangement
- off-axis illumination

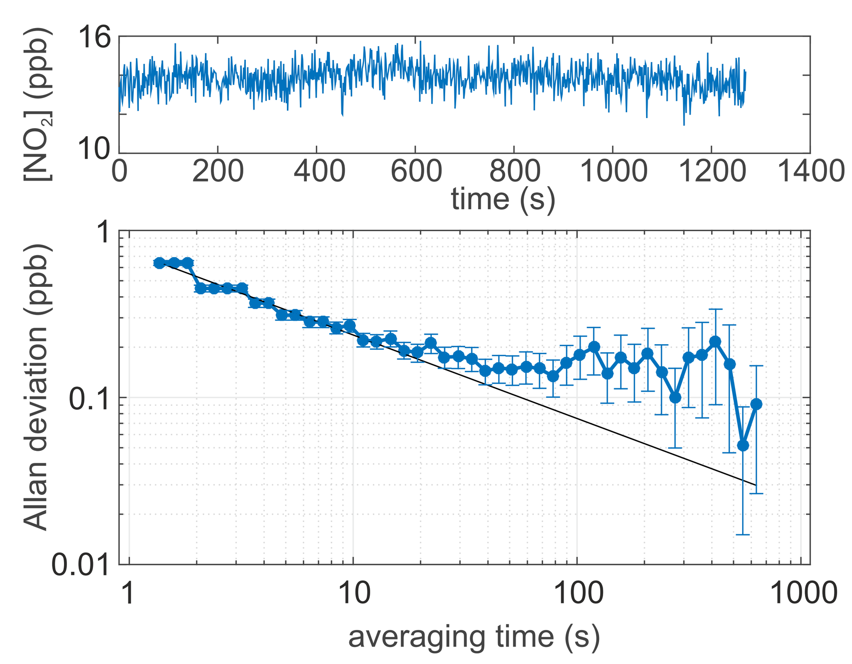


Application: NO_2 concentration measurements with parabolic, confocal cell



With the new cell design, we have peak-to-peak interference fringes of < 1‰. Using a low pass filter, they are reduced to below 0.2‰.

In terms of NO_2 measurements this corresponds to a detection limit of < 200 ppt.



Acknowledgements

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