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VIS-to-NIR absorption spectroscopy of magneto-optical materials for high-power laser applications

Fraunhofer IPM

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Faraday isolators

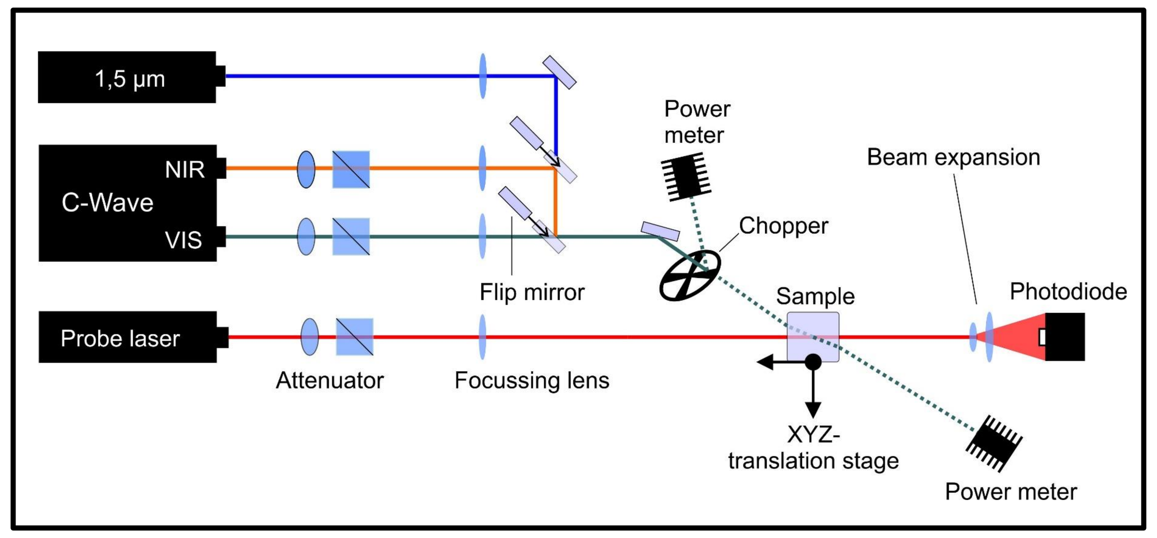
Faraday isolators are used in many laser systems in order to prevent optical feedback into the laser resonator.

The absorption by the material is a critical property, especially in the case of high-power laser applications (> 100 W): A thermal lens may lead to focal shifts and a distorted laser beam profile. In addition an inhomogeneous temperature profile in the crystal may degrade the isolator performance due to the temperature-dependence of the Verdet constant and strain-induced birefringence.

For many years, terbium gallium garnet (TGG) has been the standard material for isolators in the 1-µm region. Only recently, potassium terbium fluoride (KTF) has emerged as a new material for high-power applications [Stevens2016].

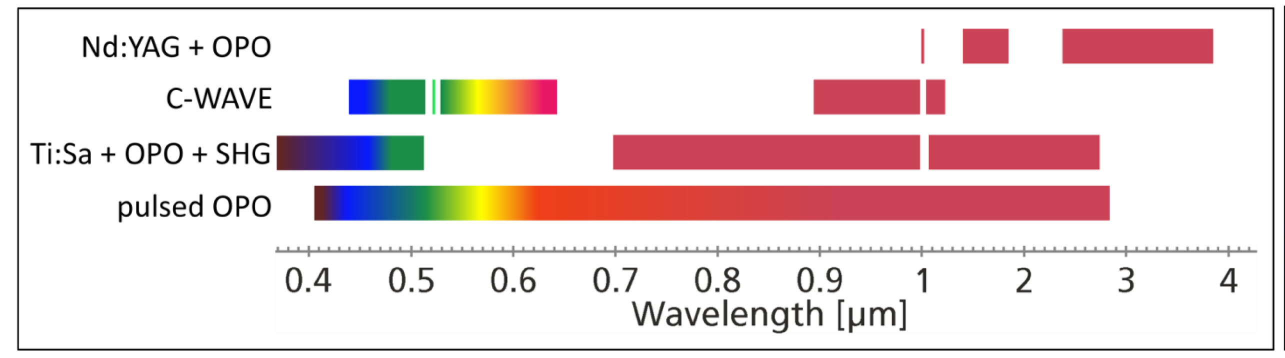
The present work aims at a detailed analysis of the absorption behavior of both materials.

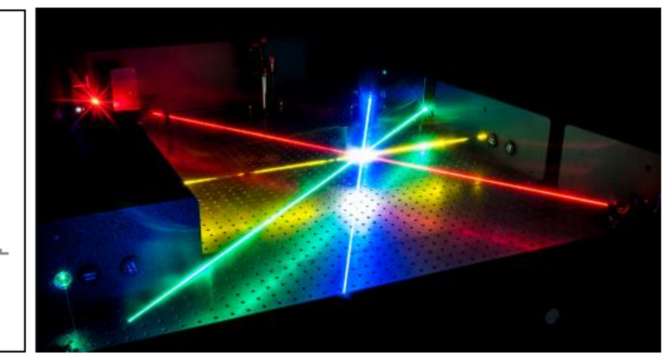
Photothermal Common-Path Interferometer



PCI setup for the VIS-NIR measurements

Wavelength coverage





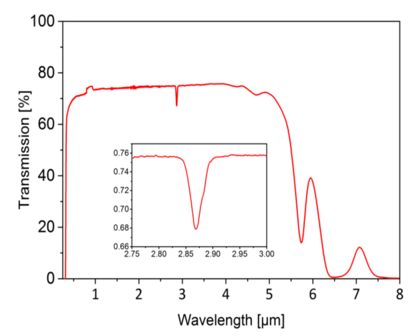
Continuous-wave optical parametric oscillators developed by Fraunhofer IPM and IMTEK/Freiburg University Freiburg are available as tunable pump sources for absorption measurements in the VIS, NIR and MIR regions.

Visible beams of four Hübner "C-WAVE" OPOs (developed at IPM) intersecting on the optical table

Calibration methods

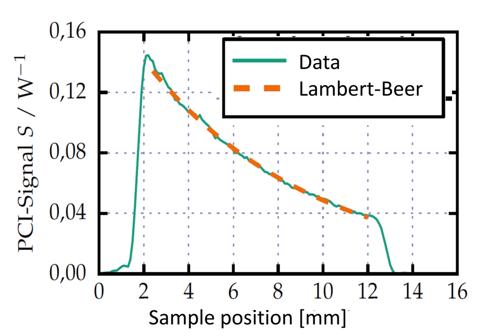
PCI, like all indirect absorption measurement methods, requires a calibration of the absorption scale. Here, the tuneability of the pump source is used to access absorption features in the spectra.

Method 1:
Lambert-Beer decay visible in the PCI scan through the sample
→ Direct determination of the extinction coefficient
(example: lithium niobate)



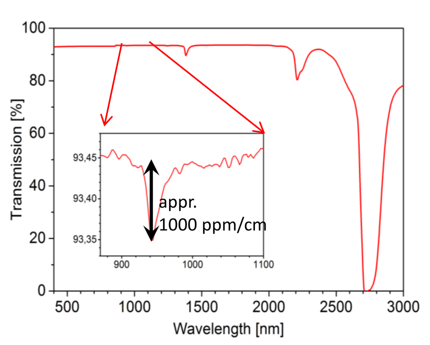
Transmission spectrum

(Leidinger2015)



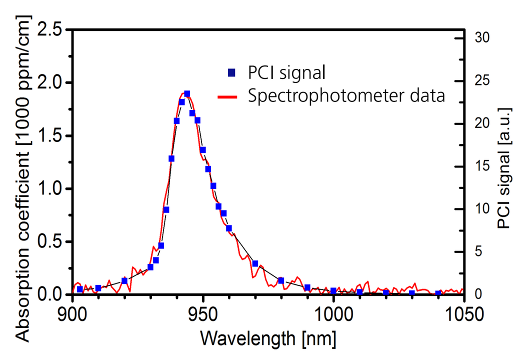
Z scan through the sample

Method 2:
Comparison of transmission and PCI scan data
→ Scaling of the PCI signal
(example: fused silica)



Spectrophotometer data

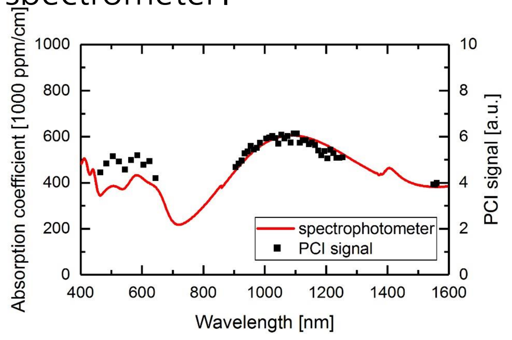
(Leidinger2015)



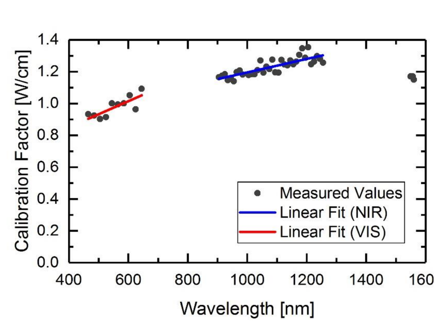
PCI vs. transmission data

From VIS to NIR

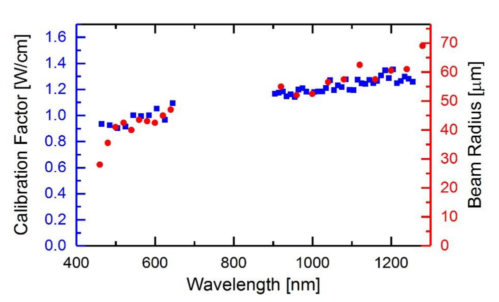
Is a calibration performed at one wavelength valid for the full wavelength range of the spectrometer?



Absorption spectrum of a neutral density filter as function of wavelength vs. PCI data
→ wavelength-dependent scaling factor



Wavelength-dependent scaling factor with a linear fit for VIS and NIR ranges, respectively



The wavelength dependence is caused by the change in the beam waist of the pump laser in the sample

→ The calibration can be transferred across the whole wavelength range with a maximum uncertainty of 10%

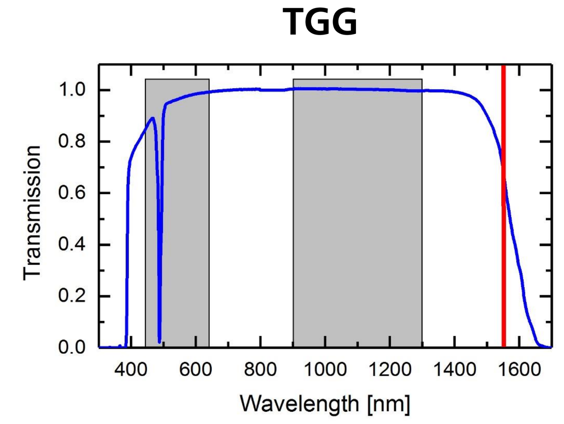
Calibration for TGG and KTF

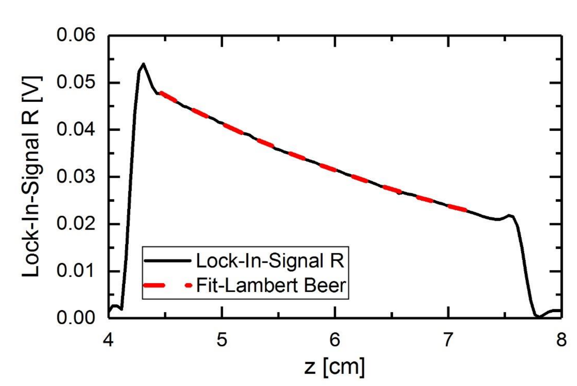
Both TGG and KTF feature a prominent absorption peak in the VIS operation range of the C-WAVE which is due to a Terbium transition around 480 nm.

In both materials, the absorbed light is partially re-emitted as fluorescence. In KTF, scattering contributes to the total extinction.

As a consequence, the multiphonon absorption at 1.5 µm is used for the calibration utilizing an additional laser. At that wavelength fluorescence is absent and scattering losses can be neglected, i.e. the extinction data represent the absorption in the material.

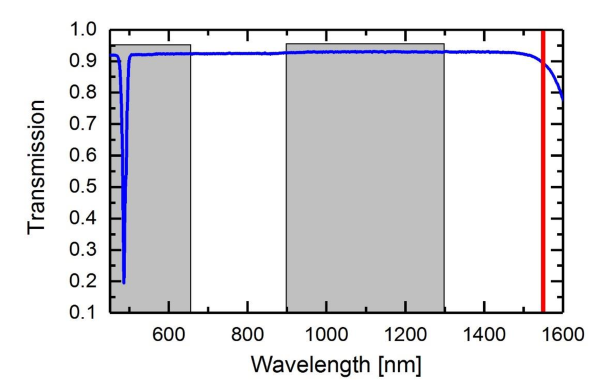
TGG

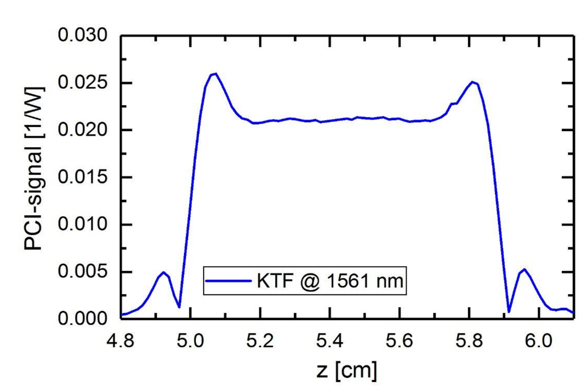




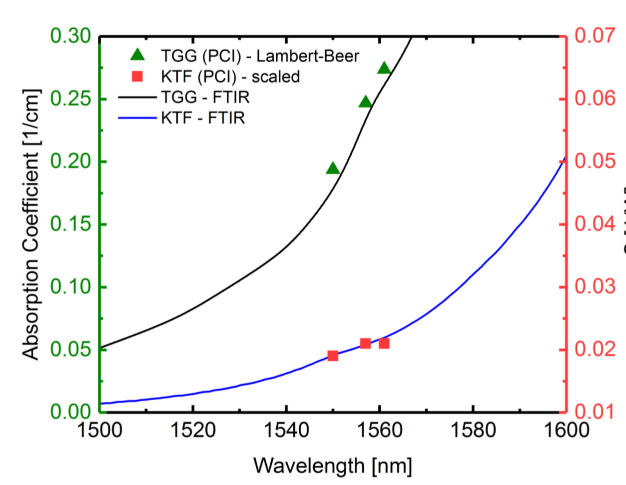
α (1550 nm) ≈ 0.2 / cm
→ direct determination of the extinction coefficient from the PCI Lambert-Beer decay

KTF





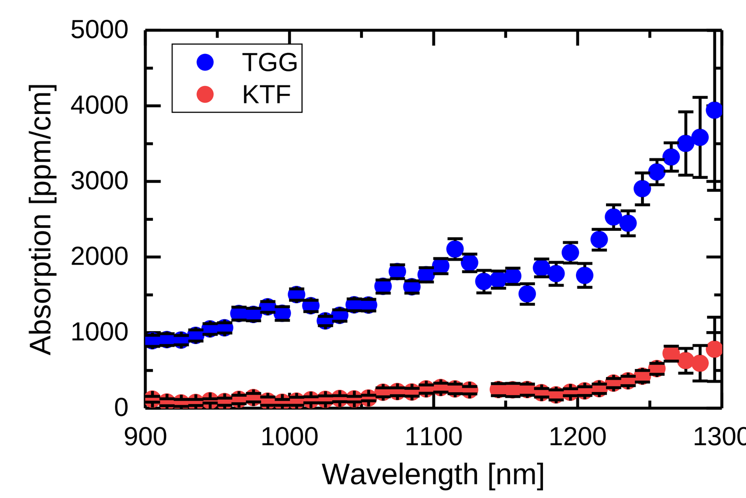
α (1550 nm) ≈ 0.05 / cm
→ comparison between PCI and FTIR data for the scaling of the absorption



TGG:
FTIR and PCI Lambert-Beer data,
(both: left axis).
Very good agreement between the data sets

KTF:
FTIR (left axis) and PCI data (right axis), scaled to yield the best agreement.
Very good linearity between the two data sets

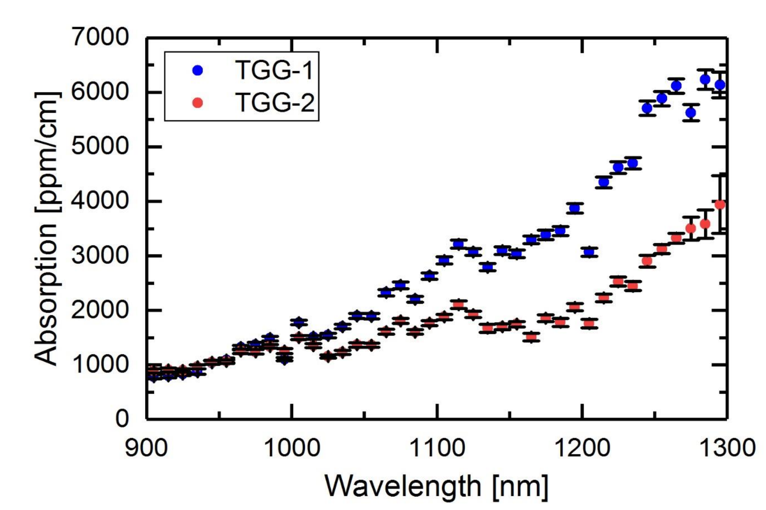
NIR absorption spectra



Property	TGG	KTF
Verdet constant (1064 nm) [rad/T*m]	39	36
Refractive index (1064 nm)	1.944	~ 1.5
Thermooptic coefficient [10^{-6}/K]	17.9	1
Thermal conductivity [W/m*K]	7.4	1.67
Specific heat [J/(g*K)]	0.40	0.43
Thermal expansion coefficient [10^{-6}/K]	7	13
Absorption coefficient (1065 nm) [ppm/cm^{-1}]	**1610 ± 90**	**210 ± 60**

Data: Stevens2016, Jalali2017, **this work**

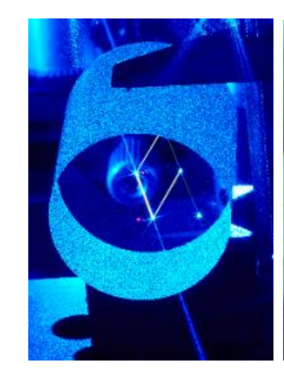
→ The combination of lower absorption and smaller thermo-optic coefficient in KTF leads to much weaker thermal lenses in the new material compared to TGG.



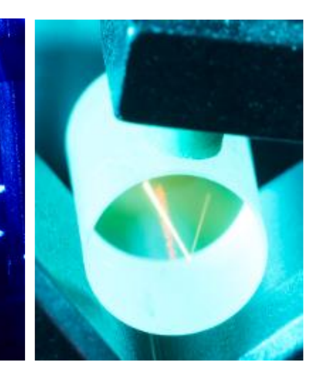
NIR spectra of two TGG crystals. The structure is caused by the multi-phonon bands.

Crystals under illumination

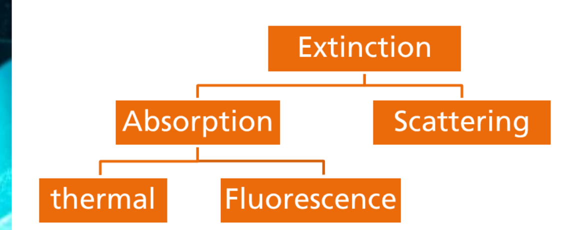
Scattering and strong green fluorescence in the KTF crystal.



TGG



KTF



Energy pathways at short wavelengths

Acknowledgements

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Federal Ministry of Education and Research

References

Jalali2017: Amir Jalali et al., "Characterization and extinction measurement of potassium terbium fluoride single crystal for high laser power applications". Opt. Lett 42, 899 (2017)

Leidinger2015: M. Leidinger et al., "Comparative study on three highly sensitive absorption measurement techniques characterizing lithium niobate over its entire transparent spectral range." Optics Express, 23, 21690 (2015)

Stevens2016: Kevin T. Stevens et a., "Promising Materials for High Power Laser Isolators", Laser-Journal 3/2016, p. 18 (2016)

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