

# Analytical Equipment @ RG Tailored Optical Materials

**David Enseling and Thomas Jüstel**

**E-mail:**

**[david.enseling@fh-muenster.de](mailto:david.enseling@fh-muenster.de)**

**[tj@fh-muenster.de](mailto:tj@fh-muenster.de)**

**Homepage:**

**[www.fh-muenster.de/juestel](http://www.fh-muenster.de/juestel)**



**Department of Chemical Engineering  
Münster University of Applied Sciences  
Stegerwaldstr. 39  
D-48565 Steinfurt, Germany**

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# Optical Spectroscopy @ Research Group Jüstel

## Overview Spectrometer Systems

- Fluorescence spectrometer  
(Fluorescence spectra )  
Shimadzu RF-5301
- Fluorescence spectrometer  
(Fluorescence spectra, ns to min-decay,  
thermal quenching, afterglow)  
Ocean Optics Spectrometer-QE 65 Pro  
Edinburgh Instruments FLS 920  
Edinburgh Instruments FLS 980
- FT-IR Spectrometer  
(Absorption spectra 400–4000  $\text{cm}^{-1}$ )  
Perkin-Elmer Spektrum 100
- Reflection spectrometer  
(Reflection/transmission spectra, quantum efficiency)  
Edinburgh Instruments FS 920
- ps pulsed LASER diodes  
(ns-decay)  
Hamamatsu EPL440, EPL375  
EPLED265
- Cryostat (3 K)  
(thermal quenching, glow curves)  
Edinburgh Instruments
- High temperature sample holder (800 K)  
(Thermal quenching, glow curves)  
Edinburgh Instruments
- VUV spectrometer  
(VUV fluorescence spectra)  
Edinburgh Instruments FS920
- UV/Vis spectrometer  
Absorption spectra 190 – 900 nm

# Optical Spectroscopy @ Research Group Jüstel

## Overview Further Analytical Equipment

- Thermal imaging camera
- Scanning electron microscope (SEM) +  
Energy-dispersive X-ray spectroscopy (EDX)
- Magnetic Susceptibility Balance (MSB)
- Powder X-Ray Diffractometer
- Particle Sizers (3)
- Elemental Analysis (C, N, O, S)
- Zeta Sizer
- DTA/TG
- BET Equipment
- Faraday Scale
- Refractometer (Multi wavelengths)

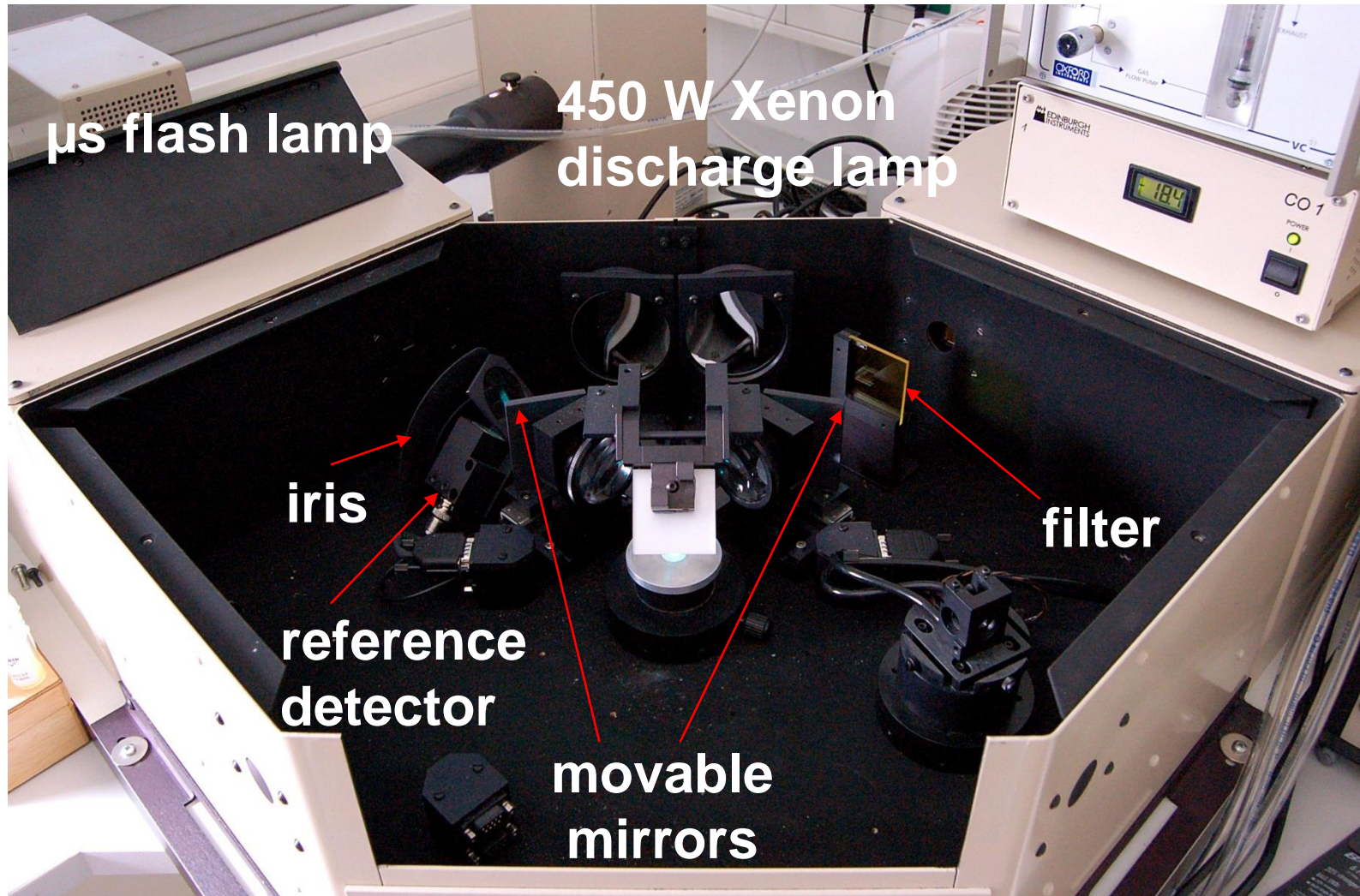
# Optical Spectroscopy @ Research Group Jüstel

## Fluorescence Spectrometer FLS 920

- **Excitation Sources:**
  - 450 W Xe discharge lamp ( $I = 25 \text{ A}$ )
  - $\mu\text{F920H}$  Flash lamp
  - EPLED265 ps LED  $\lambda_{\text{EM}} = 267.0 \text{ nm}$ ; pulse width = 800 ps
  - EPL375 ps LASER  $\lambda_{\text{EM}} = 377.6 \text{ nm}$ ; pulse width =  $<70 \text{ ps}$
  - EPL450 ps LASER  $\lambda_{\text{EM}} = 445.6 \text{ nm}$ ; pulse width =  $<70 \text{ ps}$
- **Monochromators:**
  - **Gratings:**
    - Ex  $\rightarrow$  200-900 nm 1800 lines/mm optimised to 250 nm
    - 500-1700 nm 830 lines/mm optimised to 1200 nm
    - Mirror for LASER Diodes
    - Em  $\rightarrow$  200-900 nm 1800 lines/mm optimised to 500 nm
    - 300-1200 nm optimised to 750 nm
    - 700-2500 nm 830 lines/mm optimised to 830 nm
- **Detectors:**
  - single photon PMT detection Hamamatsu R1527 (blue)
  - single photon PMT detection Hamamatsu R2658P (red, cooled  $-20 \text{ }^\circ\text{C}$ )
  - InGaAs pin diode detection Hamamatsu G 8605-25
  - F-H05 InGaAs NIR detector 900 nm – 2550 nm

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## Fluorescence Spectrometer – Mirror Optics for Powder Samples



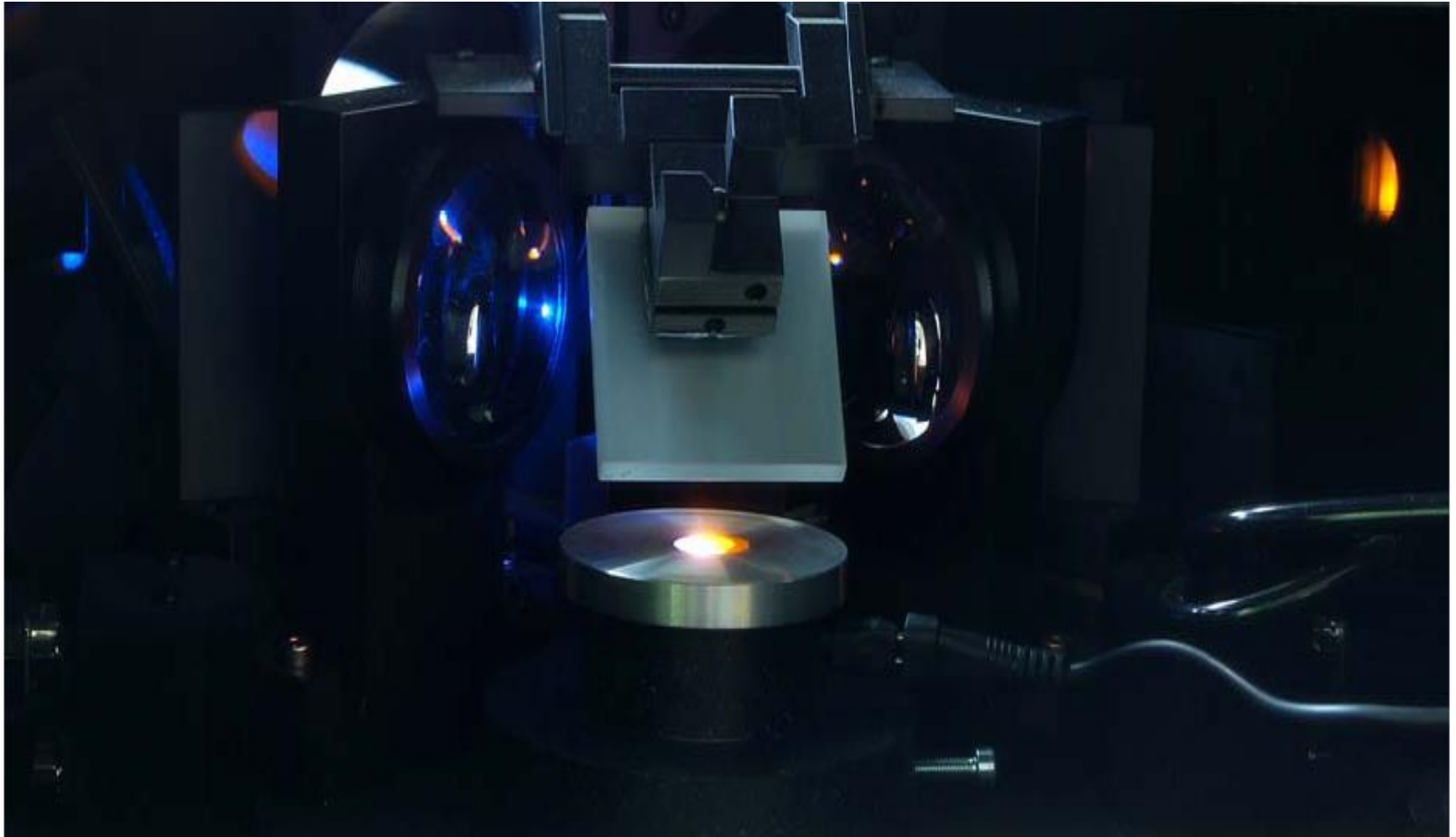
# Optical Spectroscopy @ Research Group Jüstel

## Fluorescence Spectrometer – Lense Optics for Liquid Samples



# Optical Spectroscopy @ Research Group Jüstel

**Fluorescence Spectrometer – Transmission set-up for glass, ceramic, and single crystalline samples**



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## Novel Fluorescence Spectrometer - FLS 980 Edinburgh Instruments

**STEADY STATE, PHOSPHORESCENCE AND  
FLUORESCENCE LIFETIME SPECTROMETER  
WITH TWO MONOCHROMATORS**

**System:**

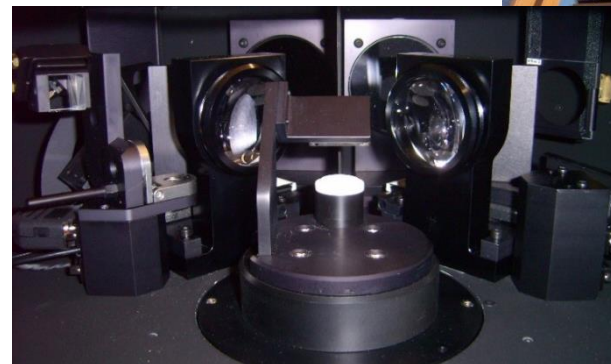
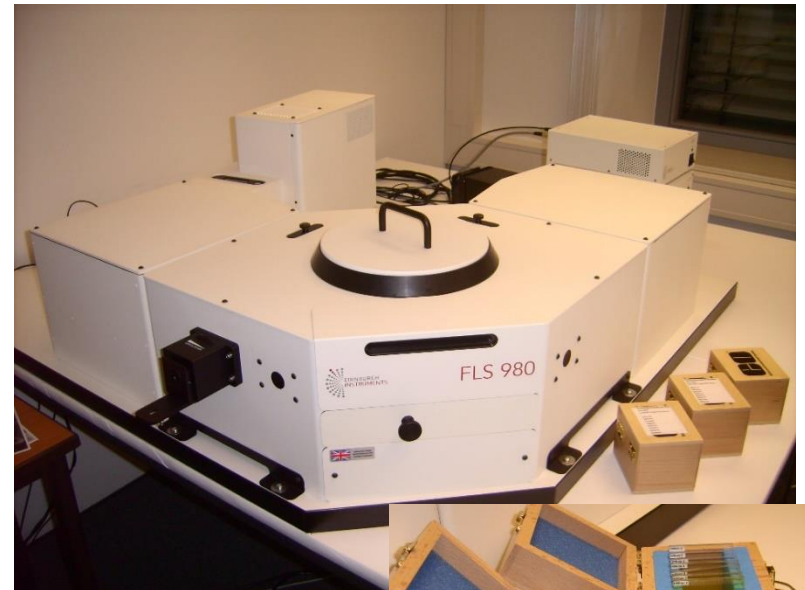
**Excitation source**

**450 W Xenon Lamp (ozone free fitted)  
 $\mu$ s Xe-Flashlamp  
EPL ps LASER port**

**Detector and Range**

**Photomultiplier R928P  
(Emission 200 – 900 nm)**

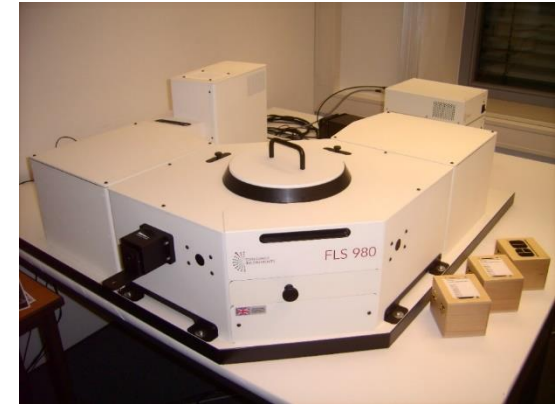
**InGaAs NIR detector  
Hamamatsu F-H05  
(Emission 900 – 2500 nm)**





# Optical Spectroscopy @ Research Group Jüstel

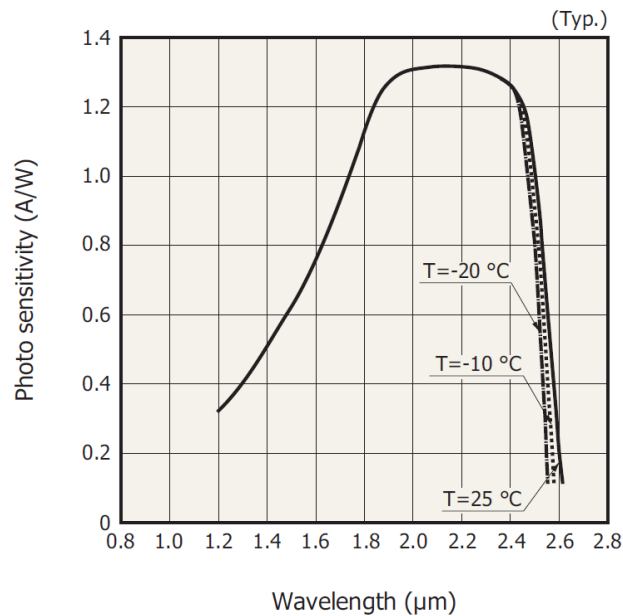
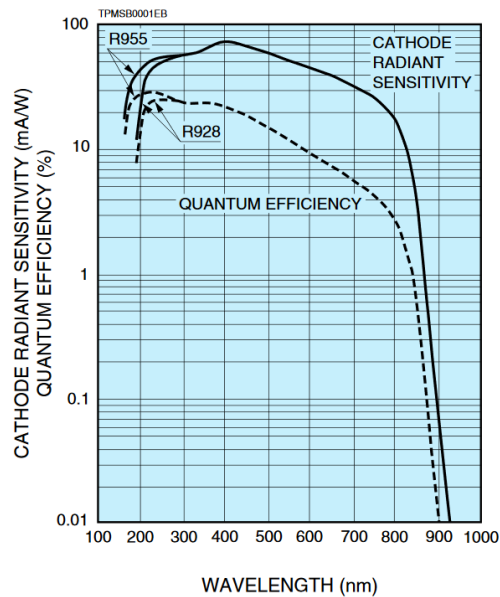
## Novel Fluorescence Spectrometer - FLS 980 Edinburgh Instruments



### Detector spectral response curves

**Photomultiplier R928P**  
(Range 200 – 900 nm)

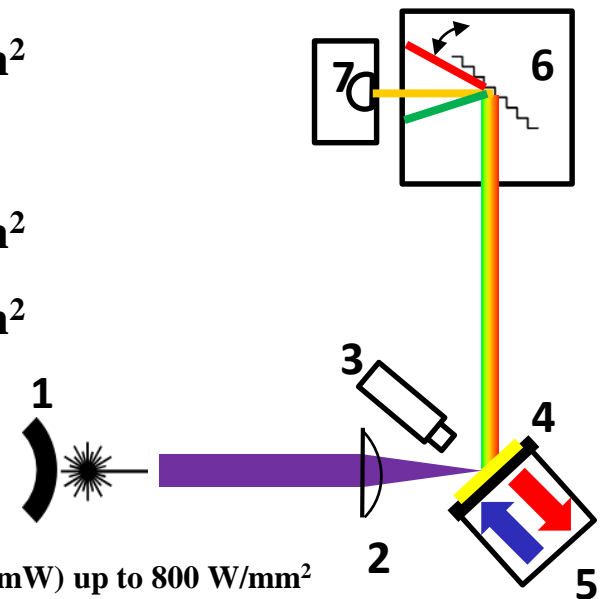
**(In,Ga)As NIR detector**  
**Hamamatsu F-H05**  
(Range 900 – 2550 nm)



# Optical Spectroscopy @ Research Group Jüstel

## Fluorescence Spectrometer – Saturation Measurements

- Fluorescence spectrometer
  - Laser excitation for saturation measurements (continuous or pulsed)
    - 375 nm Laser (50 mW) up to 500 W/mm<sup>2</sup>
    - 405 nm Laser (200 mW) up to 2000 W/mm<sup>2</sup>
    - 445 nm Laser (80 mW) up to 800 W/mm<sup>2</sup>
    - 488 nm Laser (150 mW) up to 1500 W/mm<sup>2</sup>
    - 980 nm Laser (150 mW) up to 1500 W/mm<sup>2</sup>

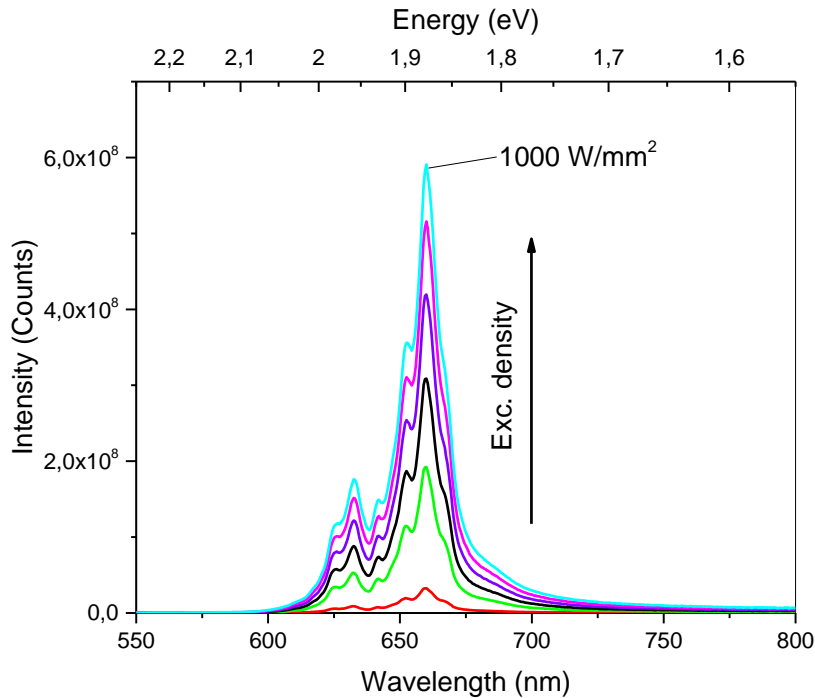


- 1 - Laser diode 445 nm (80 mW) up to 800 W/mm<sup>2</sup>
- 2 - Focusing lens
- 3 - Pyrometer
- 4 - Sample
- 5 - Passive cooling (Ag sample holder)
- 6 - Emission monochromator
- 7 - Detector (PMT)

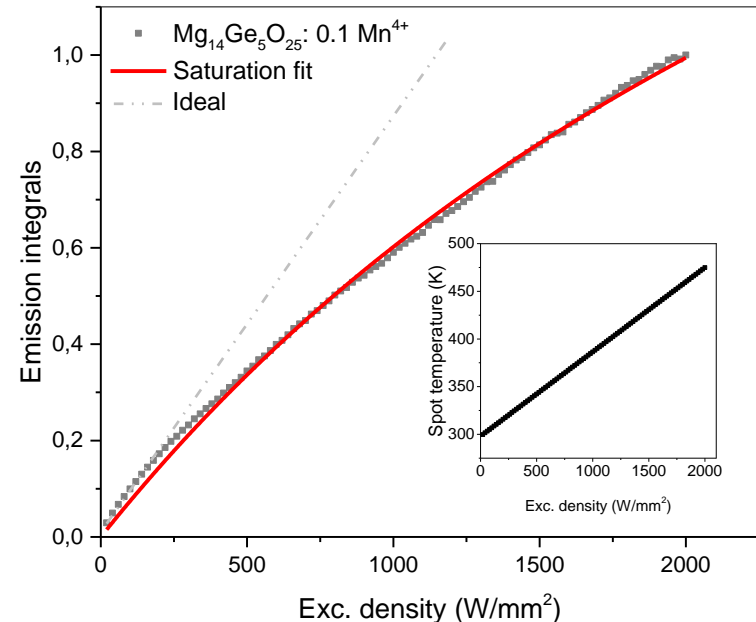
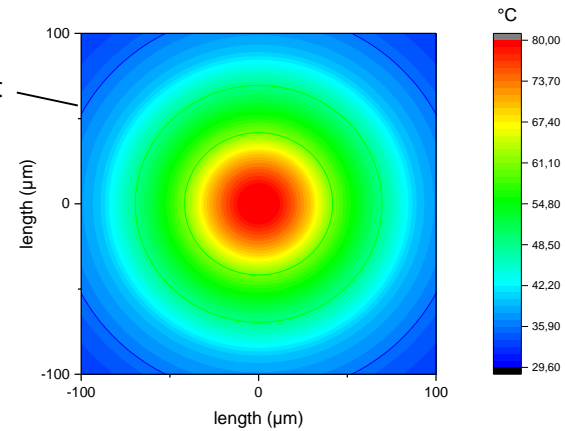
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## Fluorescence Spectrometer – Saturation Measurements

Example:  $\text{Mg}_{14}\text{Ge}_5\text{O}_{24}:\text{Mn}^{4+}(0.1\%)$



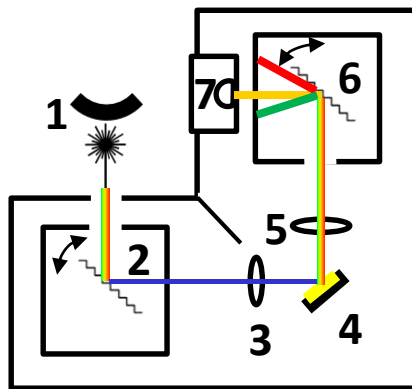
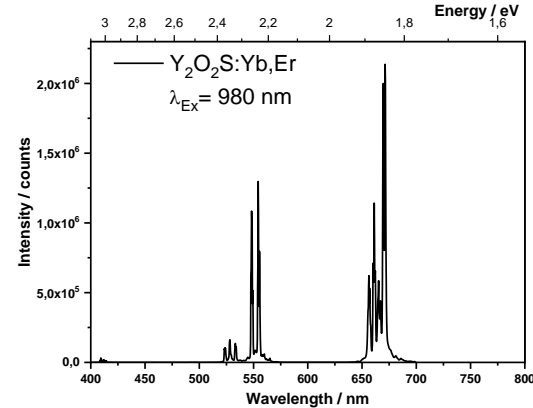
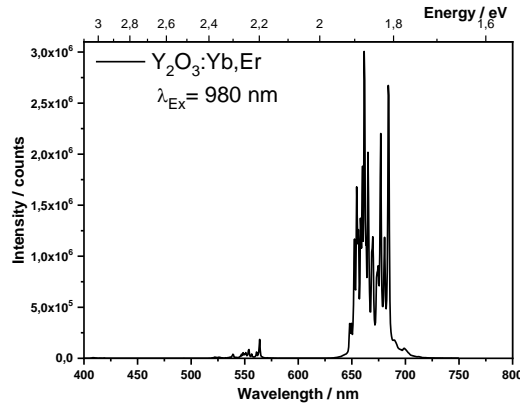
Typical laser spot



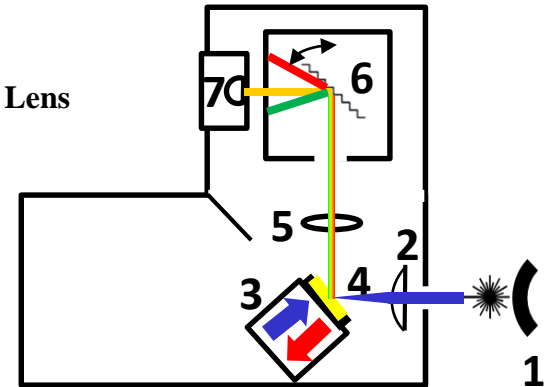
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## Fluorescence Spectrometer – Up-Converter Measurement System

For excitation with a xenon high-pressure lamp, a long pass filter must be used between the excitation monochromator and the sample to absorb the second order (half wavelength) of the selected excitation wavelength.



- 1 - Xe-Lamp / Laser
- 2 - Excitation Monochromator / Focusing Lens
- 3 - Long-pass Filter / Cooler
- 4 - Sample
- 5 - Short-pass Filter
- 6 - Emission Monochromator
- 7 - Detector



# Optical Spectroscopy @ Research Group Jüstel

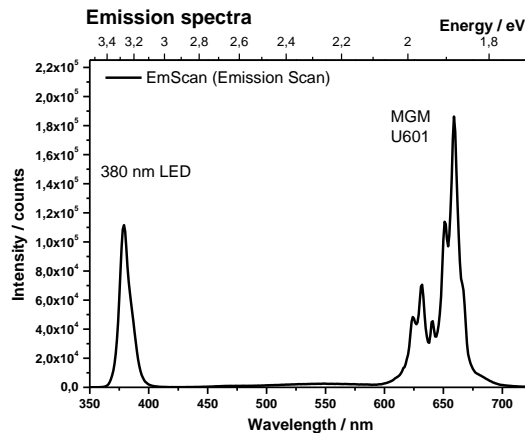
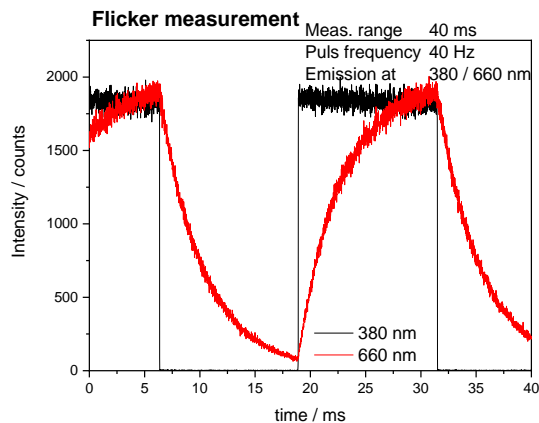
## Fluorescence Spectrometer – Flicker of Light Sources

- Fluorescence spectrometer and function generator HM8030-6

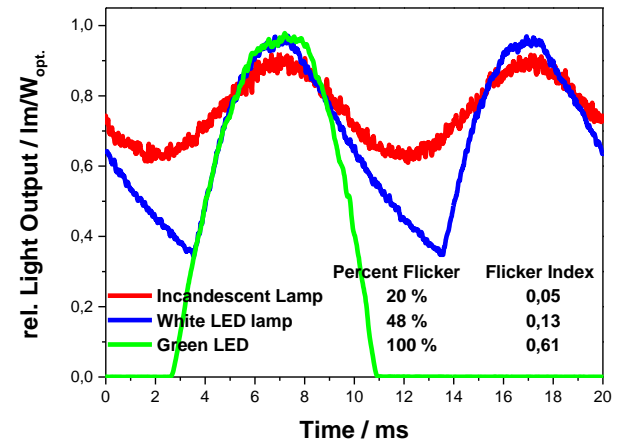
Measuring the flicker of a light source.

Flicker is a periodically change in the luminosity based on used pulsed or alternating current

- The lamps can be pulsed between 1 and 1000 Hz
- The measurement is emission wavelength depending and can be measured between 200 and 1000 nm



380 nm LED + red phosphor  
 $\text{Mg}_{14}\text{Ge}_5\text{O}_{24}:\text{Mn}^{4+}(0.1\%)$  „MGM“

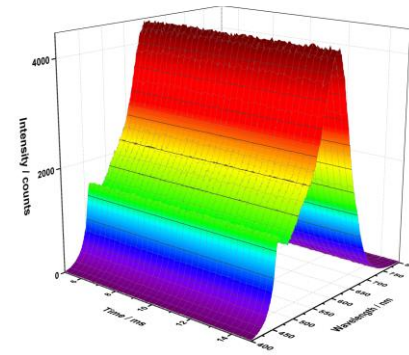


Flicker characterization of different light sources

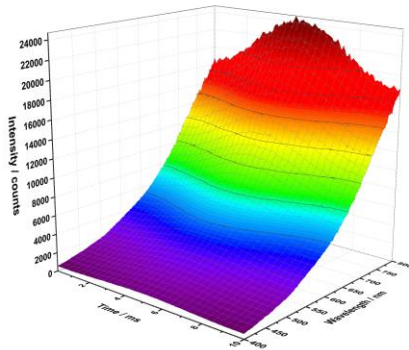
# Optical Spectroscopy @ Research Group Jüstel

## Fluorescence Spectrometer – Flicker of Light Sources

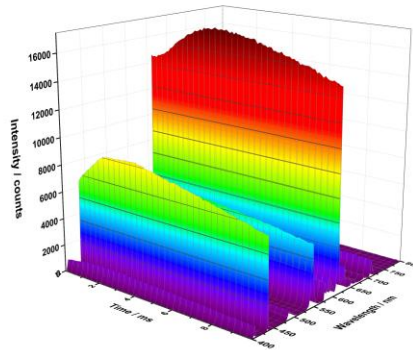
- The 3D plot illustrates the emission intensity profile as function of time and wavelength
- Lamps
  - 5 nm step width
  - 50 Hz AC



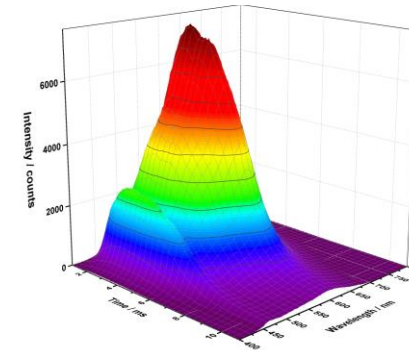
**Flicker free**



**Halogen Bulb**



**Compact  
Fluorescent  
Lamp**



**strong  
Flicker**

**Two different types of  
Filament LED lamps**

# Optical Spectroscopy @ Research Group Jüstel

## Reflection Spectrometer

- **Excitation source:** 450 W Xe discharge lamp ( $I = 25 \text{ A}$ )
- **Monochromators:** TMS300 (Czerny-Turner optics)
  - **Gratings:**  
Ex  $\rightarrow$  200-900 nm 1800 lines/mm optimised to 250 nm  
Em  $\rightarrow$  200-900 nm 1800 lines/mm optimised to 500 nm
- **Detector:** Single photon PMT detection Hamamatsu R928 (cooled  $-20 \text{ }^\circ\text{C}$ )

### Sample holder made from:

- PTFE
- Fused silica
- Aluminum

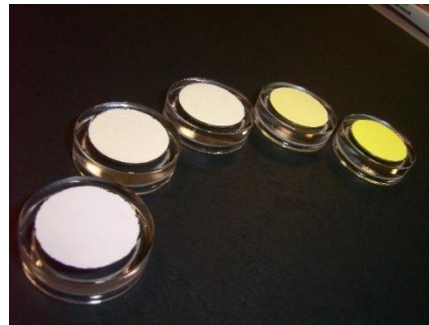
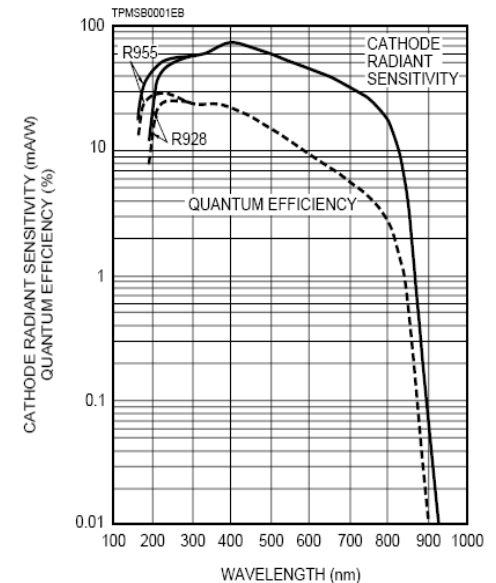


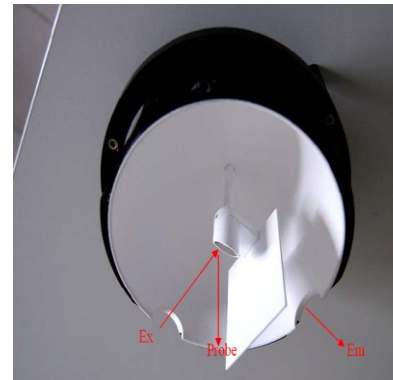
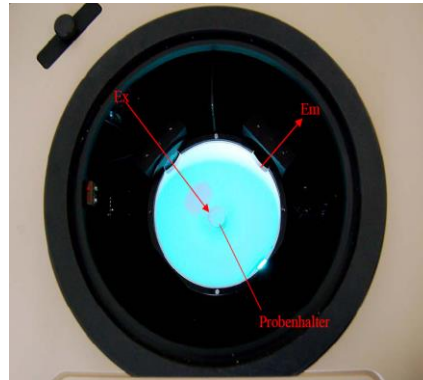
Figure 1: Typical Spectral Response



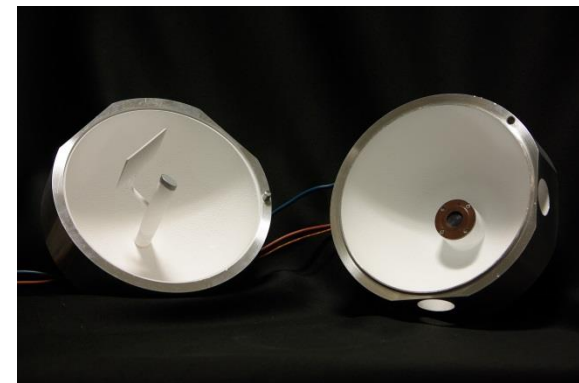
# Optical Spectroscopy @ Research Group Jüstel

## Reflection Spectrometer – Types of Integrating Spheres

**BaSO<sub>4</sub> coated**



**Spectralon (PTFE) coated**



**BaSO<sub>4</sub> coated,  
heatable to 500 K**



# Optical Spectroscopy @ Research Group Jüstel

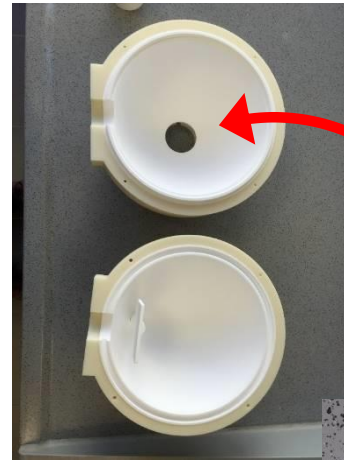
## Fluorescence and Reflection Spectrometer – LED Integrating Sphere

Suitable Spectralon Ulbricht Sphere for high power LEDs

Port for excitation with high power LEDs

300 – 1200 nm

0.02 – 5 W



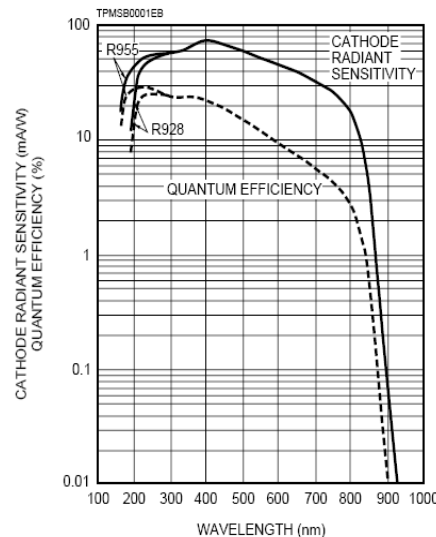
LED insertion

# Optical Spectroscopy @ Research Group Jüstel

## Vacuum Ultraviolet (VUV) Spectrometer

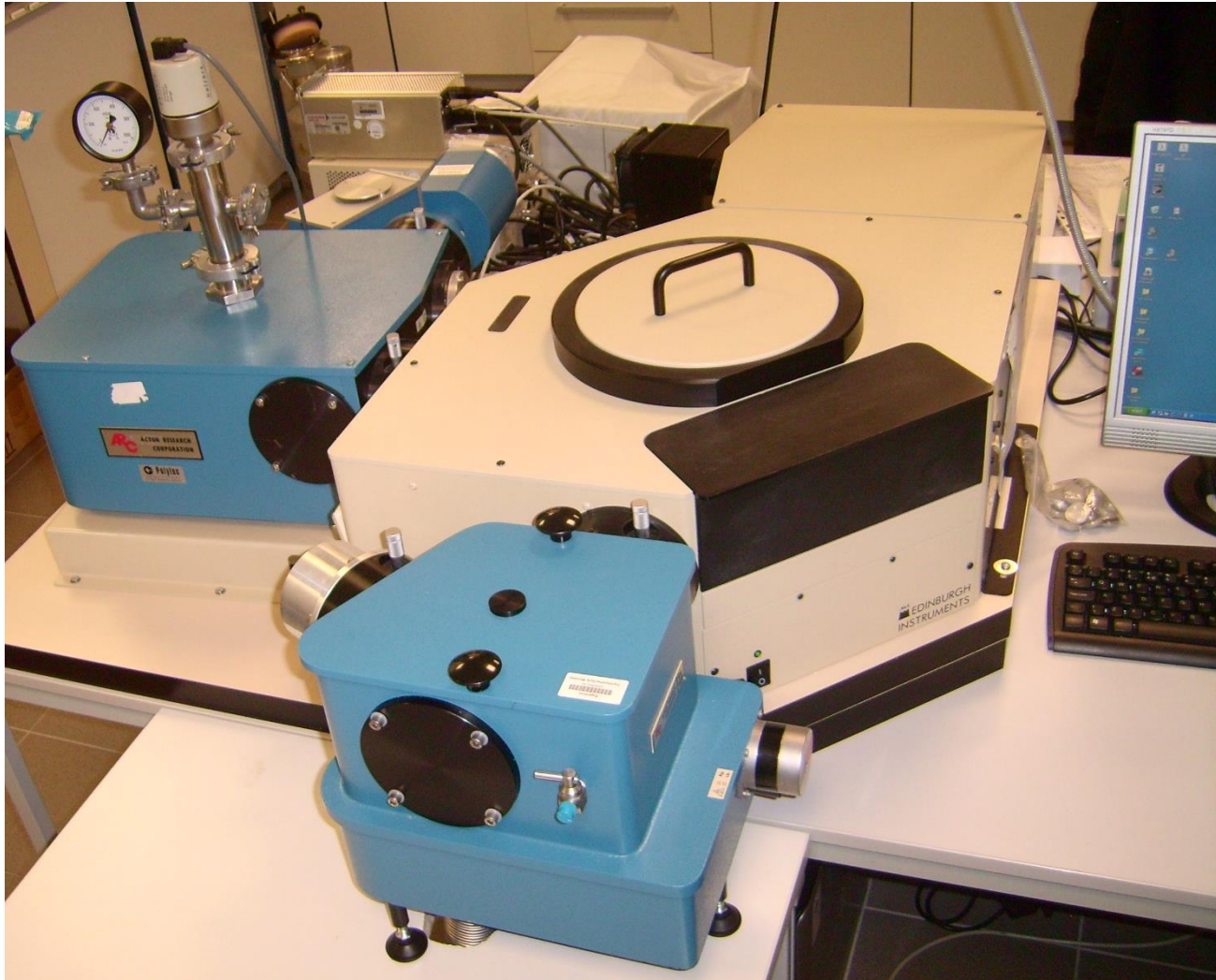
- **Excitation source:** Deuterium lamp DS-775 (115 - 370 nm)
- **Monochromators:** TMS300 (Czerny-Turner optics)
  - **Gratings:**
    - Ex → 100 - 500 nm 1200 lines/mm
    - 100 - 500 nm 2400 lines/mm
    - Em → 200 - 900 nm 1800 lines/mm optimised to 500 nm
- **Detector:** Single photon PMT detection Hamamatsu R928 (cooled -20 °C)

Figure 1: Typical Spectral Response



# Optical Spectroscopy @ Research Group Jüstel

## Vacuum Ultraviolet (VUV) Spectrometer



# Optical Spectroscopy @ Research Group Jüstel

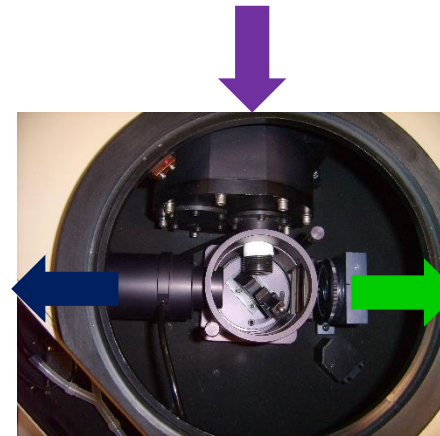
## Vacuum Ultraviolet (VUV) Spectrometer

Based on Edinburgh Instruments FS 920

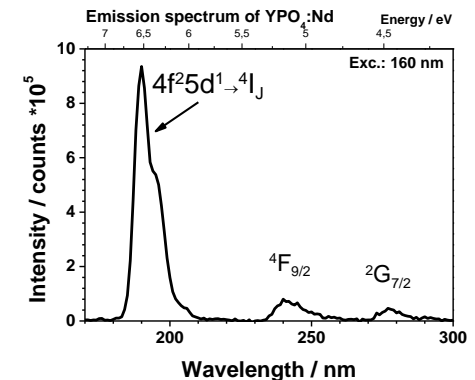
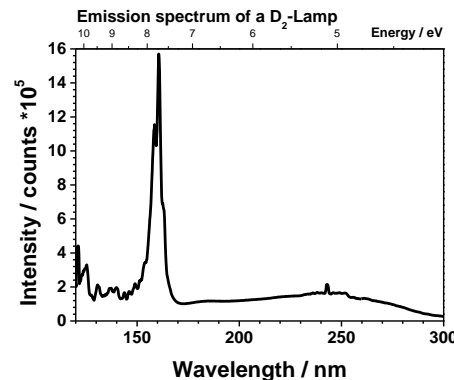
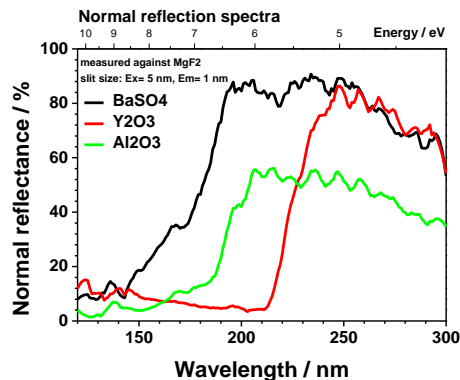
DS-775 deuterium lamp and excitation monochromator

VM504 (Acton Research Corporation) 120 – 400 nm

VUV-Emission  
monochromator VM502  
(Acton Research Corporation)  
and a single-photon counting  
PMT R8486 (Hamamatsu)  
120 – 300 nm



UV/VIS-Emission  
monochromator TMS300 and  
a single-photon counting PMT  
R928 (Hamamatsu)  
200 – 800 nm

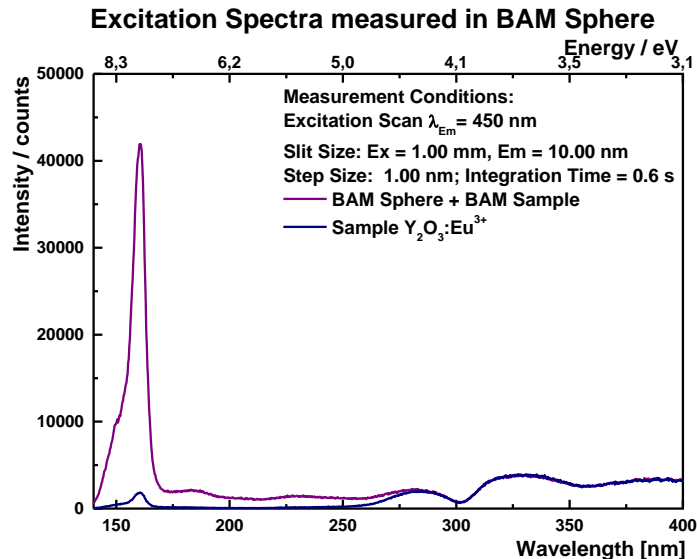


# Optical Spectroscopy @ Research Group Jüstel

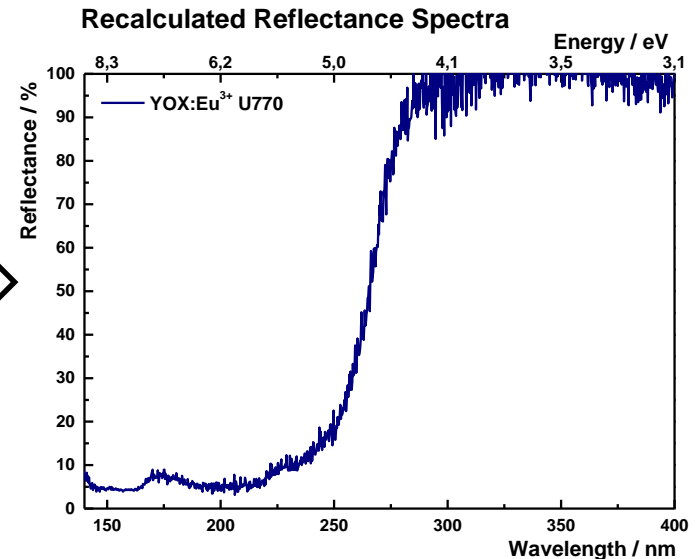
## BAM Coated Integrating Sphere for VUV Reflectance Measurements

### Principle

- 1.) Irradiation of VUV photons passing the evacuated monochromator into a  $N_2$  flushed  $BaMgAl_{10}O_{17}:Eu^{2+}$  (BAM:Eu) coated Ulbricht sphere
- 2.) Conversion of reflected VUV photons into blue light by BAM coating and integration over the sphere
- 3.) Light output is collected by a PMT via the emission monochromator
- 4.) Determination of reflection spectrum by dividing  $I(\text{Sample})/I(\text{BAM:Eu})$



Division



# Optical Spectroscopy @ Research Group Jüstel

## BAM:Eu Coated Integrating Sphere for VUV Reflectance Measurements



# Optical Spectroscopy @ Research Group Jüstel

## LAP:Ce Coated Integrating Sphere for VUV Reflectance Measurements

To measure phosphors which emit below 450 nm and above 320 nm

As addition to the BAM:Eu coated sphere. Wrong reflection spectrum in the VUV range is caused by emission below 450 nm in the BAM:Eu sphere.



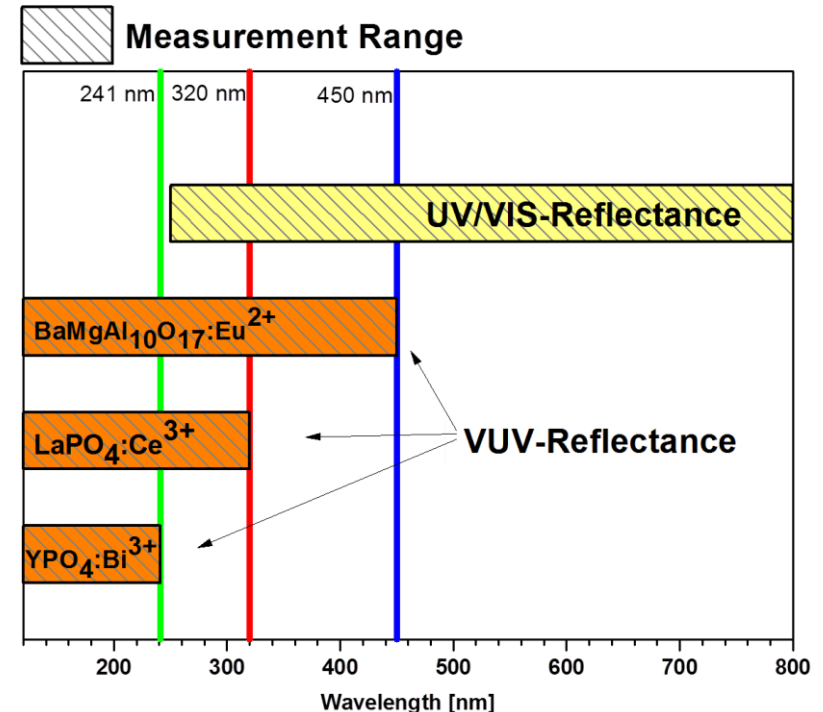
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## YPO<sub>4</sub>:Bi Coated Integrating Sphere for VUV Reflectance Measurements

To measure phosphors which emit below 450 nm and above 250 nm

As further addition to the BAM:Eu and LAP:Ce coated sphere.

Wrong reflection spectrum in the VUV range is caused by emission below 450 nm in the BAM:Eu sphere or below 320 nm in the LAP:Ce sphere



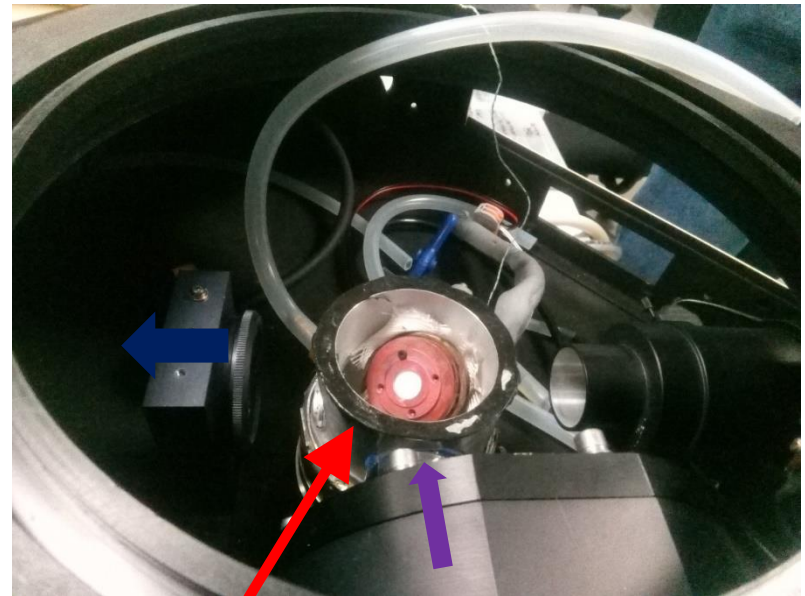
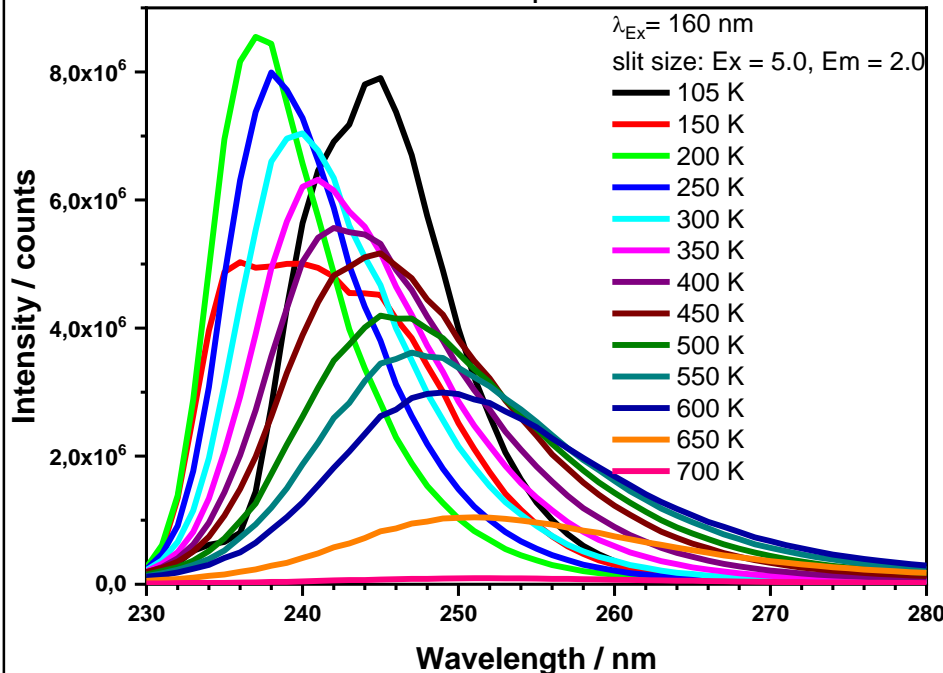


# Optical Spectroscopy @ Research Group Jüstel

## Vacuum Ultraviolet (VUV) Spectrometer

Temperature adjustable sample holder for VUV spectroscopy

Emission spectra  $\text{YPO}_4:\text{Bi}^{3+}$



Copper based sample holder

Temperature adjustable from 100 K to 700 K

Sample chamber at  $< 1 \text{ mbar}$

Window material is exchangeable, e.g.  $\text{MgF}_2$ ,  $\text{SiO}_2$

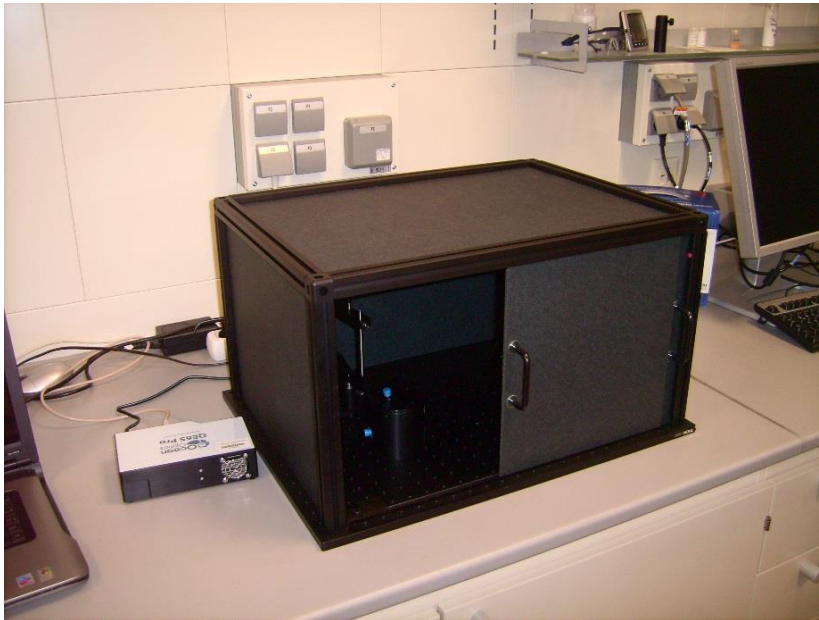
# Optical Spectroscopy @ Research Group Jüstel

## Ocean Optics Spectrometer – QE 65 Pro

### CCD Array Detector Specifications

**Hamamatsu S7031-1006 Low Etaloning**

**Emission range 350 – 1000 nm**



**Integration time of 8 ms to 60 min**

**Large measuring chamber for individual experiment set-up**

**Including spectralon coated integration sphere**

# Optical Spectroscopy @ Research Group Jüstel

## Light Measurement Integration Sphere System: Illumia plus & Integral® Software

**System: Illumia plus (Labsphere)**

**Spectral flux: 250 nm - 850 nm**

**Spectra recording: 200 nm - 1100 nm**

**Minimum measurable**

**Lumens (typical): 0.04 lumens**

**Maximum measurable**

**Lumens (typical): ~ 46000 lumens**  
**(Cool white LED source)**

**Exposure time range: 1 ms - 5<sup>3</sup> s**  
**(actual exposure time depends**  
**on sphere size and source type)**

**Software:**

**Integral LM: Included**

**Standards:**

**LM-79: Included**

**LM-82: Module available**



**Spectrometer:**  
**CDS600 and CDS610**  
**2048 element Linear CCD**  
**200 – 850 nm and**  
**350 – 1100 nm**

# Optical Spectroscopy @ Research Group Jüstel

## UVpad E

**Manufacturer: Opsytec Dr. Gröbel, Ettlingen**

**Spectral recording range:**

**Optically active input port:**

**Irradiance (Radiant flux), measuring range:**

**Irradiation dose, measuring range:**

**Exposure time range:**

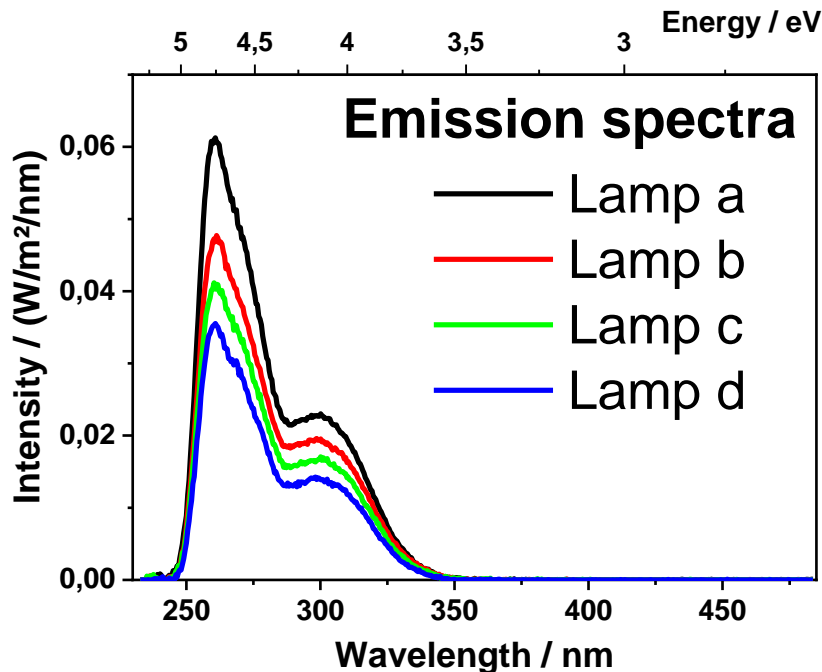
**240 nm - 480 nm**

**10 mm diameter or 78.54 mm<sup>2</sup> Area**

**0 – 5000 mW/cm<sup>2</sup>**

**1 mJ/cm<sup>2</sup> - 600 J/cm<sup>2</sup>**

**10 ms - 1000 s**



# Optical Spectroscopy @ Research Group Jüstel

## Temperature adjustable sample holder

**Nitrogen cooled cryostat, MicrostatN  
from Oxford Instruments**

- **Temperature range: from 77 K to 500 K**
- **Quick cool down: 80 K in less than 10 minutes**

**800 K-Heater**

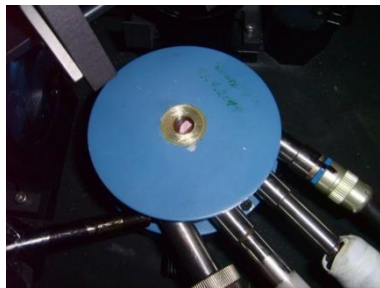
- **Temperature range: from 300 K to 800 K**
- **Quick heat up: 800 K in less than 5 minutes**

**Optistat AC-V 12 (He-Cryostat)**

- **Temperature range: from 3 K to 325 K**

• **Adjustable sample holders accommodate samples up to 8 mm thickness**

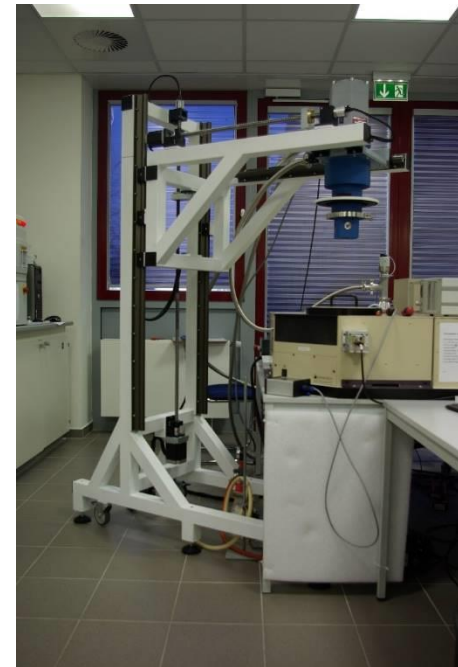
• **Suitable for reflection, excitation, and emission experiments**



MicrostatN (Oxford Instruments)



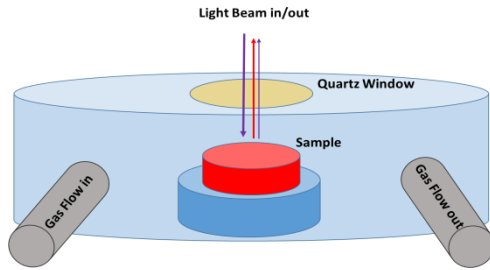
800 K-Heater



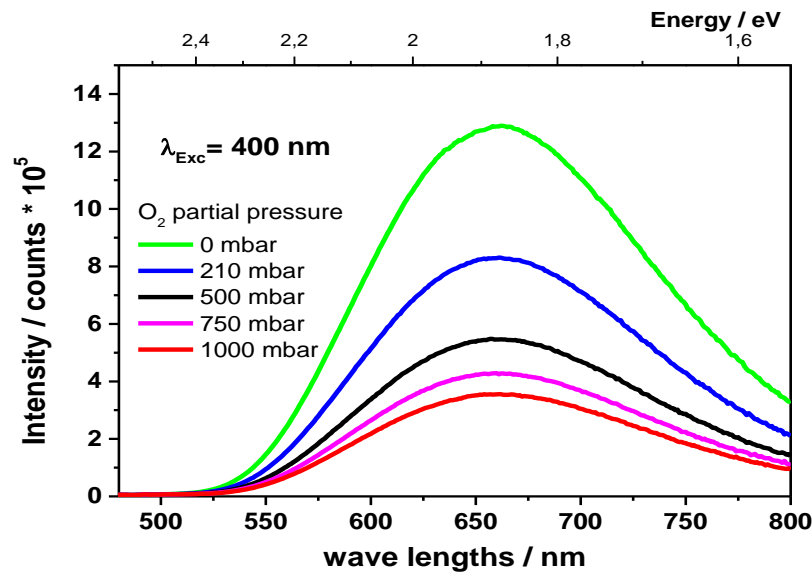
Optistat AC-V 12

# Optical Spectroscopy @ Research Group Jüstel

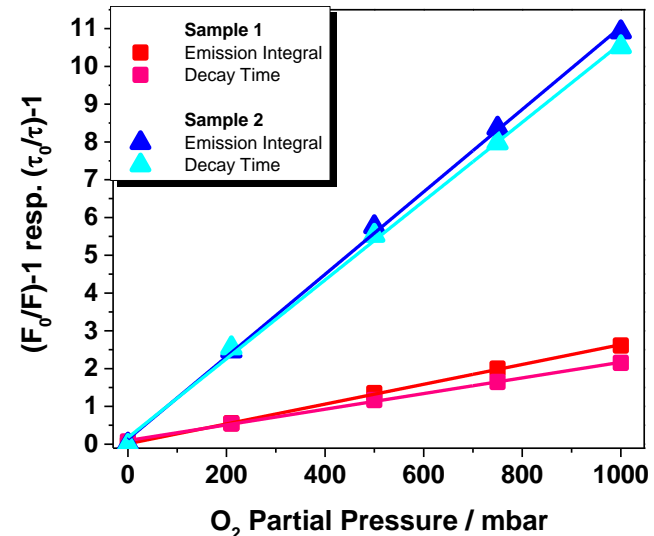
## Atmosphere Dependent Photoluminescence Measurements



Emission-, excitation-, reflection spectra, and decay curves under different atmospheres



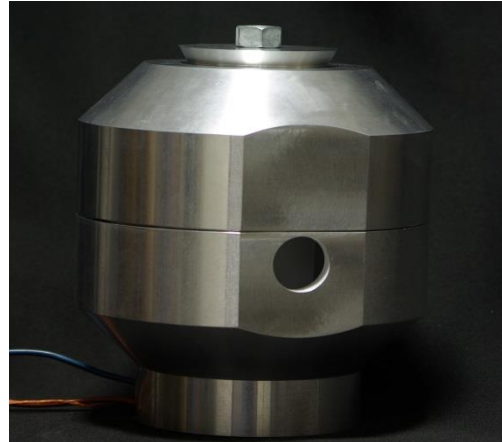
Emission spectra of microcrystalline phosphor powder under several oxygen partial pressures



Stern-Volmer plots of the emission integrals as well as the decay times of two microcrystalline phosphors as a function of oxygen partial pressures.

# Optical Spectroscopy @ Research Group Jüstel

## Temperature Dependent Reflection Spectroscopy



### Heatable BaSO<sub>4</sub> coated integrating sphere

- Temperature range from 300 to 550 K
- Quick heat up in less than 5 min

# Optical Spectroscopy @ Research Group Jüstel

## High energy excitation with $^{241}\text{Am}$ source

High energy excitation  
with  $\alpha$ -Radiation with 5.5 MeV  
and  $\gamma$ -Radiation with 60 keV

370 kBq ( $\alpha$ -decay)  
 $\tau_{1/2} = 432.2 \text{ a}$

To investigate energy transfer  
processes in luminescent materials





# Optical Spectroscopy @ Research Group Jüstel

## High energy excitation by an X-Ray source

### Radiation source

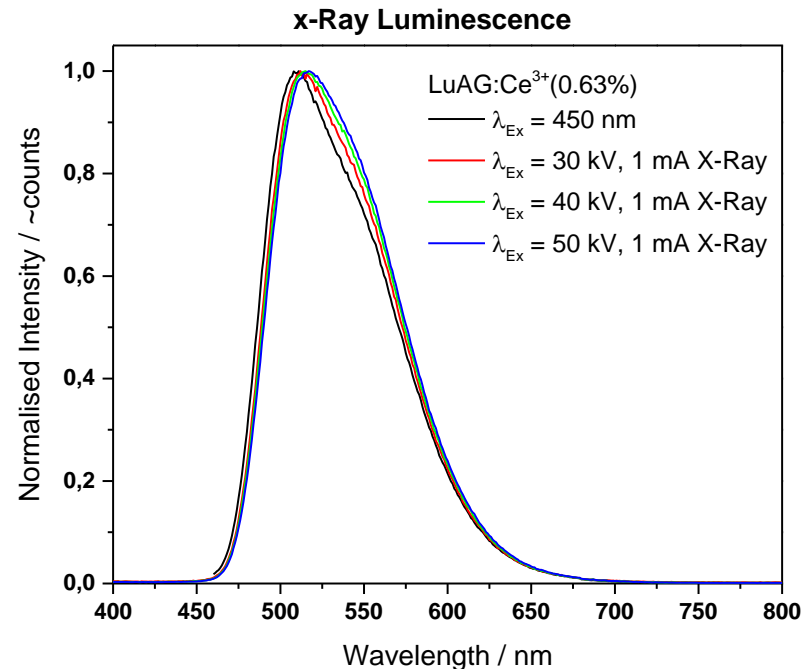
X-Ray Tube Neptune 5200 (Oxford Instruments)

Operating Voltage Range: 10 - 50 kV

Max. Power: 100 W (electron beam)

Dimensions: 210 mm L x 106 mm W

Weight: 6.2 kg



### Available single crystalline reference materials:

$\text{Lu}_{1.9}\text{Y}_{0.1}\text{SiO}_5:\text{Ce}(0.5\%)$  (LYSO:Ce)

$\text{Bi}_4\text{Ge}_3\text{O}_{12}$  (BGO)

# Optical Spectroscopy @ Research Group Jüstel

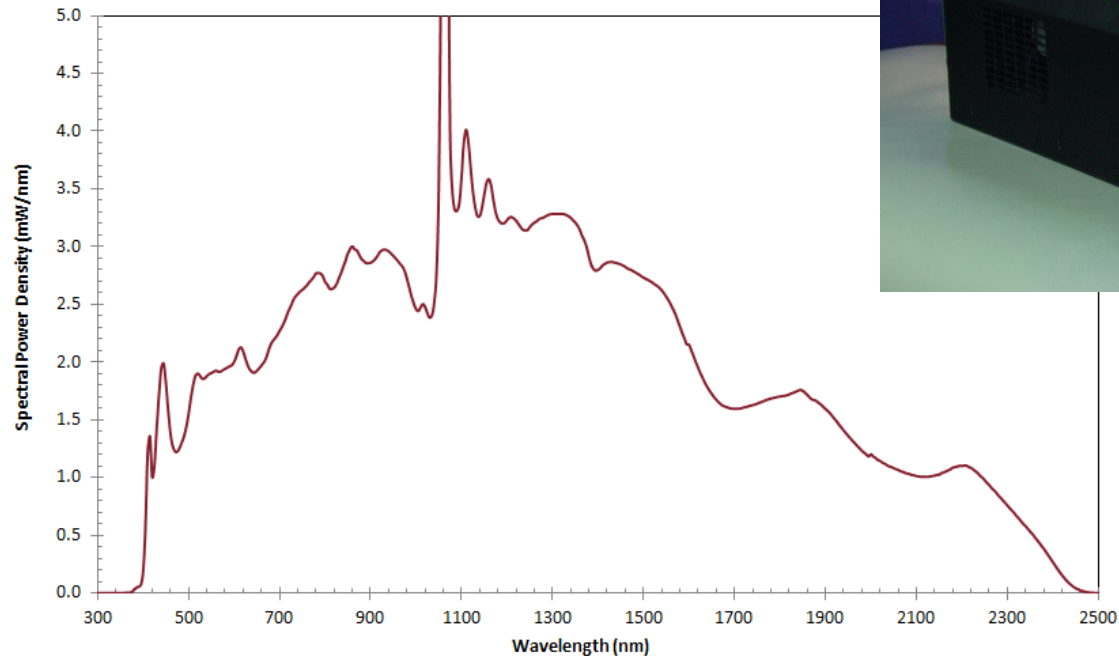
## Fianium Supercontinuum SC450-4 White Light Laser System

Excitation source for the visible and NIR range:

Wavelength Range < 460 nm to > 2  $\mu\text{m}$

Total Output Power > 4 W

Spectral Power Density > 2 mW/nm



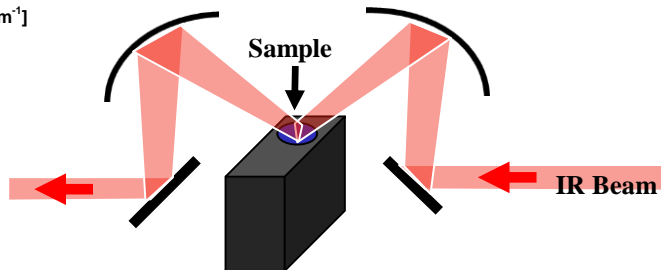
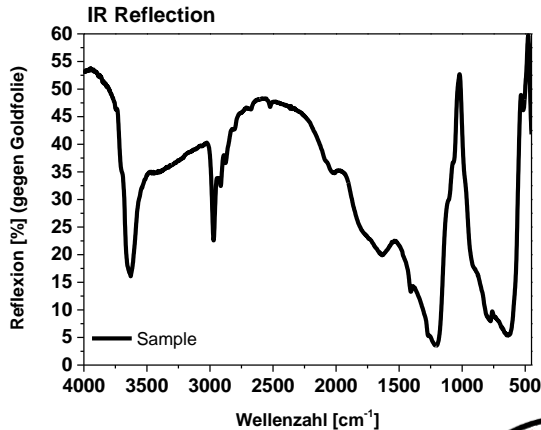
# Optical Spectroscopy @ Research Group Jüstel

## FT-IR Spectrometer Perkin-Elmer Spektrum 100

Spectral Range 400 – 4000  $\text{cm}^{-1}$

### IR Reflectance Measurement

6.5 mm in diameter and 2 mm depth  
Reference samples of gold and aluminum



Diffuse Reflectance Infrared Fourier  
Transform Spectroscopy  
(DRIFTS)



IR-Ref-Au2-3  
3  $\mu\text{m}$  granulation



IR-Ref-Au1-80  
80 grade abrasive paper  
190  $\mu\text{m}$  granulation



IR-Ref-Al2-3  
3  $\mu\text{m}$  granulation



IR-Ref-Al1-80  
80 grade abrasive paper  
190  $\mu\text{m}$  granulation

# Optical Spectroscopy @ Research Group Jüstel

## UV/VIS Spectrometer

Analytik Jena

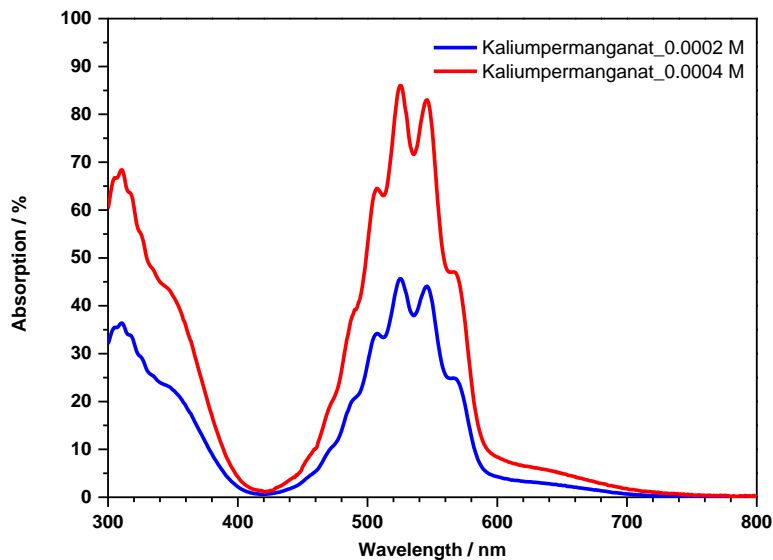
Specord 200 Plus

Double beam arrangement

Measurement range: 190 – 1100 nm



Quelle: [www.analytik-jena.de](http://www.analytik-jena.de)



# Optical Spectroscopy @ Research Group Jüstel

## Transmission spectroscopy

### Transmission spectrum

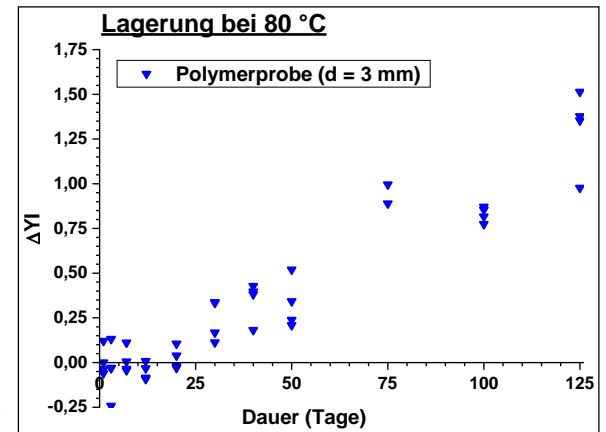
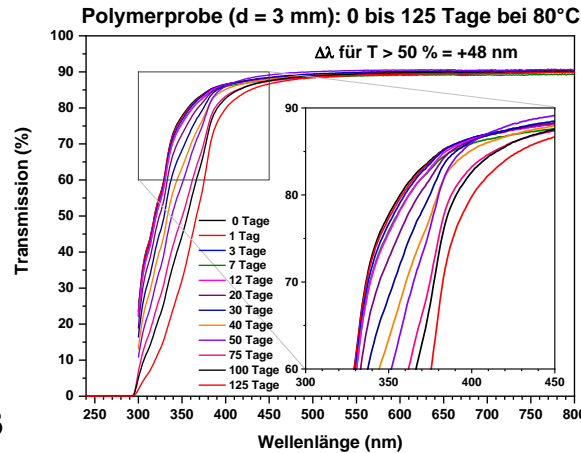
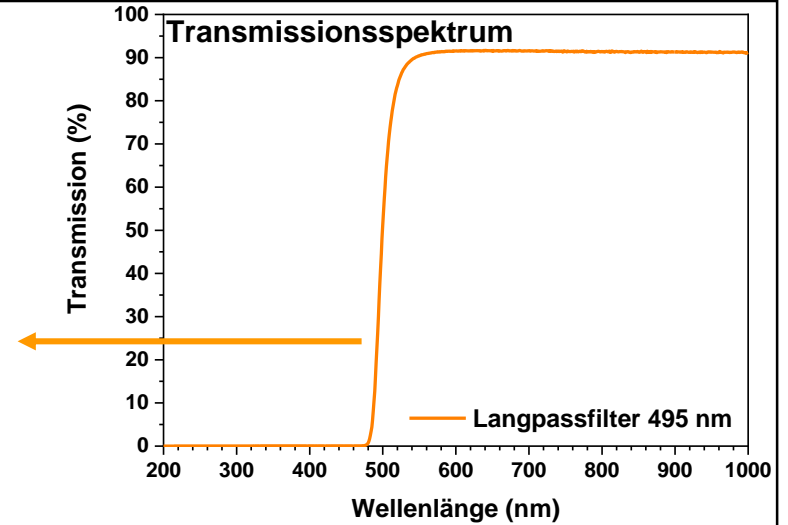


<b>X</b>	<b>Y</b>	<b>Z</b>
7030	8274	488

### Colour coordinates X, Y, Z

↓  $YI = \frac{1,28X - 1,06Z}{Y} \cdot 100\% = 102\%$

### Yellowness index YI

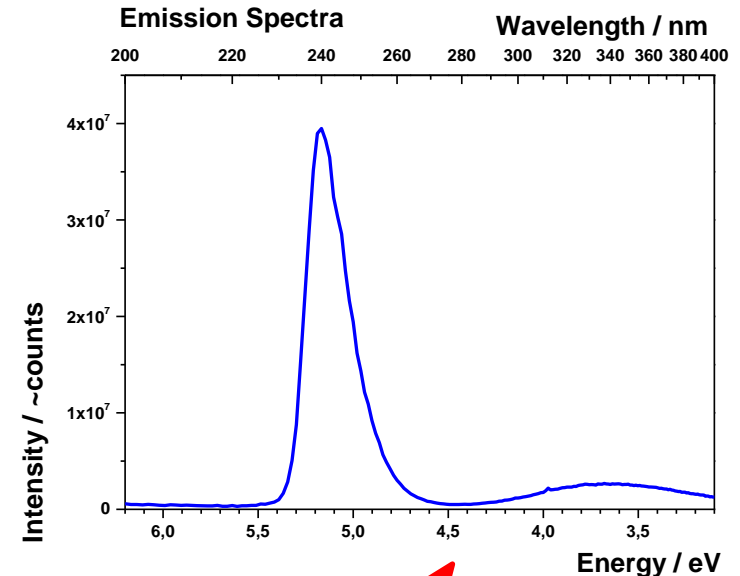
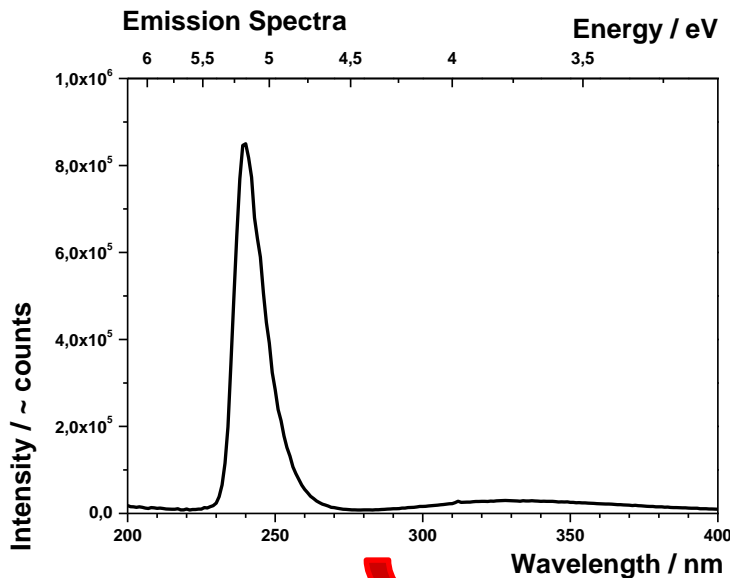


### Literature

- DIN 4892-2; DIN 6167
- ASTM D 1925-70; ASTM E 313

# Optical Spectroscopy @ Research Group Jüstel

**Spectra processing: Conversion of emission spectra from the wavelength regime to the energy regime**



**x-axis:  $E = h \cdot c \cdot \lambda^{-1}$**

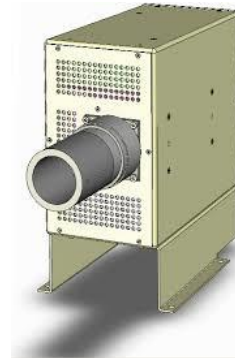
**y-axis:  $I_E = I_\lambda \cdot \lambda^2 \cdot (hc)^{-1}$**

# Optical Spectroscopy @ Research Group Jüstel

## Excitation sources for time resolved spectroscopy



**EPL ps Laser, wavelengths 265, 375, and 445 nm**  
**Frequency 20 kHz – 20 MHz**  
**Pulse width 800, < 70, and > 70 ps**



**µF900**  
**Microsecond Flashlamp**  
**Frequency 0.1 Hz – 50 Hz**  
**Pulse width 2.2 µs**



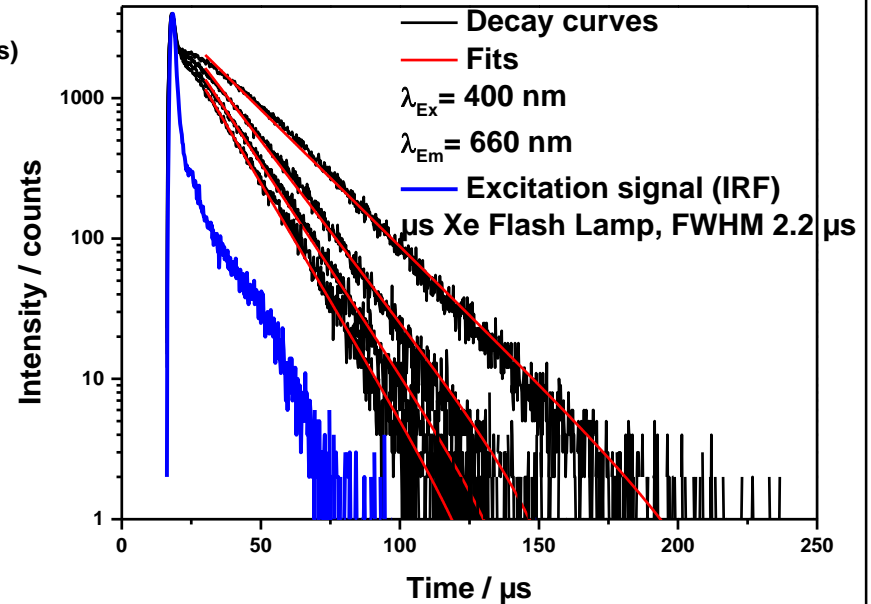
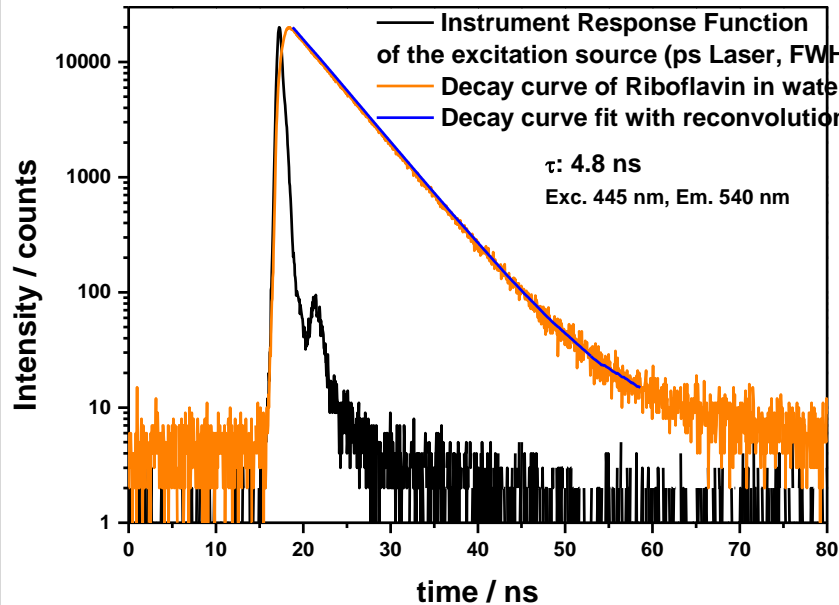
**OBIS laser, wavelength 375, 405, 445, and 488 nm**  
**Frequency 0.1 Hz – 1 MHz**  
**Pulse width various 1% - 100% of the period**  
**Laser pulse rise and fall time 5 ns**



**Various high power LEDs from 250 to 1100 nm**  
**Frequency 0.1 Hz – 100 kHz**  
**Pulse width various 1% - 100% of the period**  
**Pulse rise and fall time 20 ns**

# Optical Spectroscopy @ Research Group Jüstel

## Decay time calculation with re-convolution of the instrument response function



Re-convolution must be done for samples with a short decay time

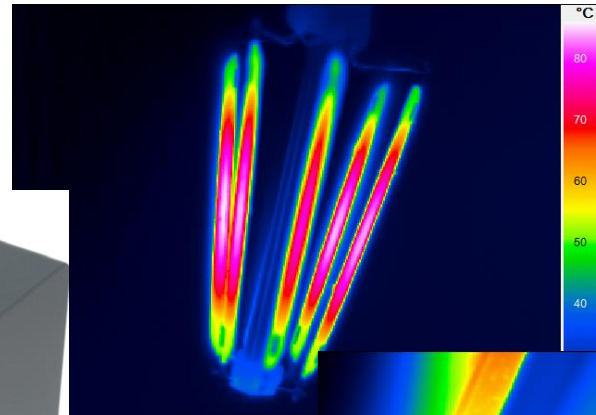
Dependent on the excitation source and the detector unit



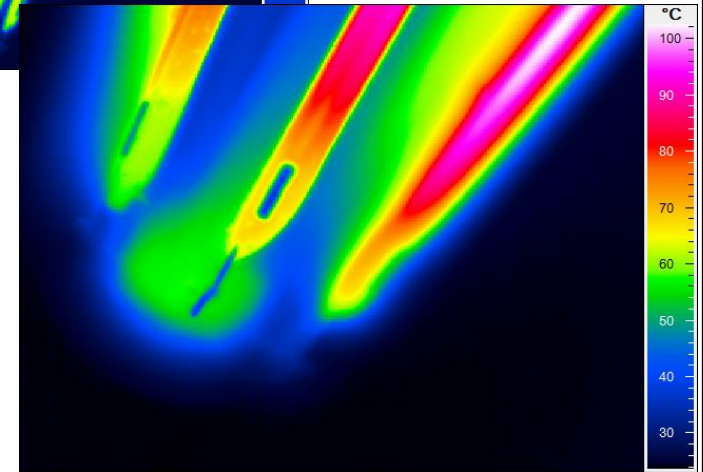
# Further Analytical Equipment

## Thermal imaging camera

VarioCAM head HiRes 384 G



Filament LED Lamp



## Technical Data

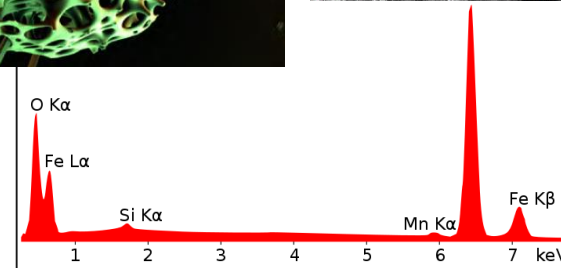
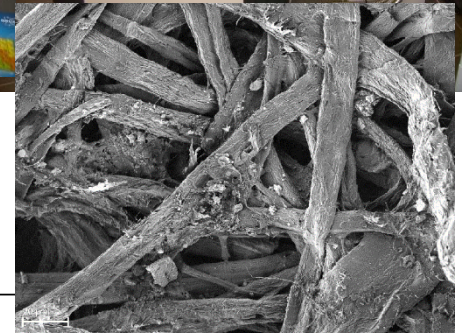
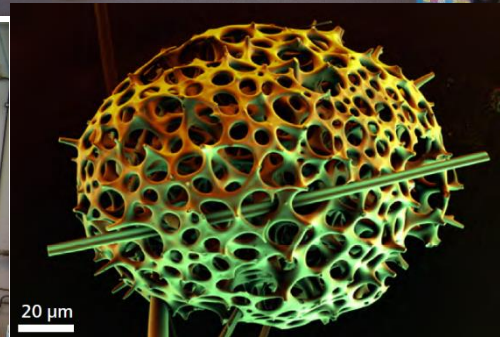
Spectral range	7.5 ... 14 $\mu\text{m}$
Temperature range	- 40 ... 1200 $^{\circ}\text{C}$
Temperature resolution @ 30 $^{\circ}\text{C}$	better than 0.05 K
Accuracy	$\pm 1.5$ K (0 ... 100 $^{\circ}\text{C}$ ); $\pm 2$ % (for $T < 0$ or $T > 100$ $^{\circ}\text{C}$ )
Emissivity	adjustable between 0.1 and 1.0, stepwidth 0.01
Imaging process, (pixel)	Focal Plane Array (384 x 288), Resolution enhancement towards (768 x 576)
Detector	non-cooled micro bolometer Focal Plane Array
IR image frame frequency	50/60 Hz
Pixel resolution	60 ... 200 $\mu\text{m}$

# Further Analytical Equipment

**Scanning electron microscope (SEM)  
+ Energy-dispersive X-ray spectroscopy (EDX)**

**Zeiss EVO MA10**

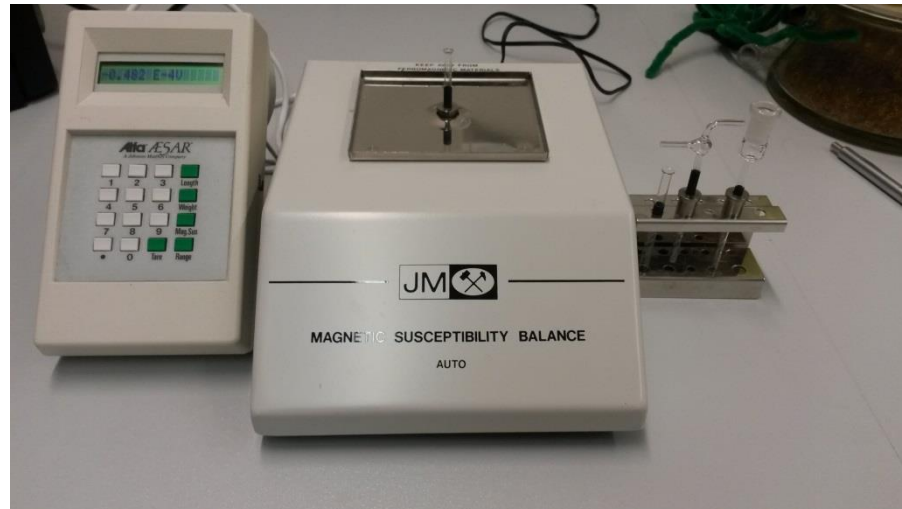
**Cathode**                      **LaB<sub>6</sub>**  
**Accelerating voltage** **0.2 – 30 kV**  
**Resolution**                      **10 nm**



# Further Analytical Equipment

## Magnetic Susceptibility Balance (MSB)

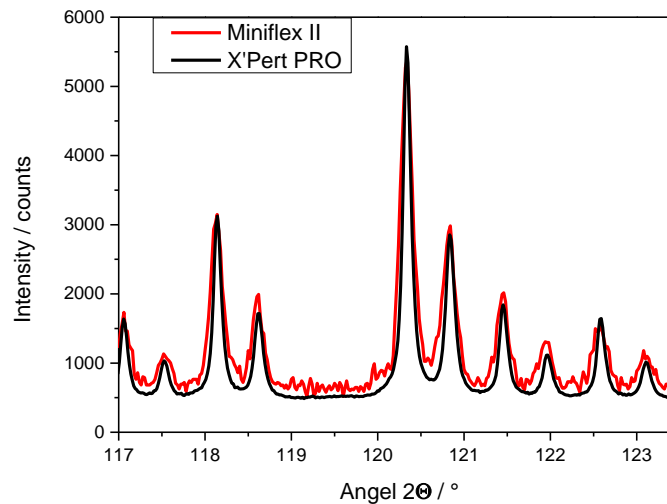
- **Magnetic properties of solids and liquids**
  - **Display of the volume susceptibility**
    - **Range  $1 \cdot 10^{-10}$  to  $1.99 \cdot 10^{-4}$  volume susceptibility units**
    - **Conversion to mass susceptibility by calculating the sample density in the test tube**



# Further Analytical Equipment

## X-Ray Diffractometer for Powder Samples

- 2 x Rigaku Miniflex II
- PANalytical X'Pert PRO



Zoom in an XRD from LuAG: Ce



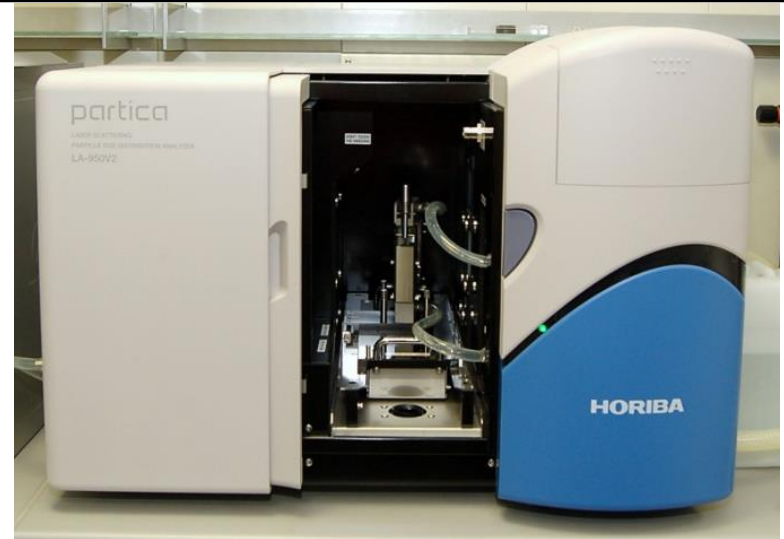
**3 kW X-Ray Tube**  
**max. Resolution 0.001 °**  
**Adjustable sample spin**  
**Theta-Theta-Geometry**  
**Multiple sample holder (15 samples)**

**450 W X-Ray Tube**  
**max. Resolution 0.005 °**  
**No sample spin**  
**Theta-2Theta-Geometry**

# Further Analytical Equipment

## Particle Sizers

- **Horiba LA-950-V2 organic**
  - Particle size range 10 nm – 3  $\mu$ m
- **Malvern NanoSizer**
  - Particle size range 0.4 nm – 10  $\mu$ m
- **Malvern MasterSizer X**
  - Particle size range 100 nm – 2 mm



# Further Analytical Equipment

## Elemental Analysis

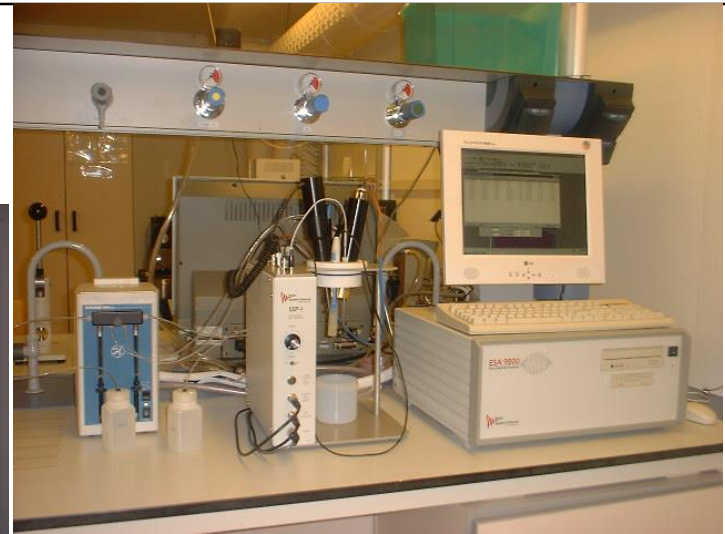
- N-/O-Analyser LECO TC 400
- C-/S-Analyser ELTRA CS 800



# Further Analytical Equipment

## Zeta Sizer (ESA)

- Matec SSP-1



## DTA/TG

- Netzsch STA 409



## BET Equipment

- Belsorp Max



# Further Analytical Equipment

## Multiwavelengths Refractometer: Abbemat MW from Anton Paar

**Measuring range** Abbemat MW  
**Refractive index** 1.32 to 1.70  $n_D$   
**Temperature** 10 to 70 °C

**Resolution**  
**Refractive index**  $\pm 0.000001 n_D$   
**Temperature** 0.01 °C

**Accuracy**  
**Refractive index**  $\pm 0.00004 n_D$   
**Temperature**  $\pm 0.03$  °C  
**Temperature stability**  $\pm 0.002$  °C

### Additional information

**Prism material** YAG (Yttrium-Aluminium-Garnet)  
**Light source** White light LED

### Available wavelengths (8 filters)

589.3 nm Na-D (standard)  
435.8 nm Hg-g  
480.0 nm Cd-F'  
514.5 nm Ar/Ion  
546.1 nm Hg-e  
632.8 nm He/Ne  
656.3 nm H-F'  
780.0 nm

### Sample morphology

- Liquids
- Polished surfaces

### Polycarbonate (PC)

