Absorption measurements by a photothermal technique

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Absorption measurements important for LIGO

- Silica material
- HR and BS coatings
- Advanced materials

  Sapphire, YAG, ...
- Advanced components

  e.g. grating beamsplitters/reflectors
- Materials for modulators and isolators

Desirable Features

- PPM sensitivity
- Longitudinal resolution

  coating vs volume loss
- Transverse resolution

  homogeneity
- Ease of use

  many samples must be studied
- Time resolved

  dynamics of induced losses

Absorption measurements by a photothermal technique

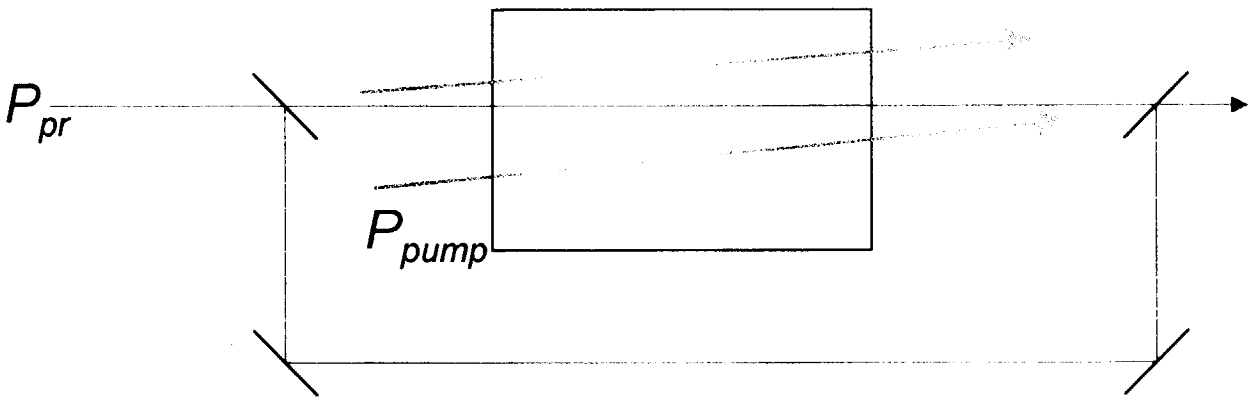
OUTLINE

- Photothermal common-path interferometer
- Space resolution
- Surface/bulk absorption signals
- Beamsplitter data
- YAG data
- Sapphire data
- Planned experiments
- Conclusions

Absorption Measurement

- Requirements
  - $< 10^{-4}\ cm^{-1}$ for NLO crystals, $< 10^{-6}\ cm^{-1}$ for power optics
  - spectrally agile: diagnostics and design data
  - time resolved (ms scale): surface vs bulk, locate inhomogeneities
  - absolute calibration possible
  - "easy" -- many samples need be characterized

- Interferometric method
  - chopped pump beam heats crystal periodically
  - phase of probe beam modulated by photothermal index change
  - read out on lock-in



$\Delta P_{pr} / P_{pr} =$ [redacted] $k\,\Delta(nL)$

$$\delta T \propto \frac{\alpha P_{pump}}{k_{th}} \frac{\omega_{th}}{\omega}$$

$$\Delta n \sim \frac{\partial n}{\partial T} \delta T$$

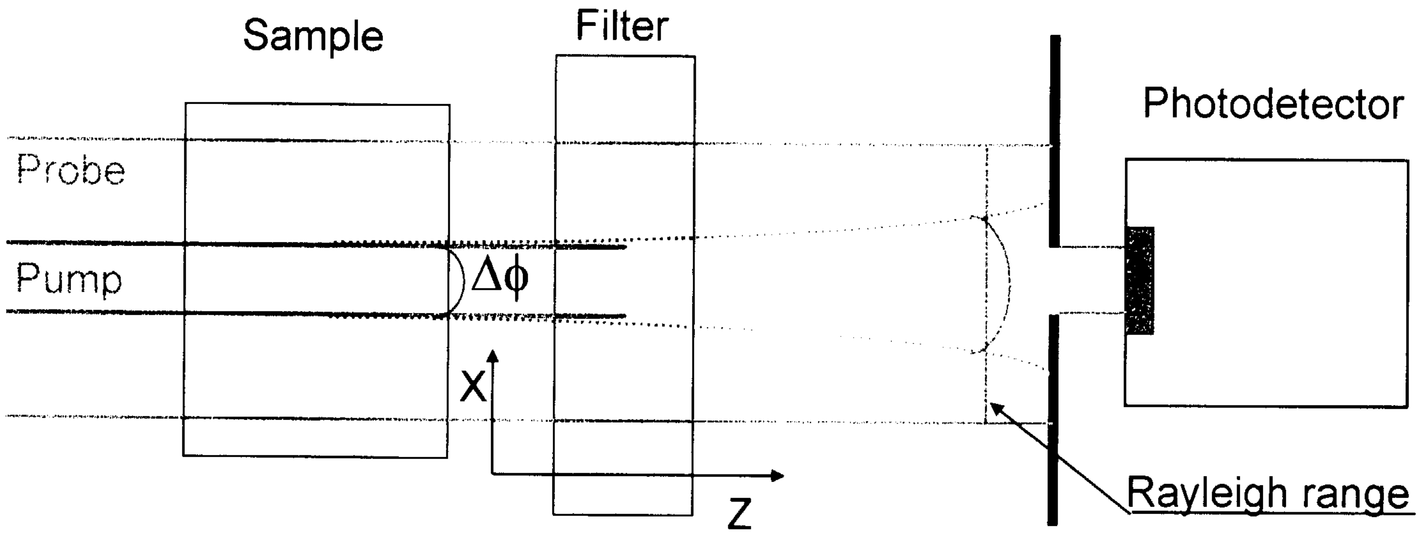
- Problem: chopping frequency limited by thermal time constant (ms)
  - acoustic/mechanical noise very problematic

- Solution: common path interferometry

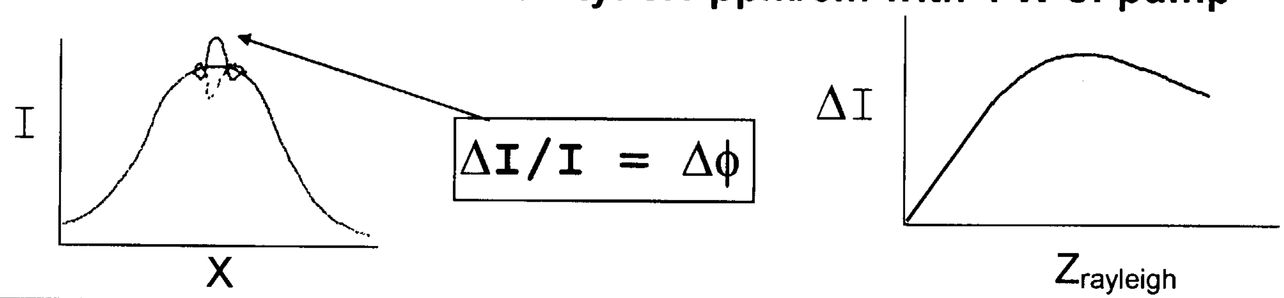
Detection basics 1: how do we measure?

Self-interference of probe in the near field

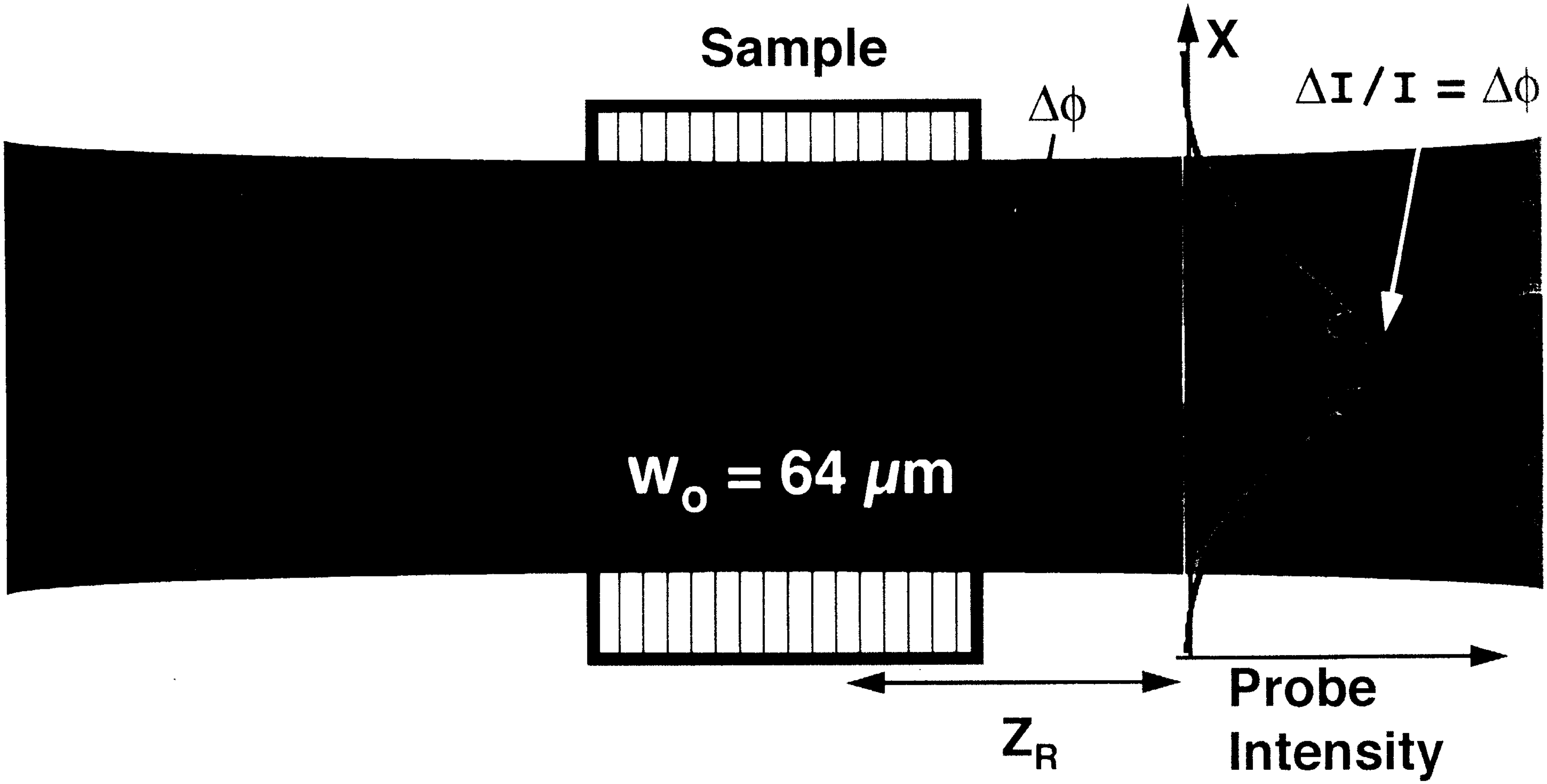
$\Delta\phi$ is phase distortion of the central part of probe beam



Interferometric sensitivity: 0.1 ppm/cm with 4 W of pump



Common-path Photothermal Interferometry (CPI):

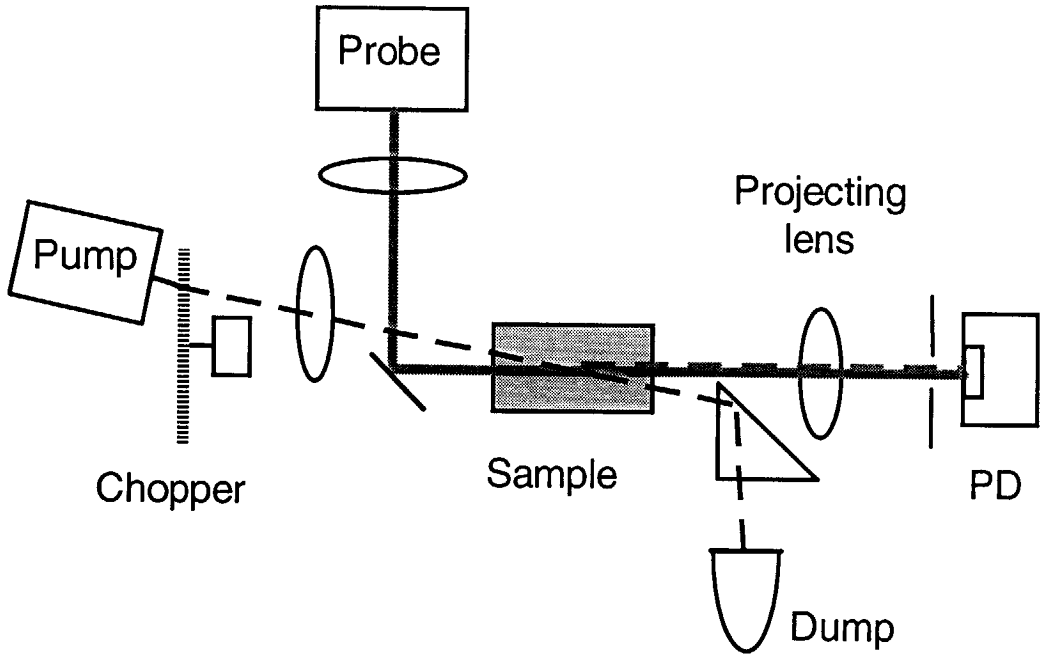


Absorption of pump → heat → $\Delta\phi$ →probe self-interference ΔI

Max ΔI at Z_R

Sensitivity: 0.1 ppm/cm with 4 W pump beam

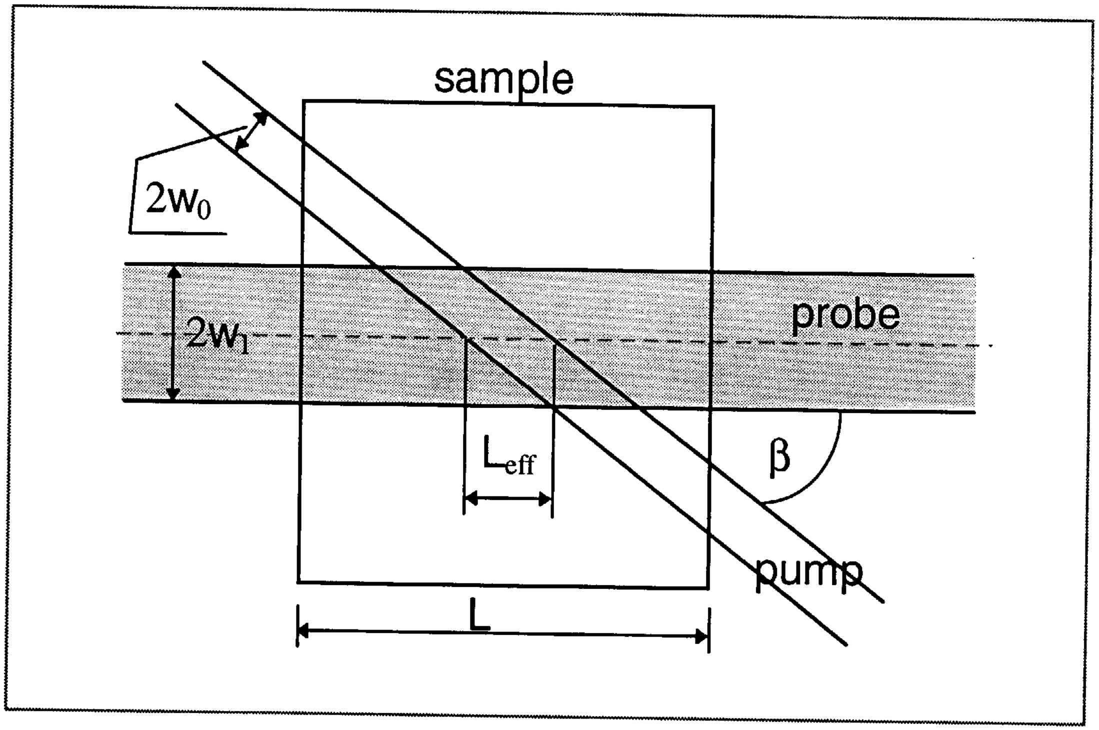
Photothermal common-path interferometer



Pump waist	50 μ	Chopping frequency	380 Hz (10Hz - 2 kHz)
Probe waist	120 μ	Crossing angle	1° - 20° (in air)
Pump power	5 W	Probe power	0.5 mW

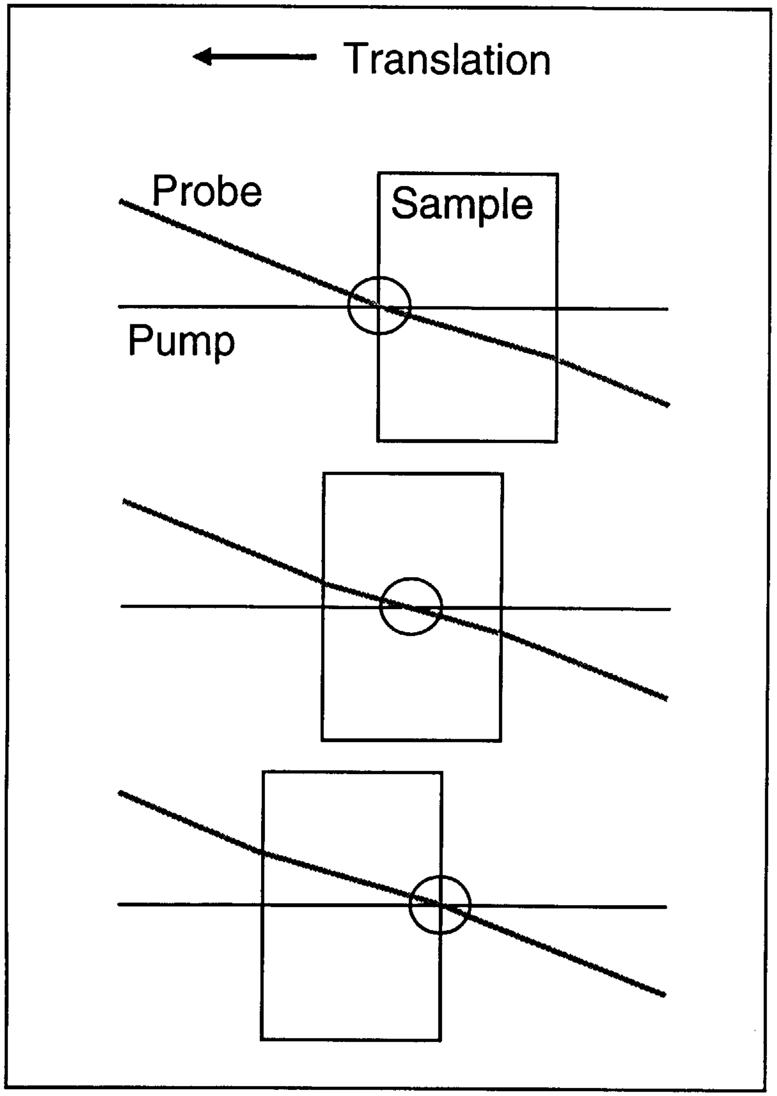
- **ac-component of probe distortion is detected by photodiode + lock-in**
- **absorption coefficient of 10^{-7} cm^{-1} can be detected with a 5 W pump**
- **crossed-beams help to avoid false signals from optics and surfaces of the sample**

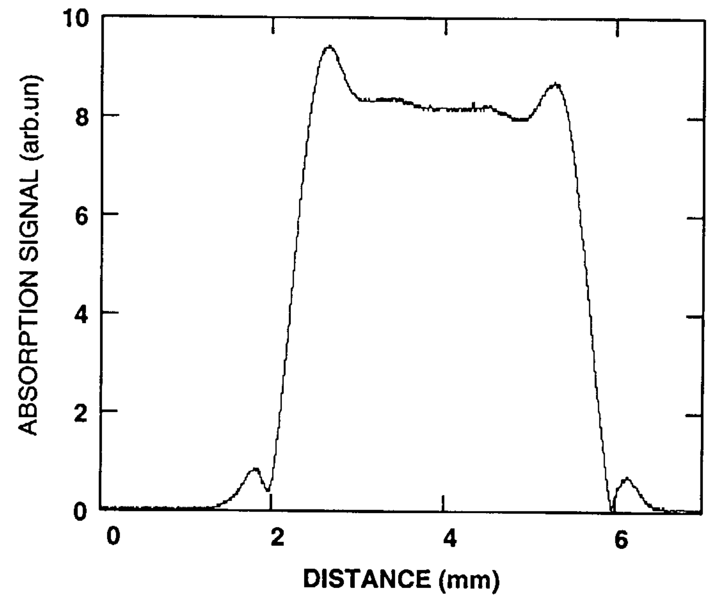
Crossed-beam arrangement



$$L_{eff} = \sqrt{\frac{\pi}{2}}\frac{w_0}{\beta}$$

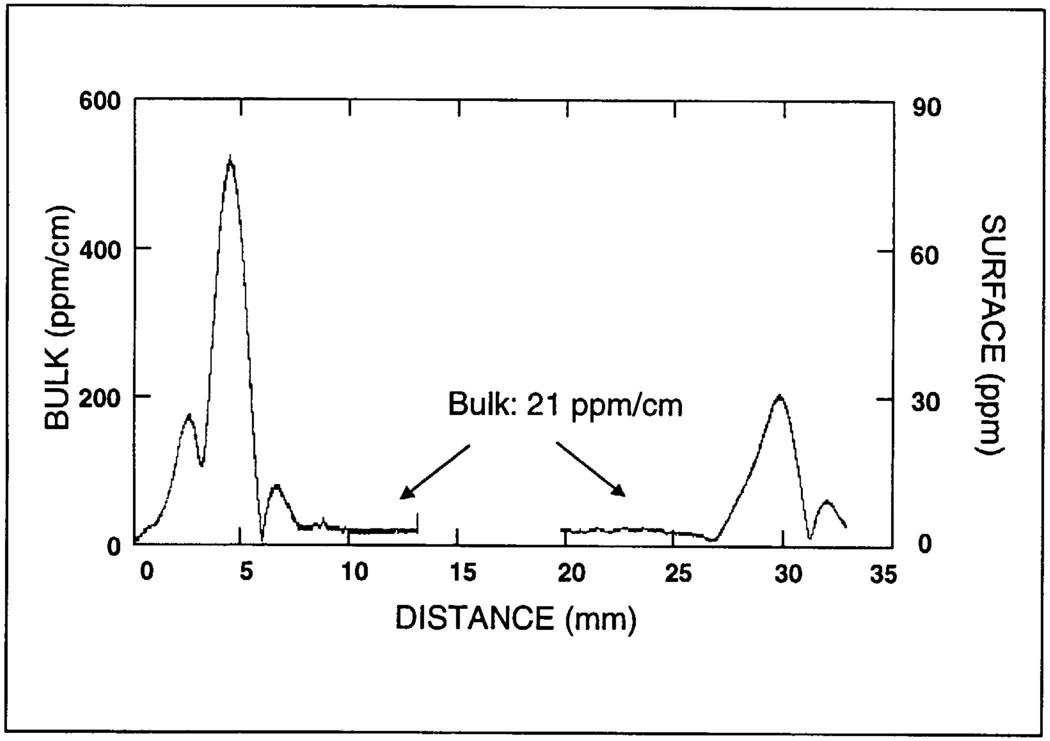
Surface-to-surface scan





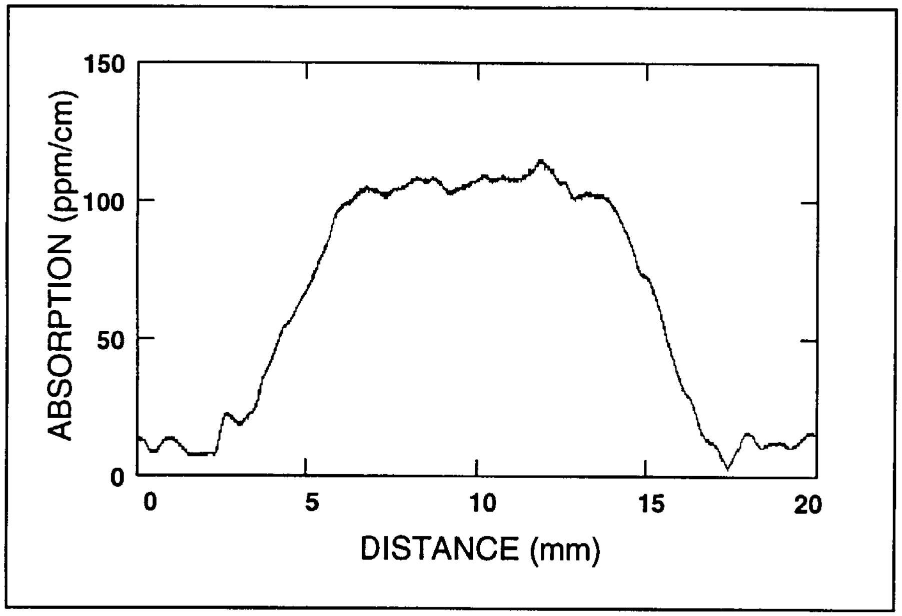
Example: 3 mm-thick neutral filter, 15%-absorbing
Leff = 0.25 mm

Absorption signal in 25mm-thick fused silica beamsplitter

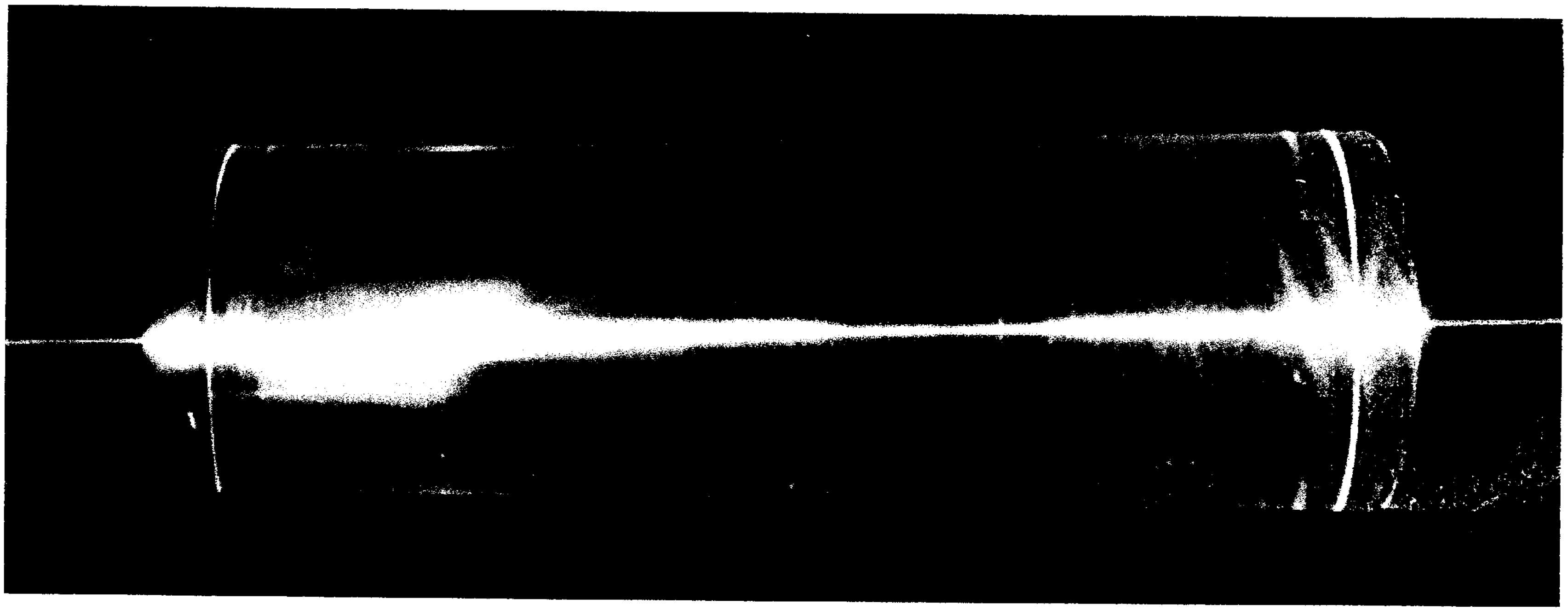


- λ = 1064 nm
- normal incidence
- nonuniform (on submillimeter scale) absorption at both surfaces: from 30 to 110 ppm
- uniform absorption in the bulk: 21 ppm/cm $\pm$ 10%

Absorption signal in 1cm^3 YAG cube: scan from surface to surface



- λ = 1064 nm
- pump power 5W
- uniform bulk absorption of 105 ppm/cm ± 10%
- normalized to Ti-sapphire reference with a correction for different dn/dT and thermal conductivity

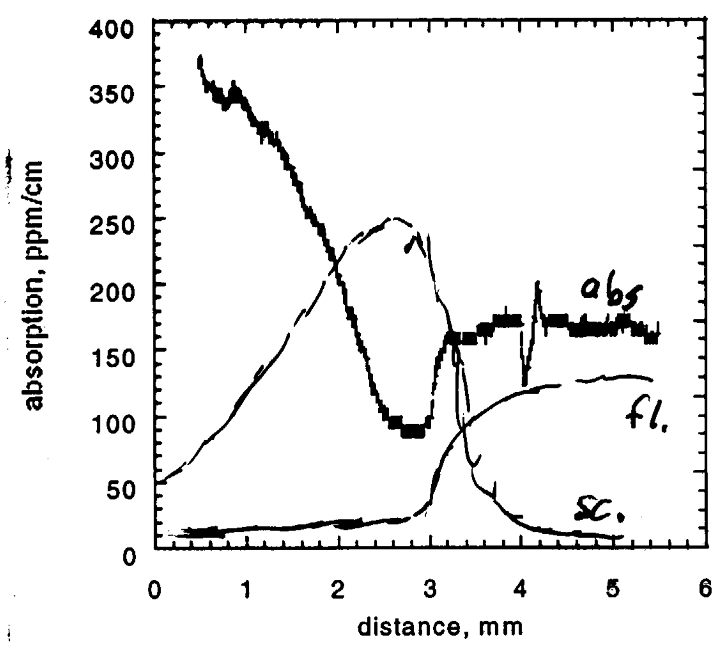


Sapphire Absorption is Complicated

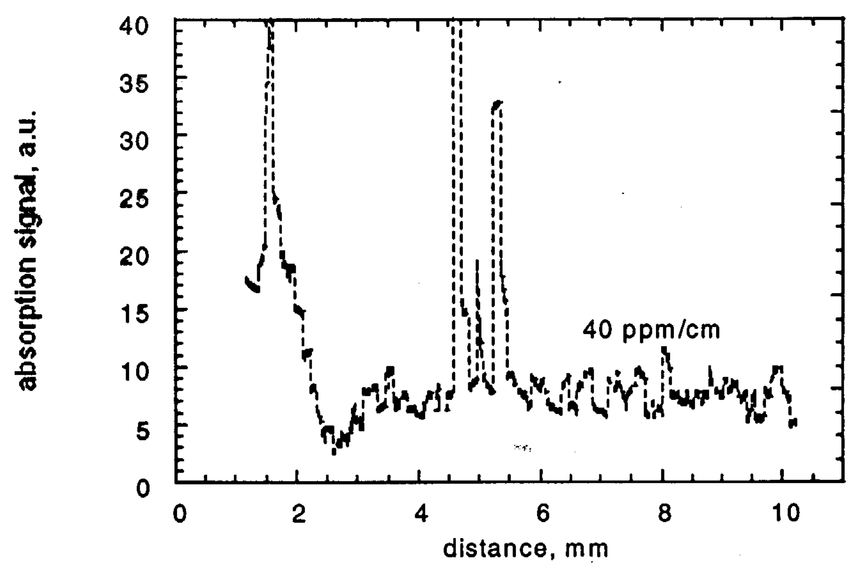
For Example:

- Shows nonmonotonic radial dependence
  - suggests influence of post-fabrication annealing process
  - alteration of redox state of impurity? Ti^{3+}/Ti^{4+} ?
- Spatial resolution important to diagnosing problems

Absorption near the cylindric surface
in CS 'white' sapphire #0
(Pump power 1 W, λ = 514.5 nm)



Absorption near the cylindric surface
in CS 'white' sapphire #0
(Pump power 0.7 W, λ =1064 nm)



Data on sapphire crystals

Crystal	α (ppm/cm) 532nm	1064nm	Scattering	α(532) / α(1064)	Fluorescence
'Window' 3mm-thick	1400 (514 nm)	81	-	17.3	≈ 0.002F, Ti^{3+}
CS 'White' #0	415 (514 nm)	41 (surface anomaly)	Large near the surface	10.1	≈ 0.001F, Ti^{3+}
CS 'White' #1	1600	84	No	19.0	0.0003F
CS 'White' #2	1310	72	Weak band in the bulk	18.2	0.001F
CS 'White' (Perth)	1910	129	Yes, broad band near one face	14.8	0.003F
CS 'Hemex Ultra'	1150	188	No	6.1	≈ 0.0001F
0.1% Ti-doped (reference #2)	0.68/cm (total) 0.145/cm (thermal part)	6400	Yes, macro-defects	22.7 (thermal part)	F, Ti^{3+}
0.05% Ti-doped laser rod (reference #1)	-	19000*	-	-	0.7F, Ti^{3+}

*Absorption measured directly
Relative fluorescence brihtness estimated with calibrated neutral filters,
Ti-doped reference #2 brightness denoted as F