Optical absorption measurements in sapphire

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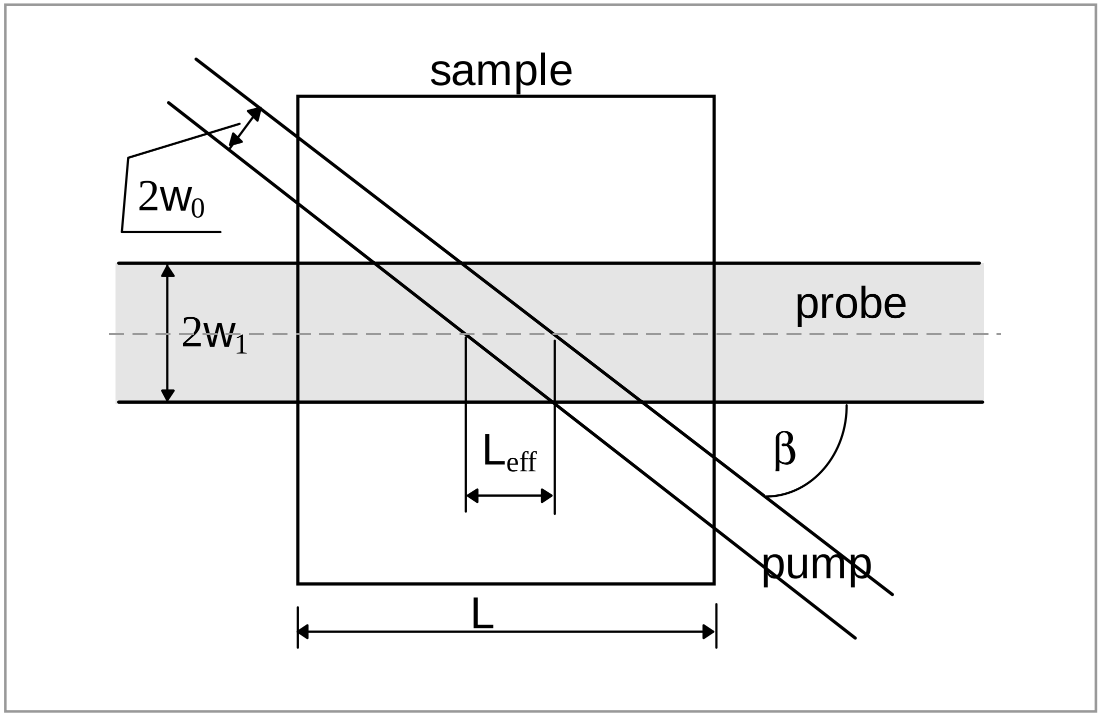
Optical absorption measurements in sapphire

OUTLINE

- Background
- Photothermal technique
- As-grown sapphire
- Annealed sapphire
- How to go below 40 ppm/cm
- Prospects

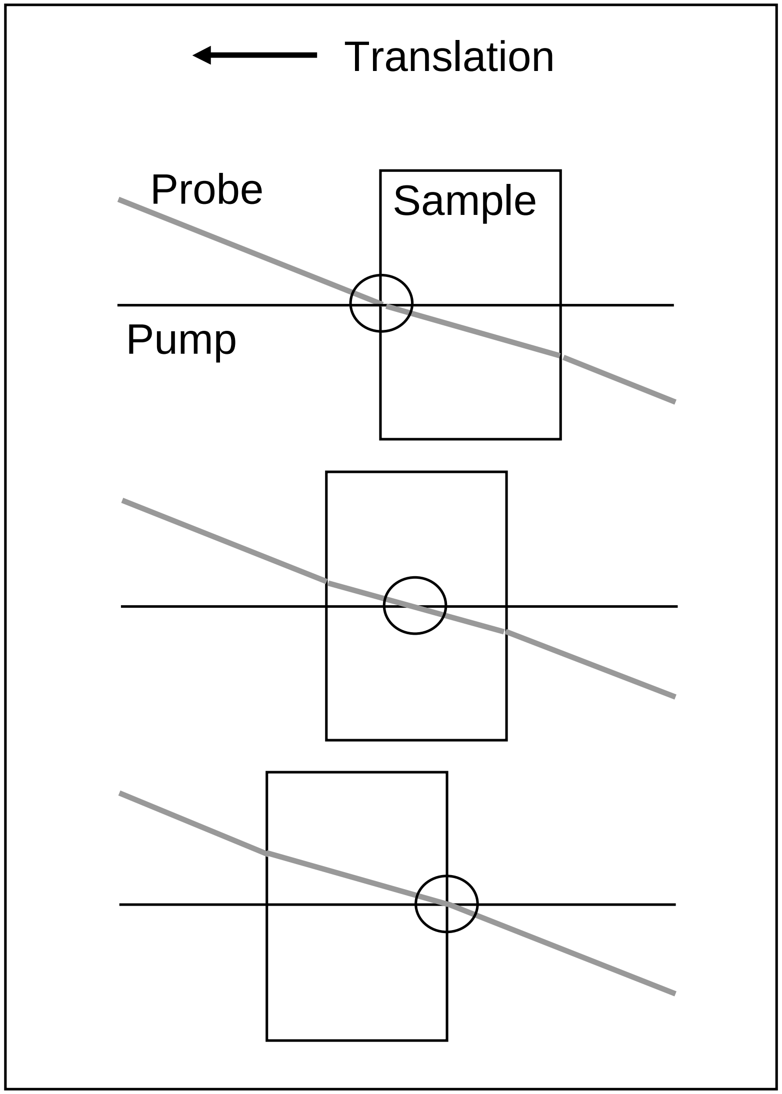
Space resolution

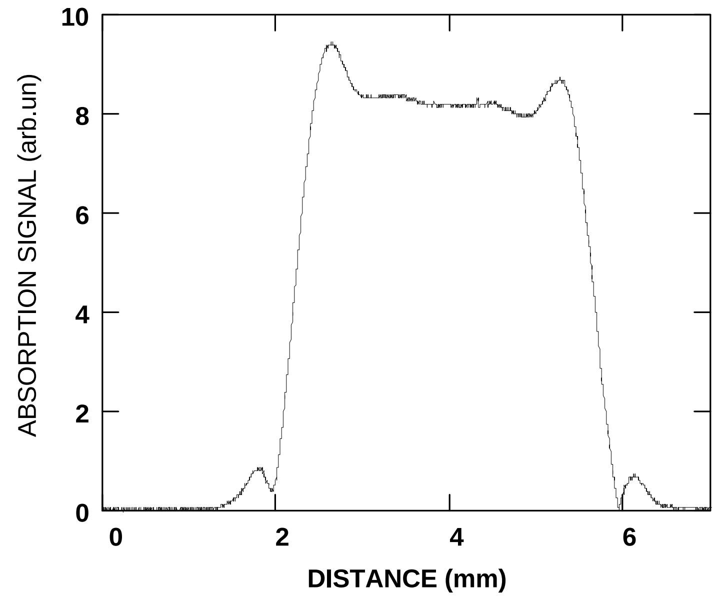


$$L_{eff} = \sqrt{\frac{\pi}{2}} \frac{w_0}{\sin \beta}$$

$$\alpha = \kappa \frac{P}{L_{eff}}$$

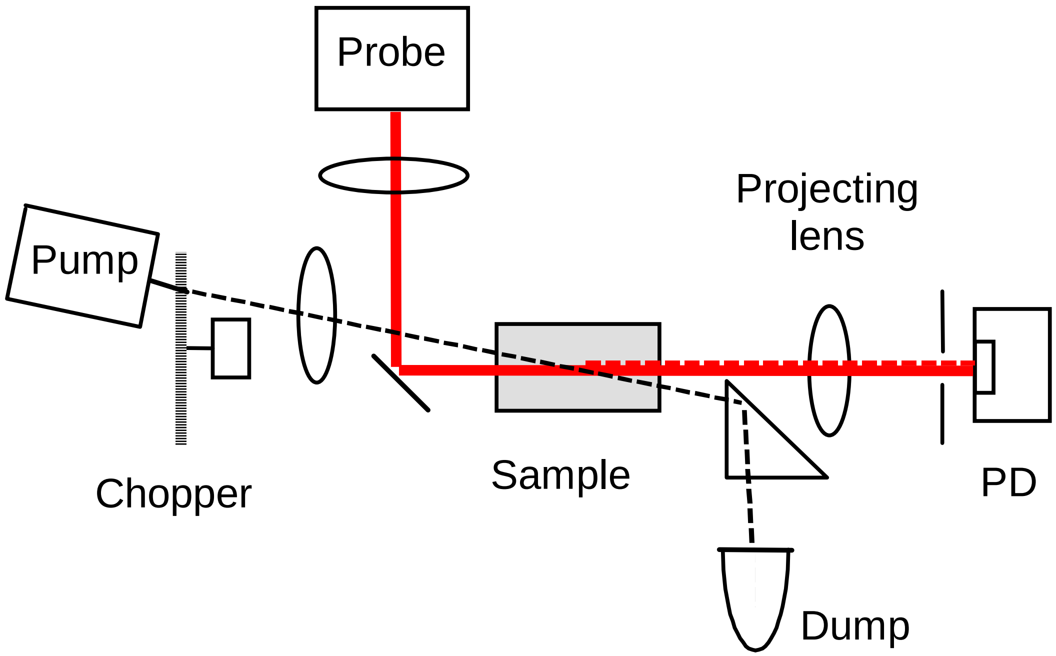
Space resolution: surface-to-surface scan





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

Photothermal Common-path Interferometer (PCI)



Pump waist	50 µ	Chopping frequency	380 Hz (10Hz - 2 kHz)
Probe waist	120 µ	Crossing angle	1^o - 20^o (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**

Data on sapphire crystals (1998)

Crystal	α (ppm/cm) 532nm	1064nm	Scattering	Fluorescence
'Window' 3mm-thick	1400*	81	No	2×10^{-3} F, Ti^{3+}
CS 'White' #0	415* (bulk, anomaly near the surface)	41 (bulk, anomaly near the surface)	Large near the surface	1×10^{-3} F, Ti^{3+} (bulk)
CS 'White' #1	1600	84	No	3×10^{-4} F
CS 'White' #2	1310	72	Weak band in the bulk	1×10^{-3} F
CS 'White' (Perth)	1910	129	Yes, broad band near one face	3×10^{-3} F
CS 'Hemex Ultra'	1150	188	No	1×10^{-4} F
0.1% Ti-doped (reference #2)	0.68/cm (total) 0.145/cm (thermal part)	6400	Yes, macro-defects	F, Ti^{3+}
0.05% Ti-doped laser rod (reference #1)	-	19000**	-	0.7F, Ti^{3+}

* 514 nm

** Absorption measured directly

Relative fluorescence brightness estimated with calibrated neutral filters, Ti-doped reference #2 brightness denoted as F

Data on sapphire crystals (1999)

Crystal	α (ppm/cm) 514nm	1064nm	Scattering	Fluorescence
CS ‘White’, H_2-annealed	605	53	No	$\approx 2 \times 10^{-4}$ F
CS ‘White’, O_2-annealed	600 (bulk, anomaly near the surface)	47 (bulk, anomaly near the surface)	Large near the surface	$\approx 2 \times 10^{-4}$ F (bulk)
Substrate (TRW)	-	66	No	-
‘Window’ 3mm-thick	1400*	81	No	2×10^{-3} F, Ti^{3+}
0.1% Ti-doped (reference #2)	0.68/cm (total) 0.145/cm (thermal part)	6400	Yes, macro-defects	F, Ti^{3+}

Relative fluorescence brightness estimated with calibrated neutral filters,
Ti-doped reference #2 brightness denoted as F

Data on sapphire crystals (2000)

Crystal Systems, Inc.

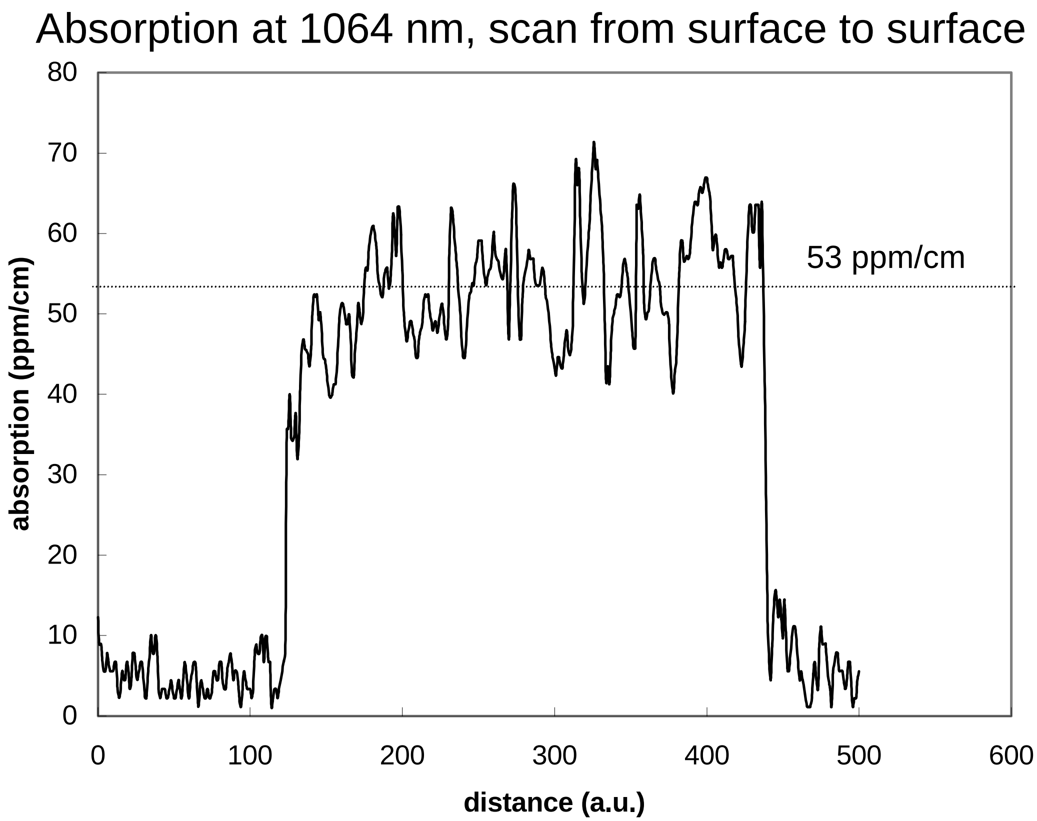
Crystal	α (ppm/cm) 514nm	α (ppm/cm) 1064nm	Scattering	Fluorescence
1T	1730	124	No	10×10^{-5} F
1M	1800	103	No	5×10^{-5} F
1B	1430	91	No	2.5×10^{-5} F
2T	900	57	No	4×10^{-4} F
2M	900	87	No	10×10^{-4} F
2B	1410	92	No	40×10^{-4} F
3T	920	62	No	10×10^{-5} F
3M	1470	121	No	5×10^{-5} F
3B	840	66	No	5×10^{-5} F
4T	830	46	No	10×10^{-4} F
4M	1200	126	No	2×10^{-4} F
4B	1200	94	No	1×10^{-4} F

Nuclear Research Center – Negev, ISRAEL

Crystal	α (ppm/cm) 514nm	α (ppm/cm) 1064nm	Scattering	Fluorescence
1579	1570	147	No	2×10^{-3} F
1958	1600	140	No	2×10^{-3} F
1741	1560	211	No	2×10^{-3} F

Annealed sapphire data

20 mm-long, H_2-annealed sample

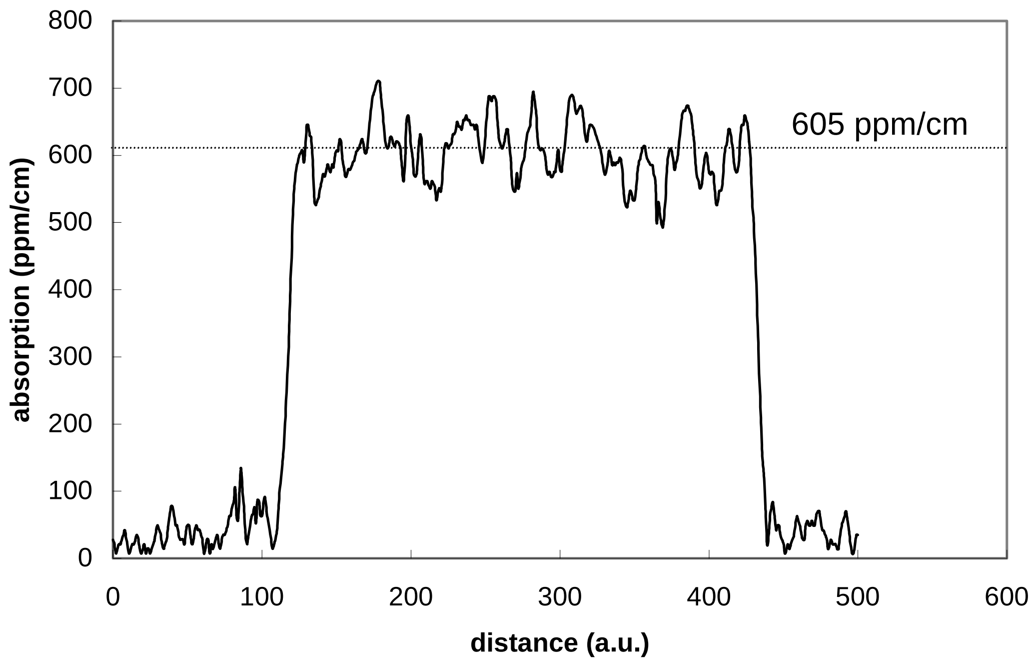


- Reference sample: Ti-doped sapphire with the absorption of 6400 ppm/cm at 1064 nm

Annealed sapphire data

20 mm-long, H_2-annealed sample

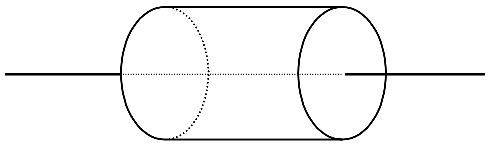
Absorption at 514 nm, scan from surface to surface

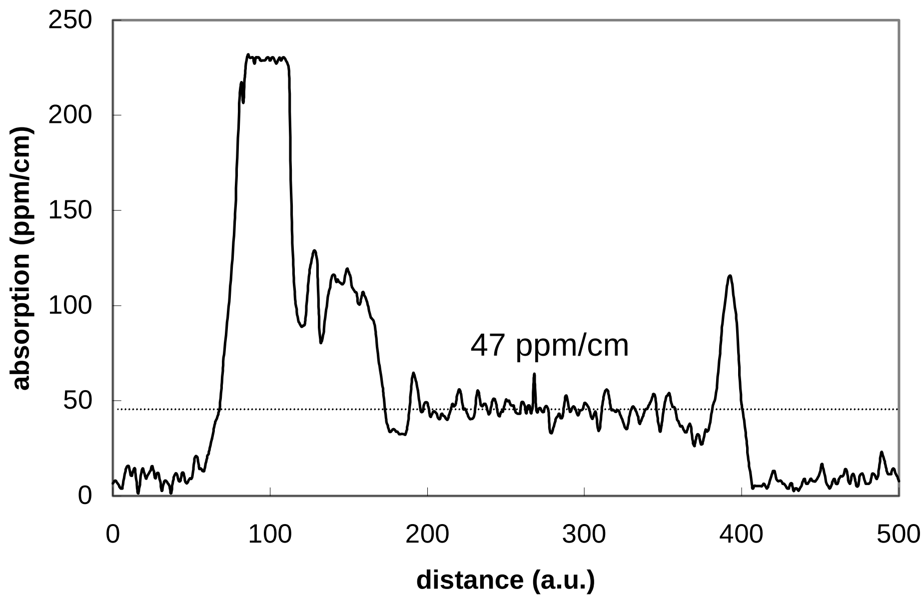


Annealed sapphire data

20 mm-long, O_2-annealed sample

Absorption at 1064 nm, scan from surface to surface

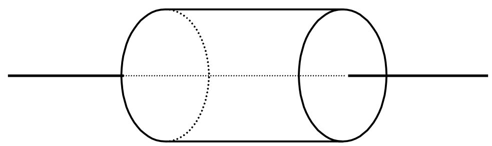


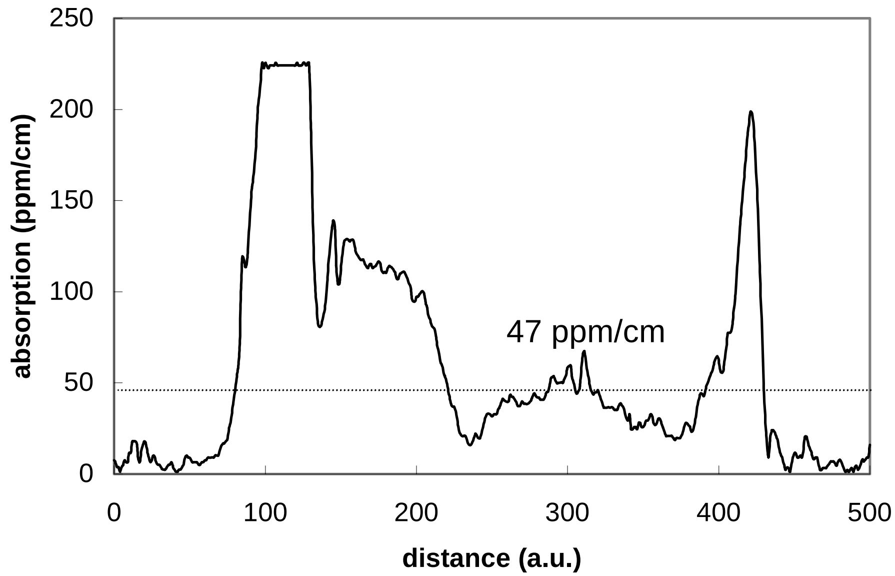


Annealed sapphire data

20 mm-long, O_2-annealed sample

Absorption at 1064 nm, scan from surface to surface

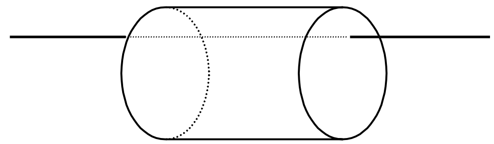


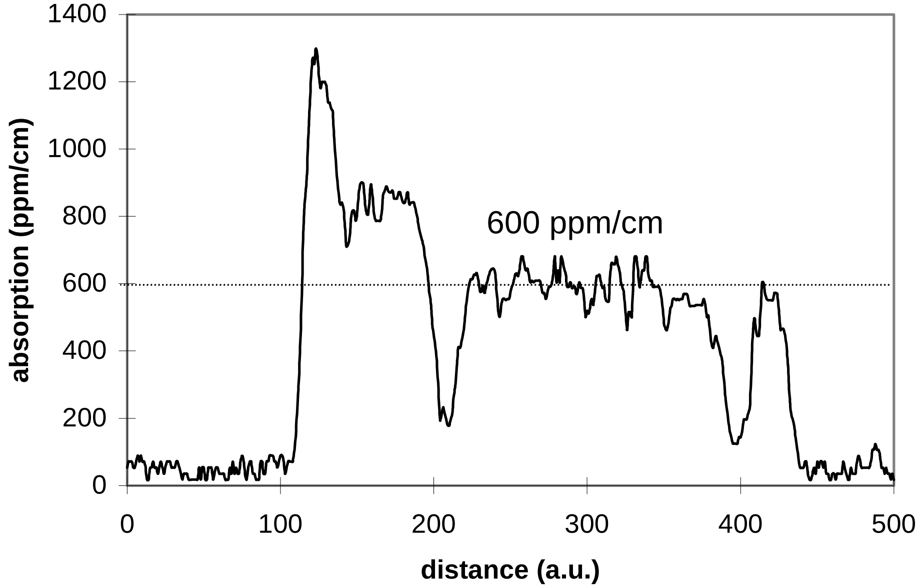


Annealed sapphire data

20 mm-long, O_2-annealed sample

Absorption at 514 nm, scan from surface to surface

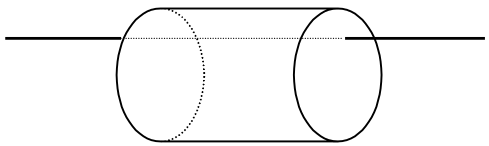


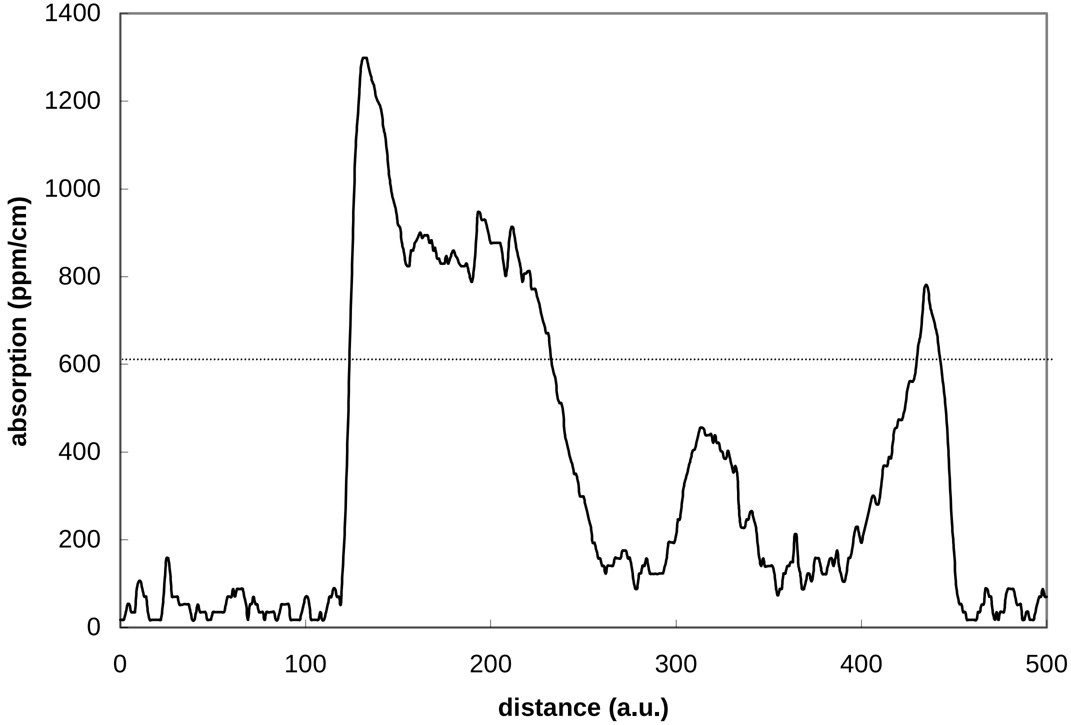


Annealed sapphire data

20 mm-long, O_2-annealed sample

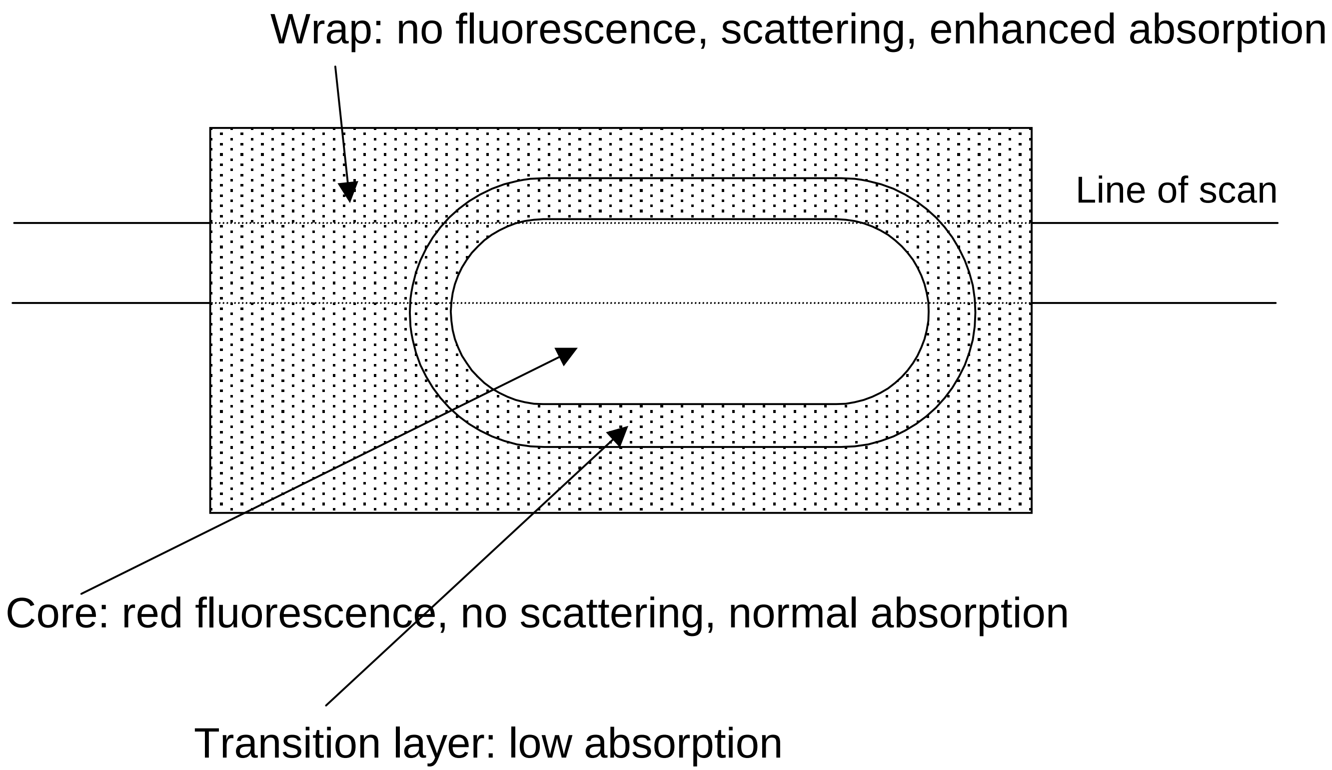
Absorption at 514 nm, scan from surface to surface





Model

O_2-annealed sample



Conclusions

- The best as-grown sapphire shows 40 ppm/cm of absorption at 1064 nm
- H_2-annealed sapphire shows no change in absorption, fluorescence or scattering
- O_2-annealed sapphire shows a complex response to oxidation with local decrease of both IR and green absorption
- Defects responsible for current IR and green absorption levels are yet to be identified
- Proper annealing may offer means to reach the 10-15 ppm/cm level. Further decreases will depend on the ability to identify and eliminate specific defects