Optical absorption measurements in sapphire

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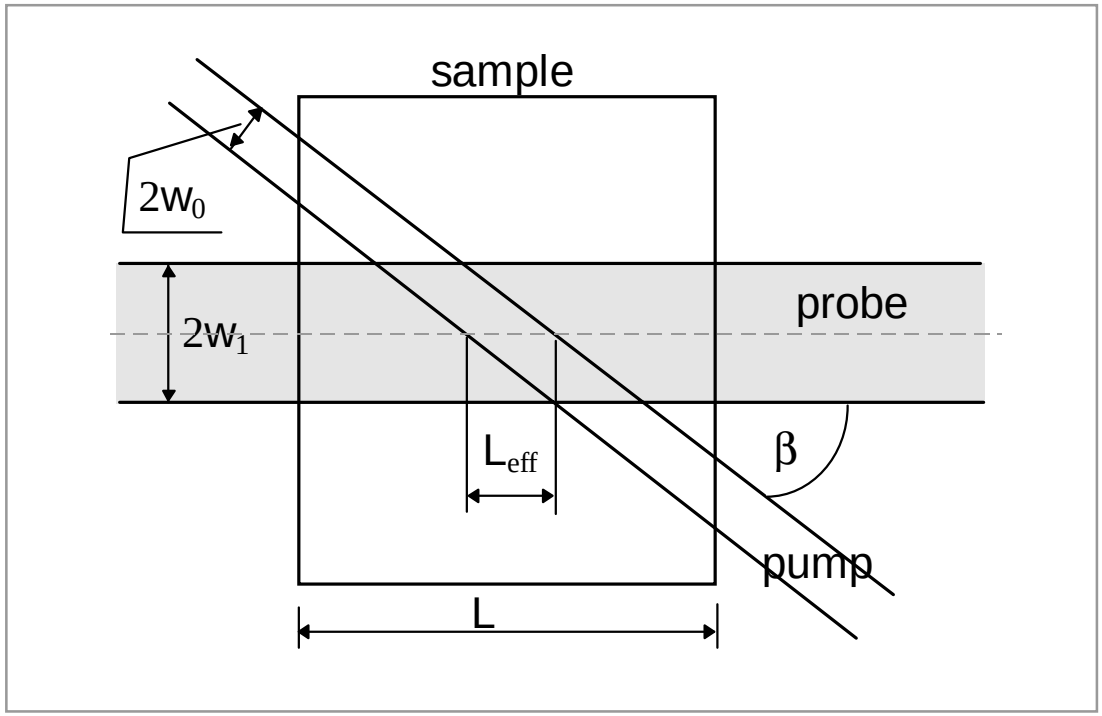
Optical absorption measurements in sapphire

OUTLINE

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

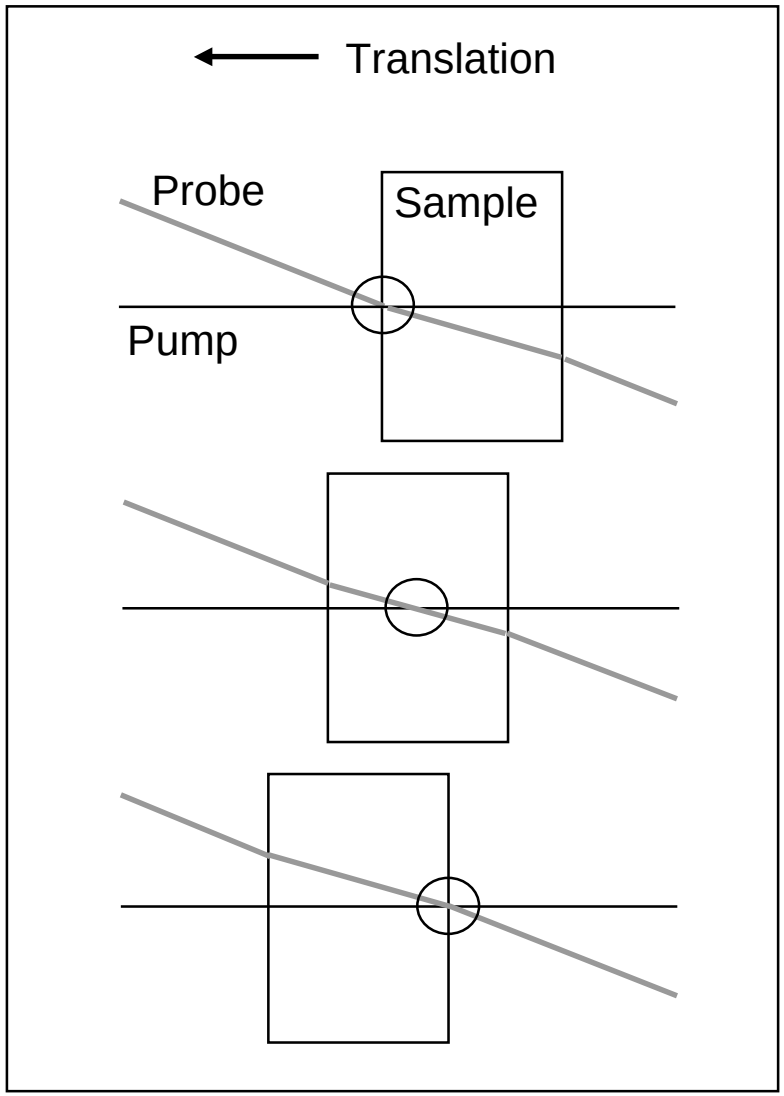
Space resolution

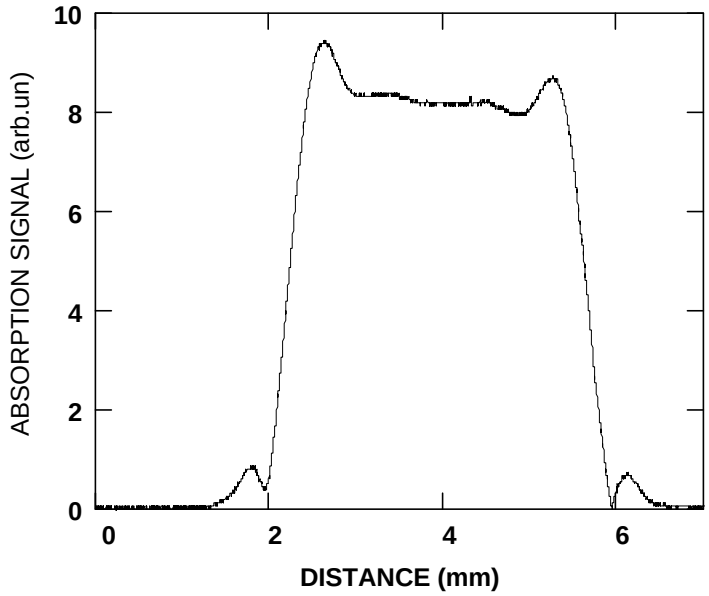


$$L_{eff} = \sqrt{\frac{\pi}{2}} \frac{w_0}{\sin \beta}$$

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

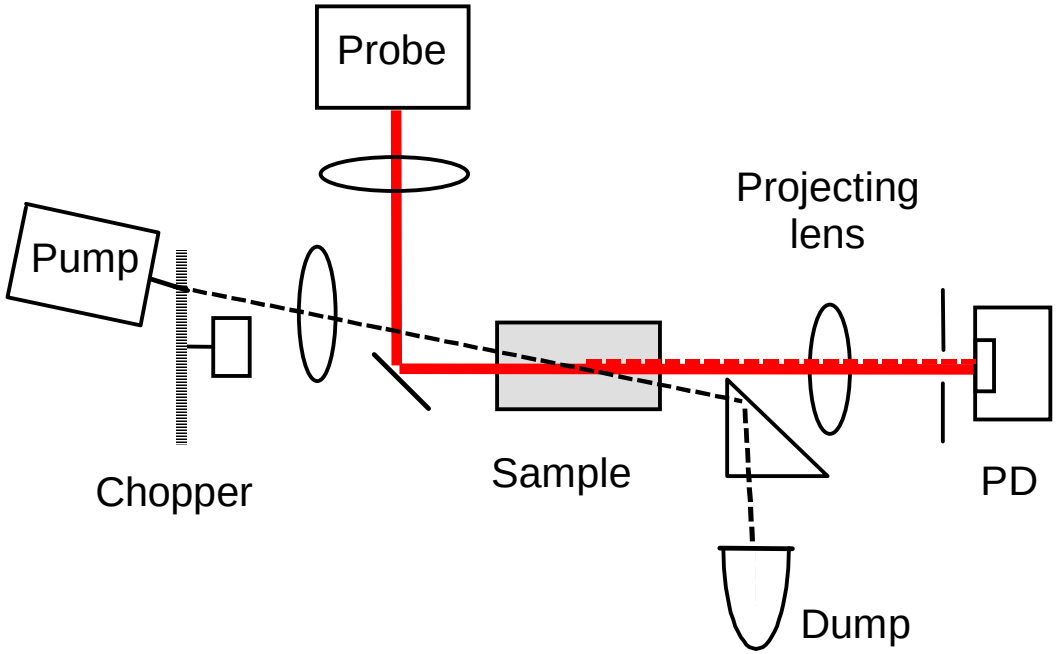
Space resolution: surface-to-surface scan





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**

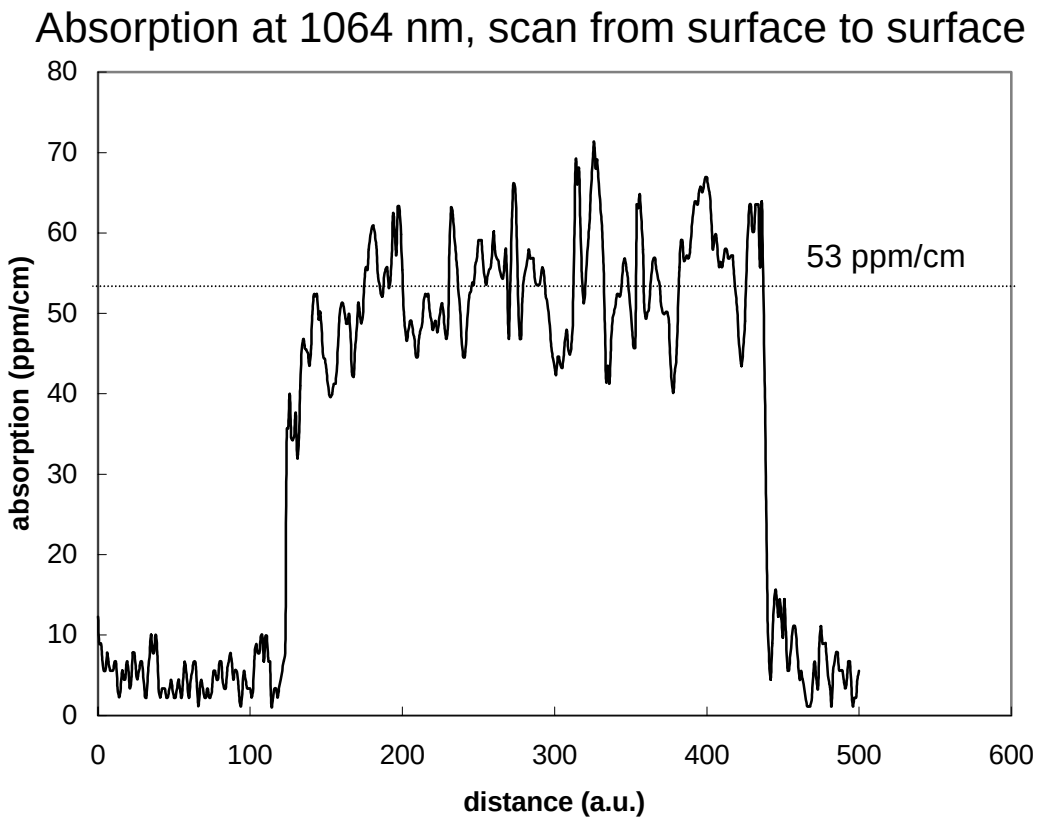
Data on sapphire crystals (1999)

Crystal	α (ppm/cm) 514nm	α (ppm/cm) 1064nm	Scattering	Fluorescence
CS 'White', H_2-annealed	605	53	No	≈ 2 x 10^{-4} F
CS 'White', O_2-annealed	600 (bulk, anomaly near the surface)	47 (bulk, anomaly near the surface)	Large near the surface	≈ 2 x 10^{-4} F (bulk)
Substrate (TRW)	-	66	No	-
'Window' 3mm-thick	1400*	81	No	2 x 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

Annealed sapphire data

20 mm-long, H_2-annealed sample

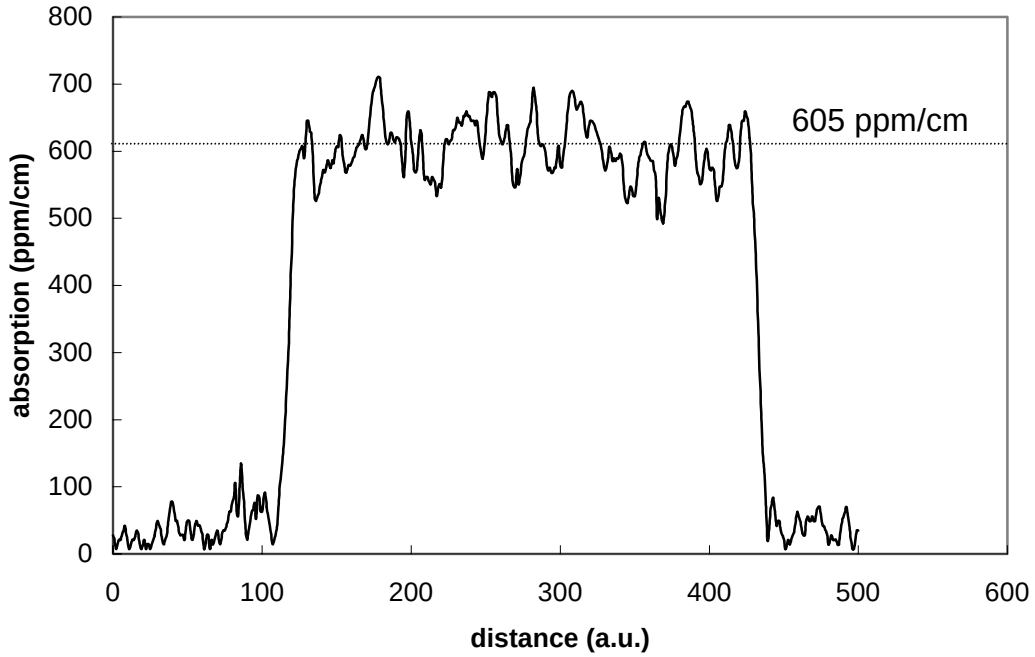


- Reference sample: Ti-doped sapphire with the absorption of 6400 ppm/cm at 1064 nm

Annealed sapphire data

20 mm-long, H_2-annealed sample

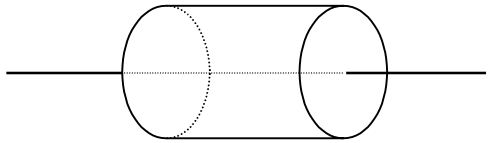
Absorption at 514 nm, scan from surface to surface

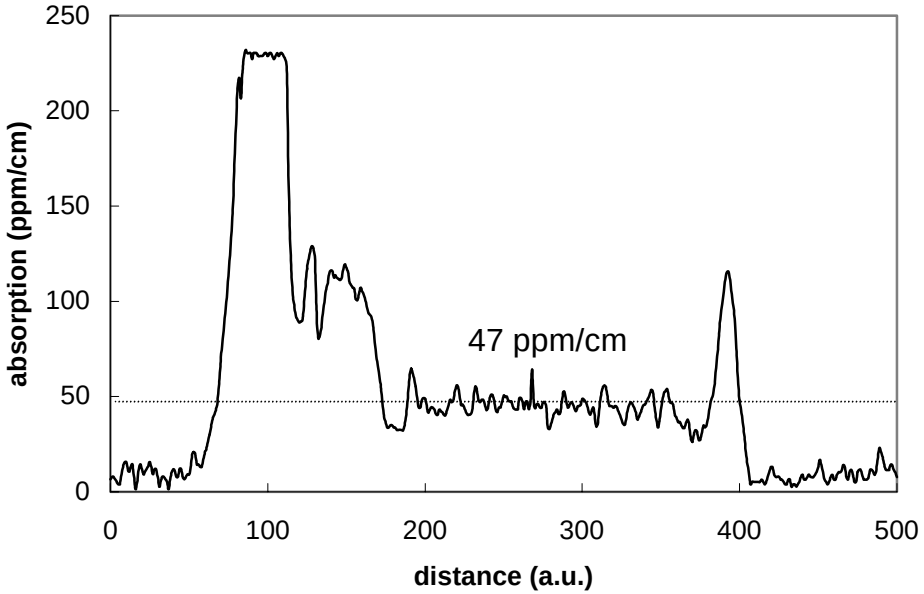


Annealed sapphire data

20 mm-long, O_2-annealed sample

Absorption at 1064 nm, scan from surface to surface

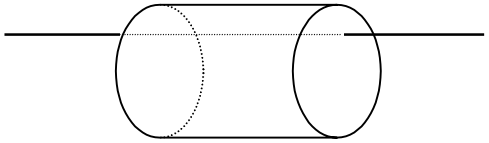


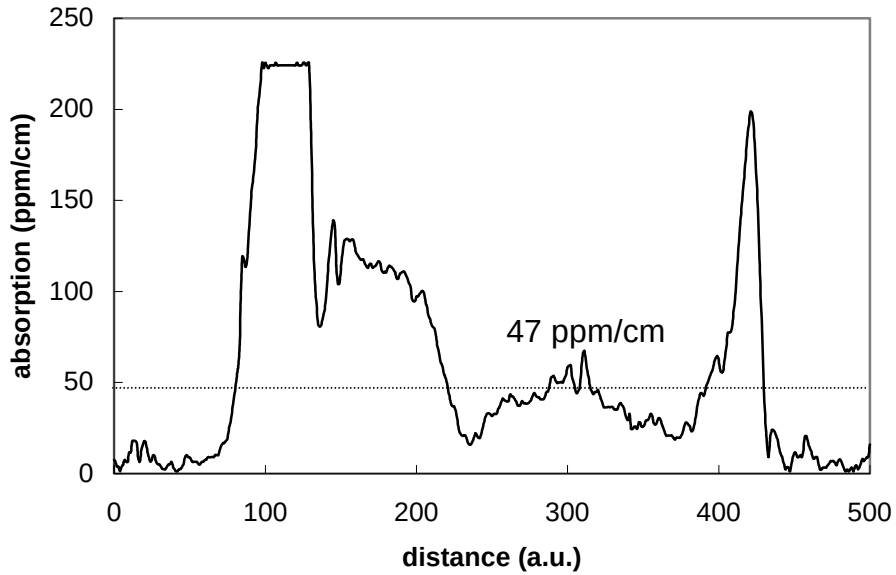


Annealed sapphire data

20 mm-long, O_2-annealed sample

Absorption at 1064 nm, scan from surface to surface

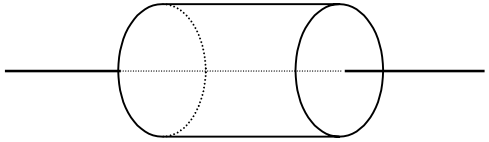


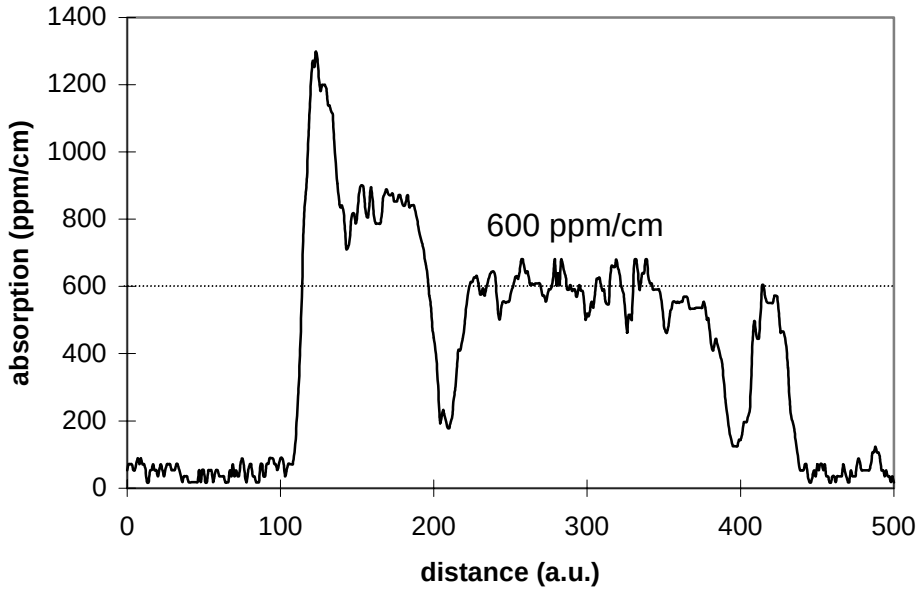


Annealed sapphire data

20 mm-long, O_2-annealed sample

Absorption at 514 nm, scan from surface to surface

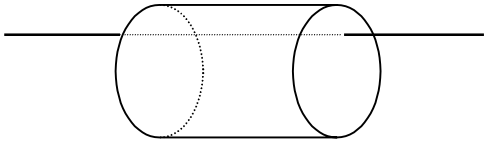


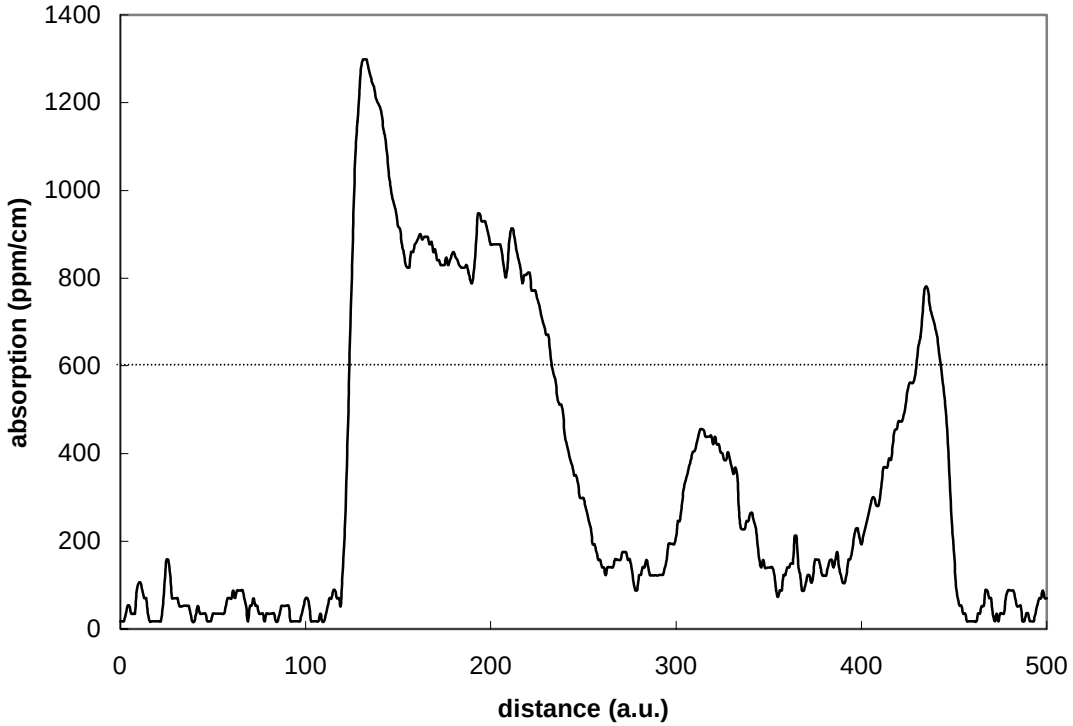


Annealed sapphire data

20 mm-long, O_2-annealed sample

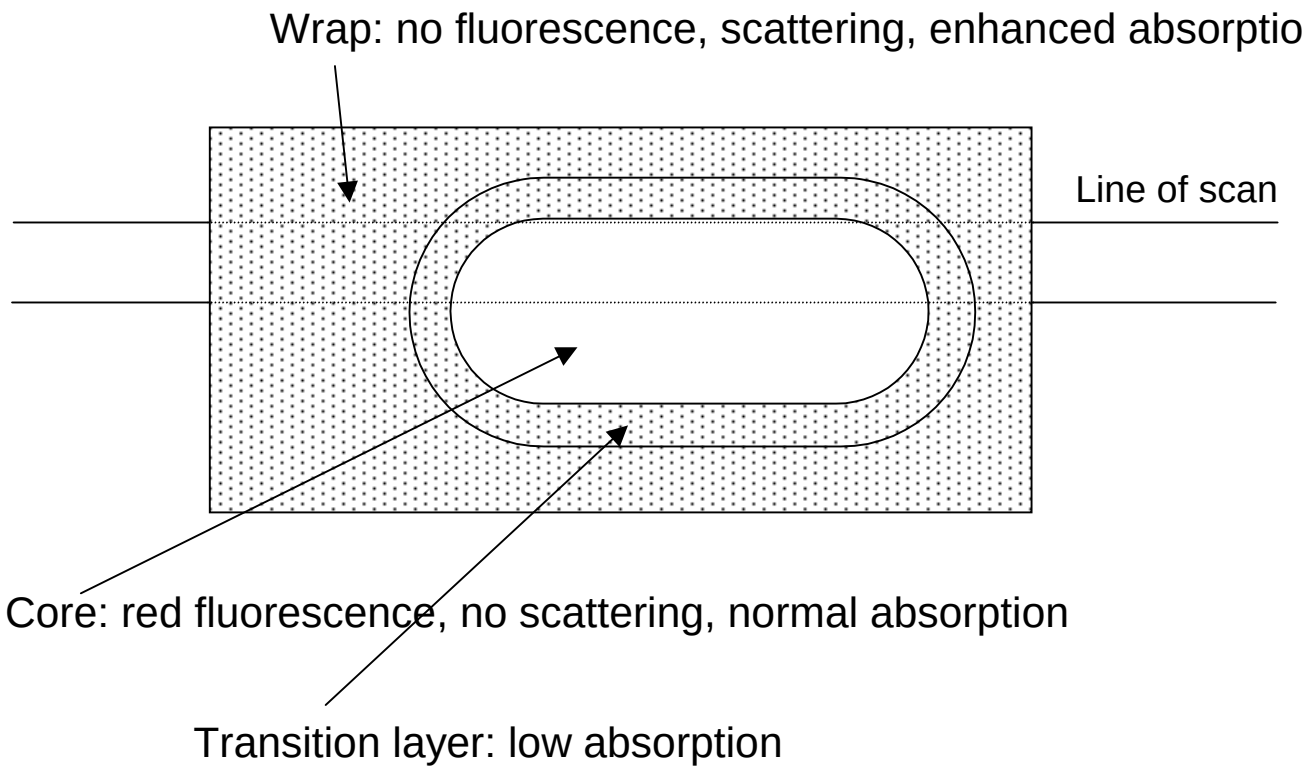
Absorption at 514 nm, scan from surface to surface





Model

O_2-annealed sample



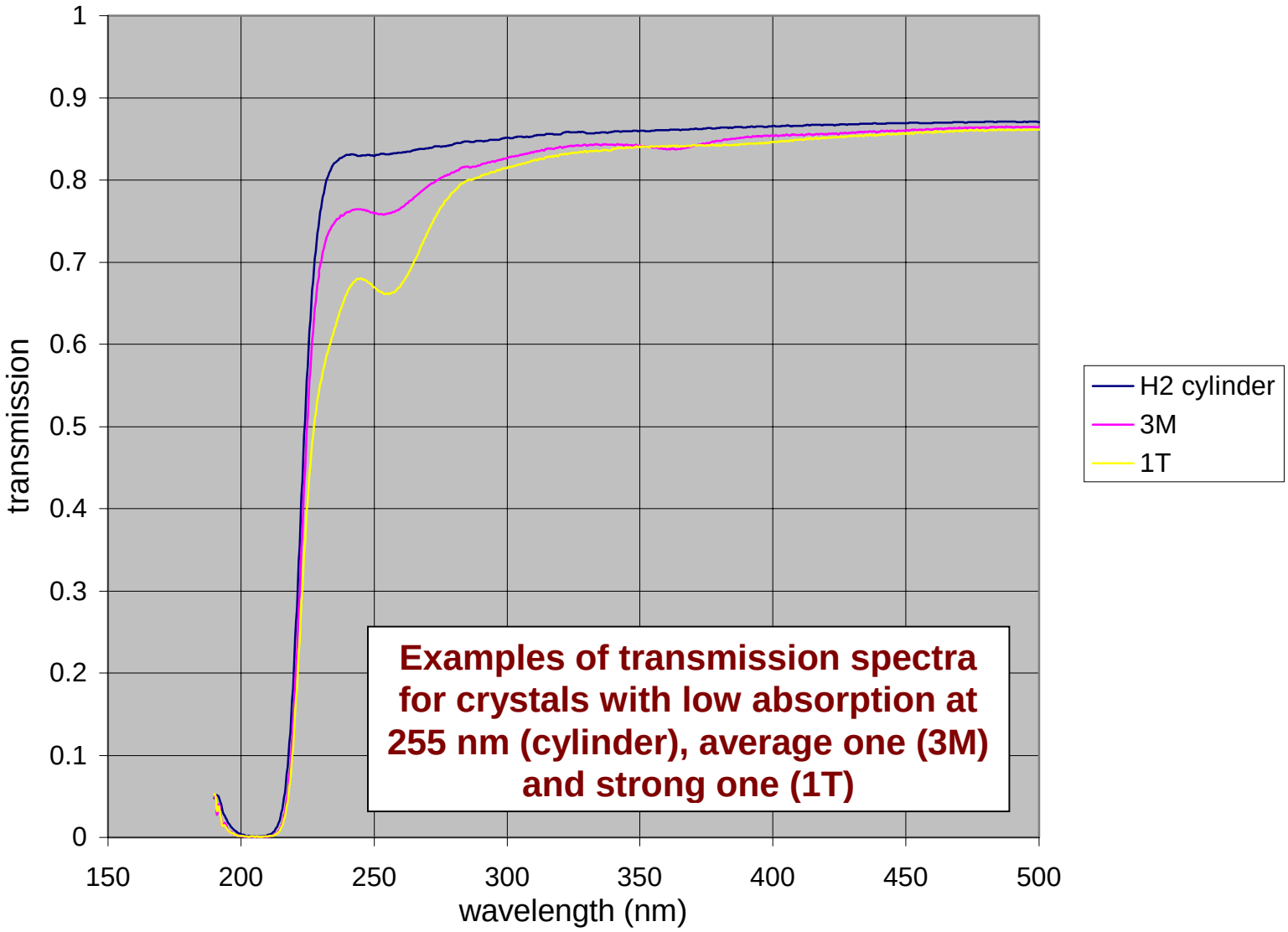
Data on CSI sapphire crystals (2000)

Absorption in sapphire cubes for both polarizations, ordinary (o) and extraordinary (e).

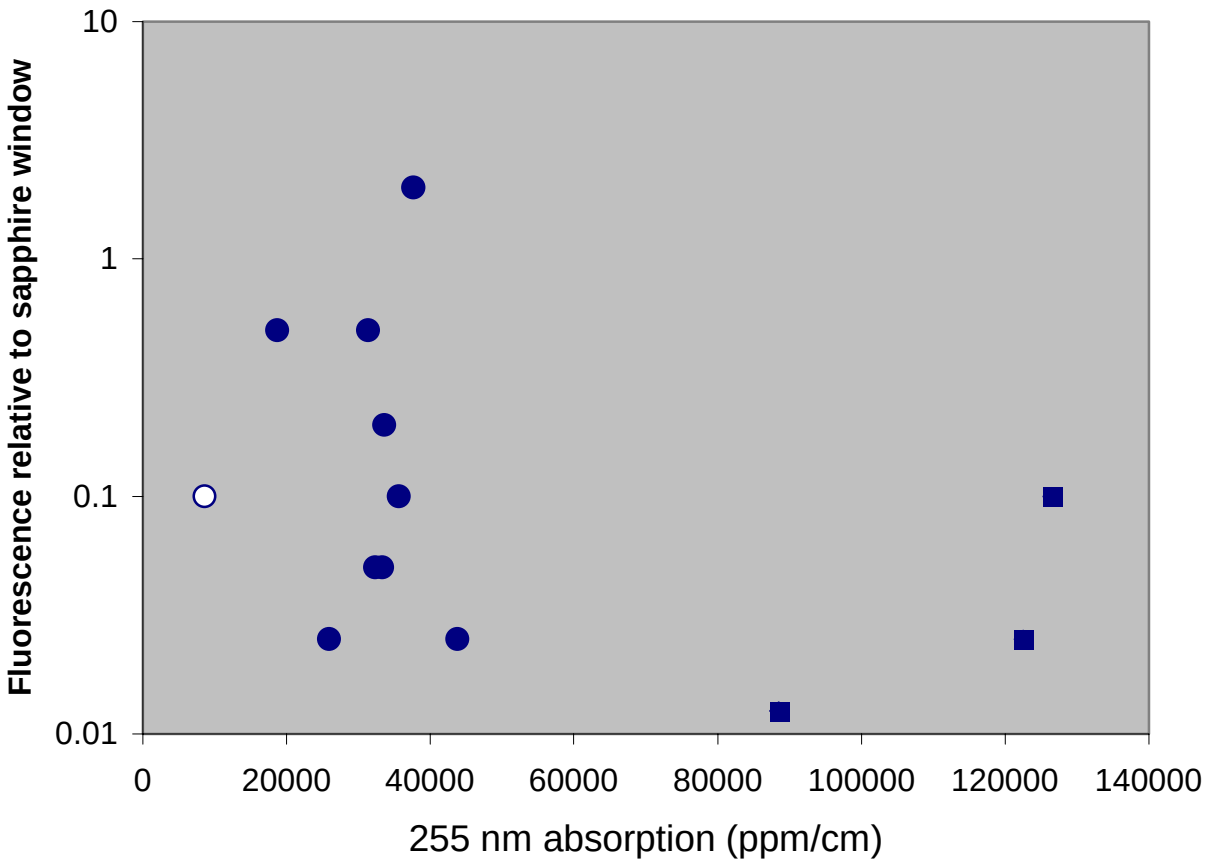
Crystal	IR absorption, ppm/cm		Green absorption, ppm/cm		Fluorescence brightness relative to sapphire window*	
	o	e	o	e	o	e
1T	110-190	130-230	1500-3000	9800-26000	1/10	1/2
1M	95	199	2260	7900	1/40	1/5
1B	93	220	2100	4700	1/80	1/20
2T	67	75	1360	1900	1/5	1
2M	77	92	1150	2200	1/2	2
2B	101	140	1530	2670	1	5
3T	60	80	820	1300-1700	1/20	1/5
3M	90	150-200	1200-1400	2500	1/40	1/10
3B	60-80	130-160	900	1500	1/40	1/10
4T	60	70-90	900	1800	2	1/2
4M	130	170-230	1600-1950	2600	1	1/5
4B	70-120	75-140	900-1200	1800-2500	1/20	1/2

*Sapphie window showed brightness of 2 x 10^{-3} relative to 0.1%-doped Ti-sapphire crvstal

Transmission of CSI sapphire in UV-VIS

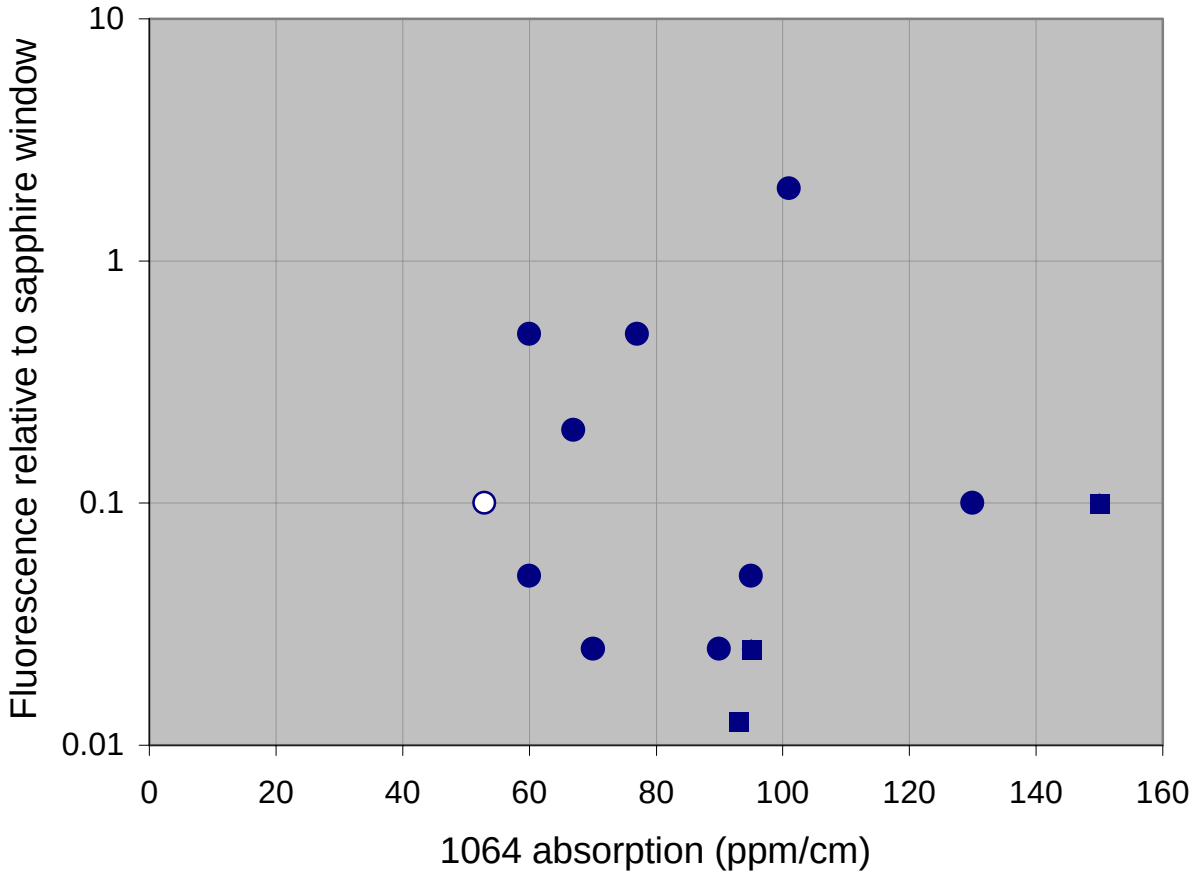


Fluorescence vs 255 nm absorption band in CSI sapphire

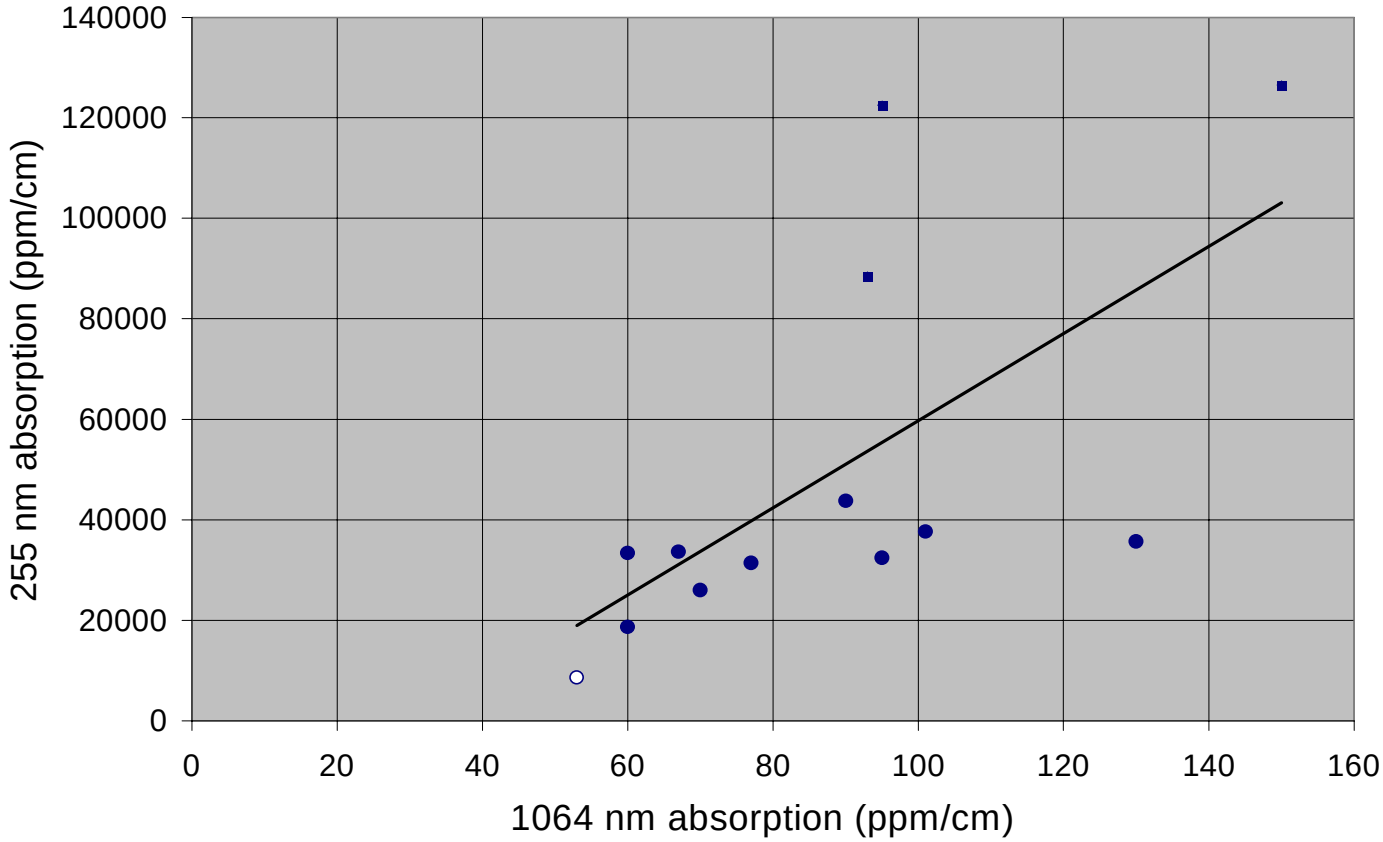


Open circle: hydrogen-annealed cylinder
Squares: crystal #1

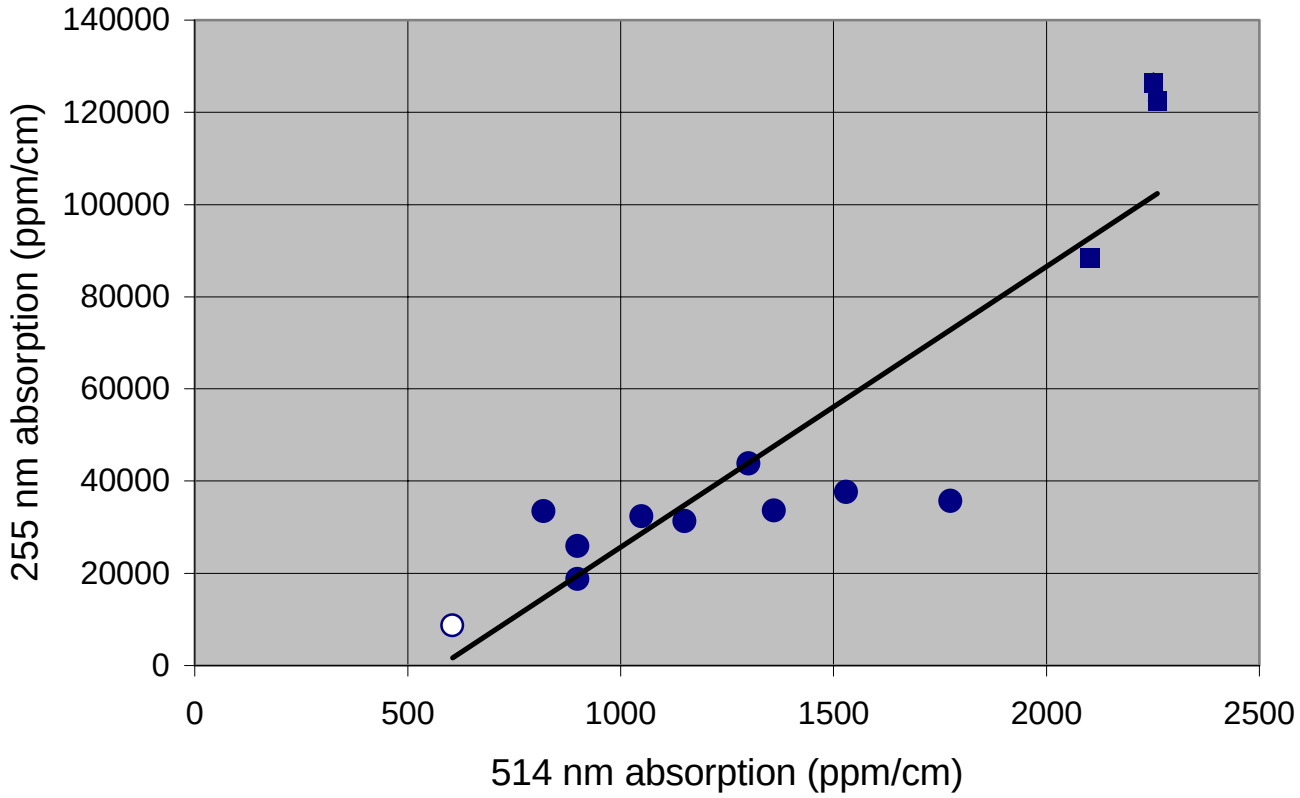
Fluorescence vs absorption at 1064 nm in CSI sapphire



Correlation of absorption at 255 and 1064 nm



Correlation of absorption at 255 nm and 514 nm



Conclusions

- The best as-grown sapphire shows 40 ppm/cm of absorption at 1064 nm
- 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. Ti seems now to be an unlikely source of residual IR absorption
- Proper annealing in oxygen may offer means to reach the 10-15 ppm/cm level. Further decreases will depend on the ability to identify and eliminate specific defects