Photothermal absorption measurements in optical materials

A.L. Alexandrovski, M.M. Fejer, R.R. Route, R.L. Byer

Ginzton Laboratory, Stanford University, Stanford, CA 93405-4085
alexei@loki.stanford.edu, fejer@ee.stanford.edu

Materials studied to date

- Lithium tantalate
- Spinel
- PPLT
- Lithium niobate
- RTP
- KTP
- PPLN
- LBO
- Fused silica
- BBO
- Sapphire
- YAG
- Paratellurite

Absoprtion (and photorefraction) in some optical materials

Material	α_{1064nm} (cm^{-1})	α_{514nm} (cm^{-1})	Green induced IR absorption	Track formation	Photo-refraction
LN	$8x10^{-4}$	$8x10^{-3}$	strong	-	Strong
SLN	$7x10^{-4}$	0.03	strong	-	Strong
LN:Mg	$6x10^{-4}$	0.03	very weak	-	No
LT	$7x10^{-4}$	$5x10^{-3}$	very weak to moderate	-	weak to strong
SLT	$3\text{-}6x10^{-4}$	0.1-0.006	very weak	-	Weak
LT:Mg	$4x10^{-4}$	-	no	-	No
PPLN	$5\text{-}20x10^{-4}$	~0.01	strong	weak, at >200^0C	Weak
PPLT	$\sim10^{-3}$	~0.01	weak	-	Weak
KTP	$2\text{-}50x10^{-6}$	$5\text{-}50x10^{-5}$	weak to moderate	weak to strong	no to weak
PPKTP	$4x10^{-5}$	$3x10^{-4}$	-	-	No
RTP	$2x10^{-5}$	$2x10^{-4}$	moderate	moderate	Weak
BBO	$<1\text{-}2x10^{-6}$	$<2\text{-}10x10^{-6}$	no	strong with UV pump	No
LBO	$<1\text{-}10x10^{-6}$	$<2\text{-}8x10^{-6}$	no	-	no
TiO_2	$10^{-3}–10^{-4}$	>0.01	very weak to strong	weak to strong	no
YAG	$\sim10^{-4}$	-	-	-	no
Sapphire	$4–10x10^{-5}$	$6\text{-}13x10^{-4}$	no	no	no
Spinel	$\sim10^{-4}$	0.03	-	-	no
Fused silica	$1–20x10^{-6}$	-	no	no	no

Motivation

- Absorption effects in UV-VIS and IR:
  - 10^{-6} cm^{-1} may be of importance for high-average-power applications;
  - bulk and surface effects are to be detected separately;
  - photochromic effects (such as 'Green Induced IR Absorption') are essential for nonlinear materials.
- Spectrophotometry and calorimetry are not precise, limited in capabilities.
- Photothermal technique proved to be a unique match!
- The power of the developed photothermal tool can help to understand mechanisms of optical loss in different materials.

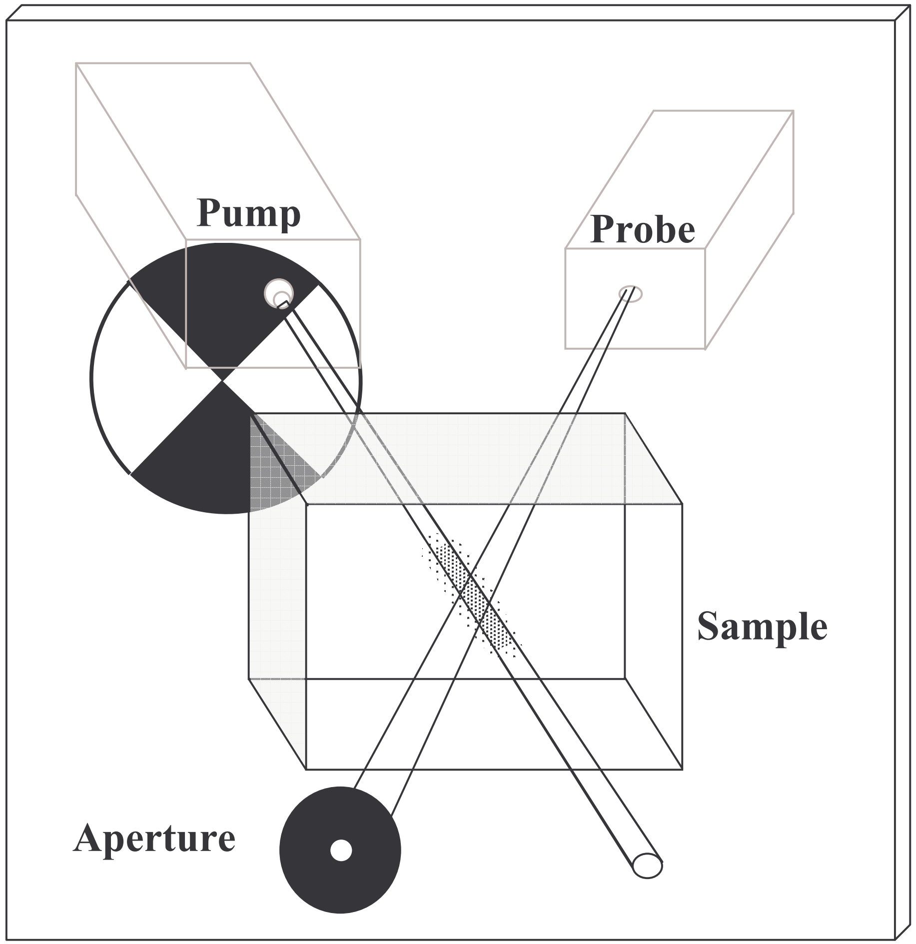
Outline

- About Photothermal Common-path Iinterferometer (PCI)
- Spatial resolution of PCI
- Annealed sapphire: 3D map
- Coatings and surfaces
- Gray-tracking in KTP
- LBO: surfaces dominate!

Photothermal Common-path Interferometer (PCI)

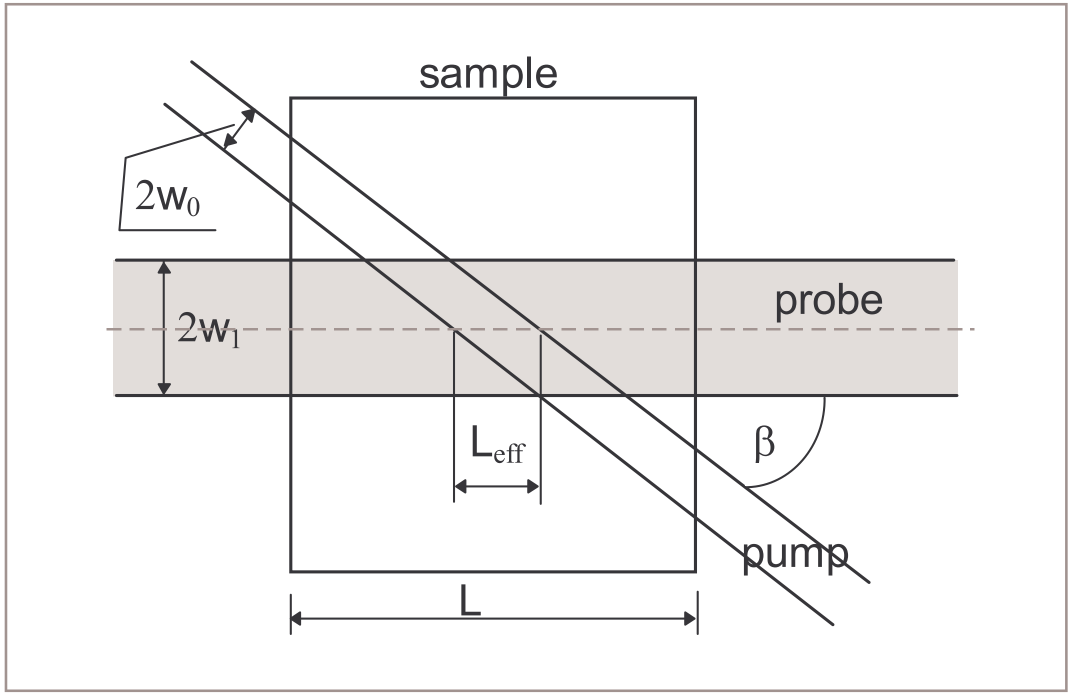
- PCI is an improvement of the thermal lensing (TL) technique for the detection of a low absorption losses
- PCI was introduced in 1997-1998 in Stanford University
- PCI is designed to detect a weak phase distortion of a probe introduced by absorption of a focused pump
- PCI is the most sensitive photothermal device which utilizes an interferometric sensitivity for a phase distortion detection but uses a single probe beam
- PCI concept is applicable for solid, liquid and gaseous samples as well as for characterization of bulk samples, coatings, and multilayered devices

PCI basics



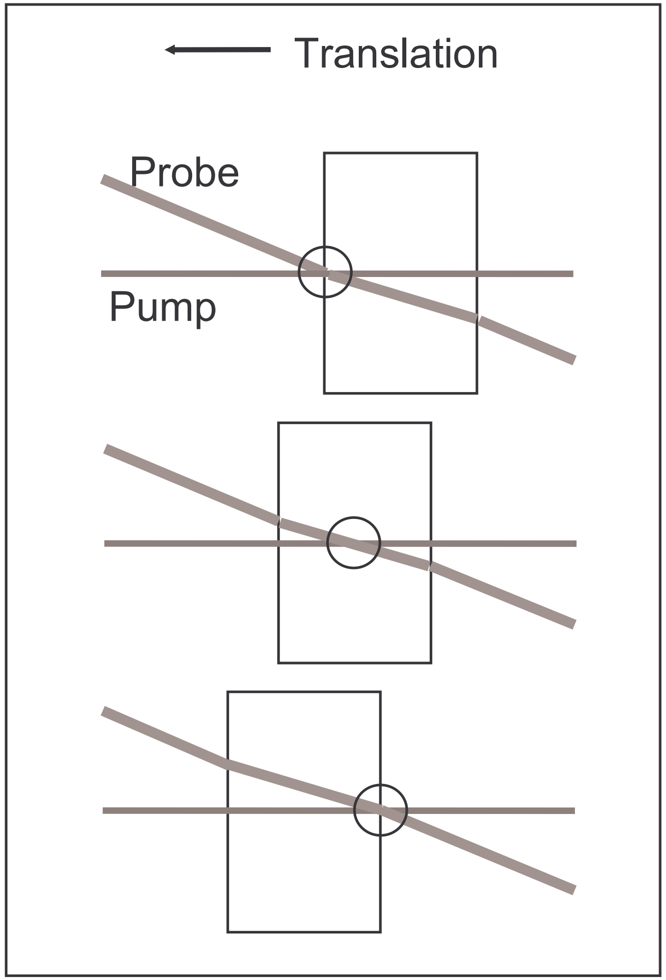
- CW, chopped pump provides <u>periodic</u> heating
- CW probe beam experiences <u>periodic</u> phase distortion
- Beams are crossed to allow some spatial resolution, i.e. crossed inside the sample to measure the <u>bulk</u> absorption
- Periodic distortion of the probe is detected after an aperture
- Lock-in is used to measure the detected AC-signal with a shot-noise-limited sensitivity

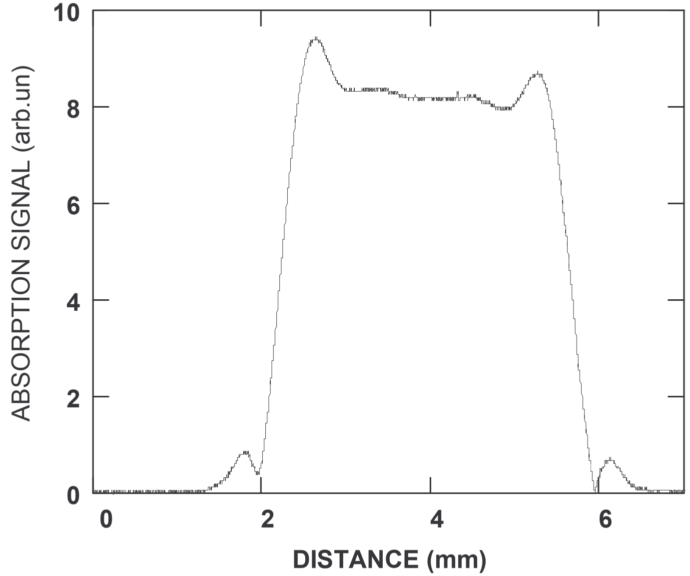
PCI: space resolution



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

Space resolution: example (surface-to-surface scan)

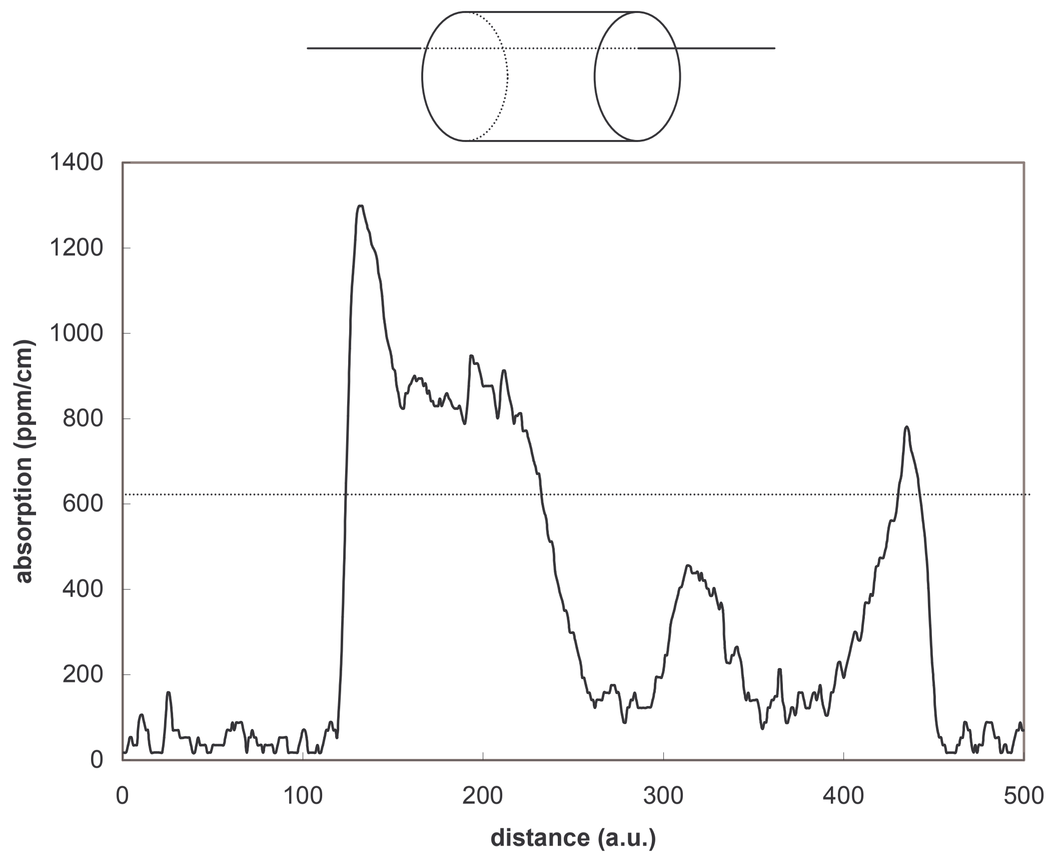




Example: PCI signal for a 3 mm-thick neutral filter,15%-absorbing
Leff = 0.25 mm

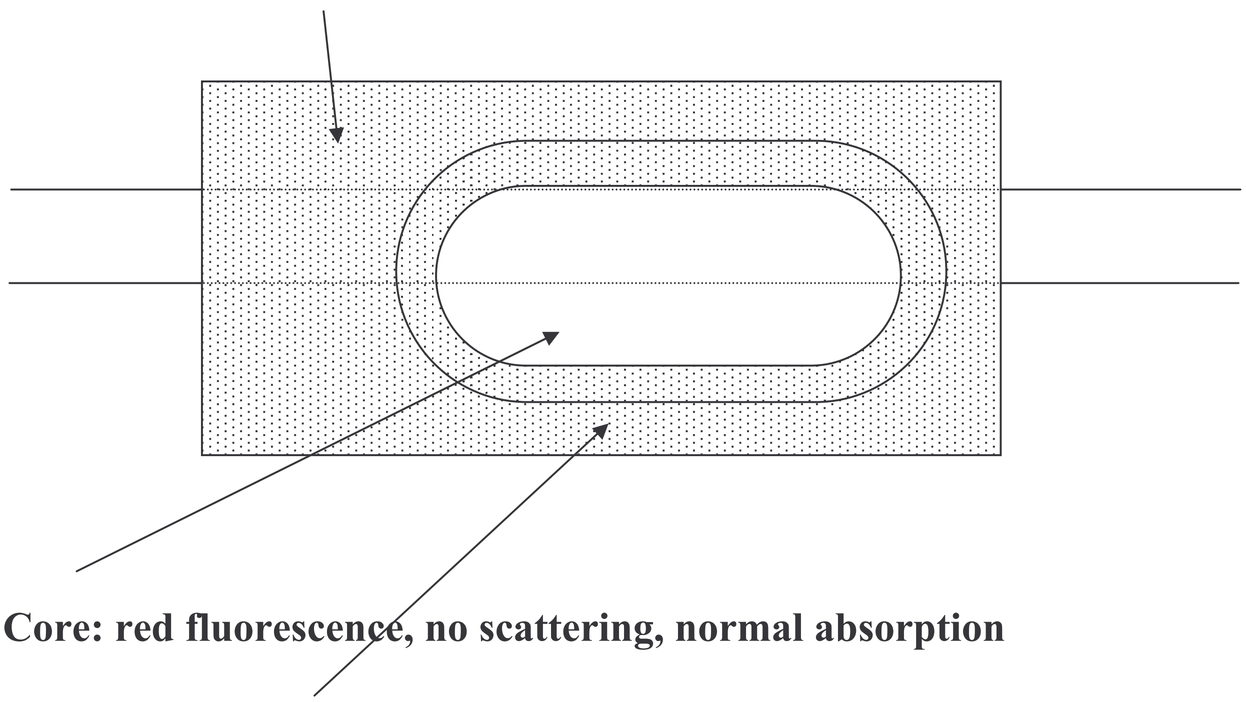
Sapphire: 20 mm-long, O_2-annealed sample

Absorption at 514 nm, scan from surface to surface



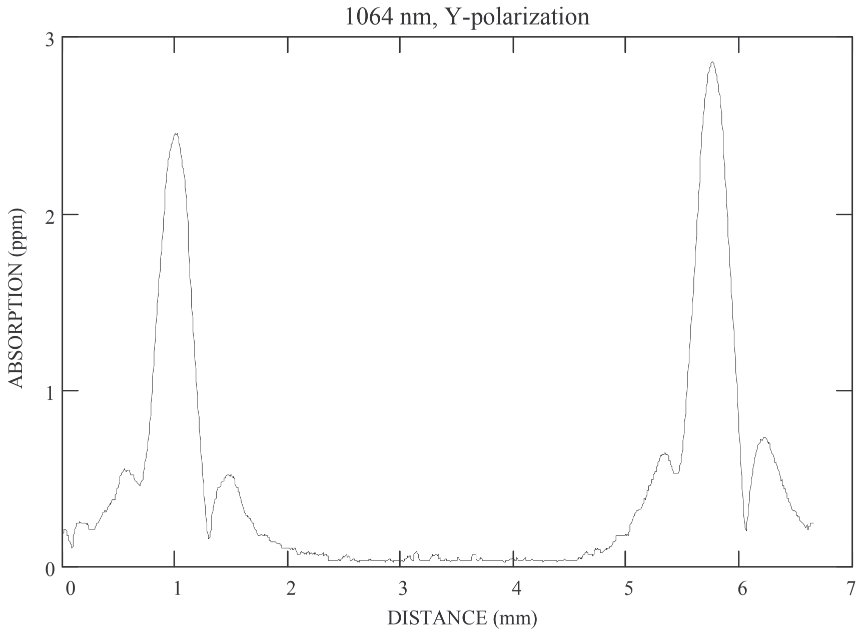
Sapphire: the result of annealing in oxygen

O_2-anneald sample



LBO: surfaces dominate!

Surface absorption in 3 x 3 x 5 mm, 8°-X-cut, coated LBO crystal

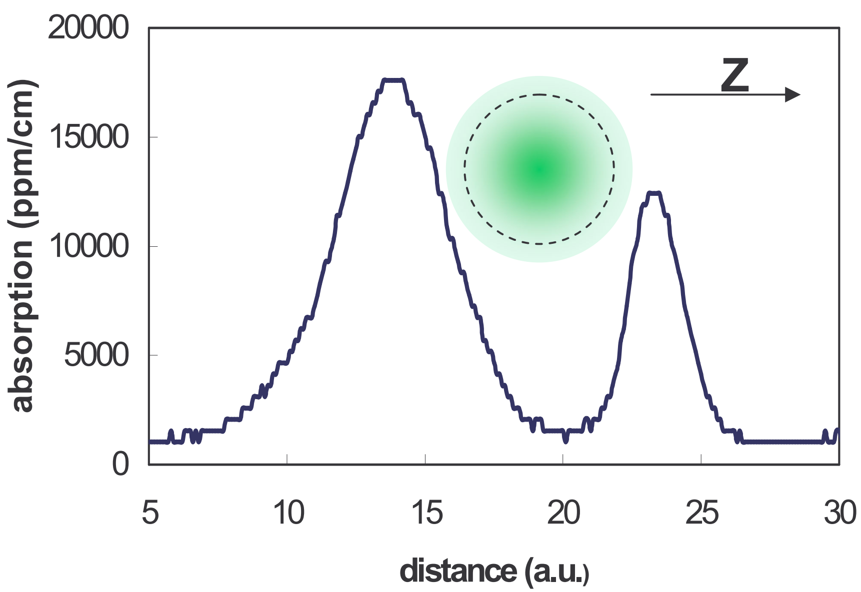


- **The bulk absorption in LBO is very small**
- **The surface absorption effect is greatly enhanced because of strong thermal expansion**
- **Nearly the same happens for the green absorption, at 532nm.**

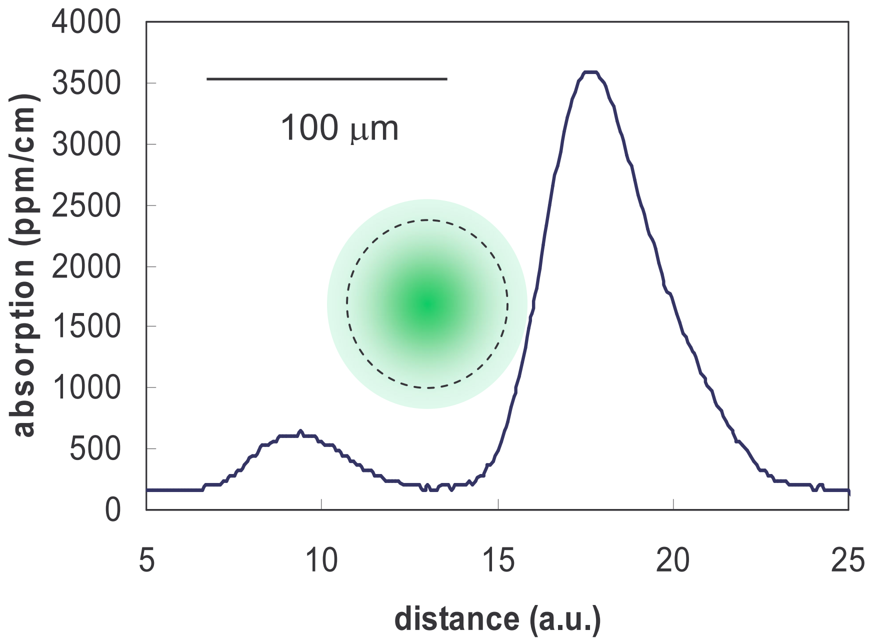
Crystal	**Wavelength, polarization**	**Surface absorption***	**Bulk****	**Comments**
3x3x5 mm, AR coated	532 nm, Y	15 ppm	< 5 ppm/cm	Surface signal bleaches
	1064 nm, Y	2.5 ppm	< 1.5 ppm/cm	
	532 nm, Z	13 ppm	< 5 ppm/cm	Surface signal bleaches
	1064 nm, Z	2.5 ppm	< 1.5 ppm/cm	

CW gray-track in KTP

Green scan (514 nm)



IR scan (1064 nm)



120 microns between peaks with a green spot of 70 microns

CW gray-track in KTP: model

Laser induced electrochromic damage: electrolysis in the green beam region initiated by a photogalvanic current

$$j_e = \sigma_e E + kI$$
$$j_i = \sigma_i E$$

$$j_e + j_i = 0$$
$$E = -\frac{kI}{\sigma_e + \sigma_i}$$

$$E \approx -\frac{kI}{\sigma_i} \to 0$$
$$j_i = -kI$$

- KTP is known as an ionic conductor
- Rapid, within minutes, drift of the absorption maximum on the +Z side of green beam further in the +Z direction when the green pump is shifted in this direction
- Less gray-tracking corresponded with apparently high-resistivity KTP
- Photorefraction was directly observed in RTP and high-resistivity KTP

Conclusions

- PCI showed exceptional combination of sensitivity and versatility.

- The situation is much more complex than was believed to be: many materials show not only wide scatter in absorption values but display different types of photochromic, nonlinear behavior dependent on power, time, sample history, etc.

- The high sensitivity of PCI device to any index distortion ($\sim 10^{-6}$) allowed us to monitor photorefraction along with absorption measurements.

- In certain cases, especially with low-absorbing materials such as borates or fused silica, it was found that absorption at the degraded or coated surface dominates over the bulk one.