THERMO-OPTICAL CONSTANTS OF SESQUIOXIDE LASER CERAMICS $Yb^{3+}:Ln_2O_3$ (Ln=Y,Sc,Lu)

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Nizhny Novgorod, 2012

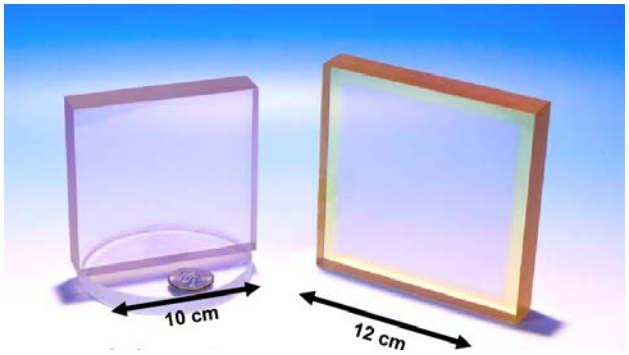
Outline

- Introduction
- Measurements of heat load
- Thermally induced depolarization measurements
- Thermal lens measurements
- Summary

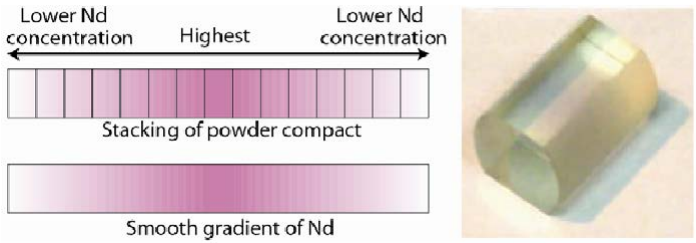
Introduction

The significant properties of ceramic as a material for high-average power lasers

- Possibility to produce a large-aperture optical element
- High homogeneity of dopant ions or possibility to make the necessary distribution of dopant
- Greater strength and thermal shock parameter



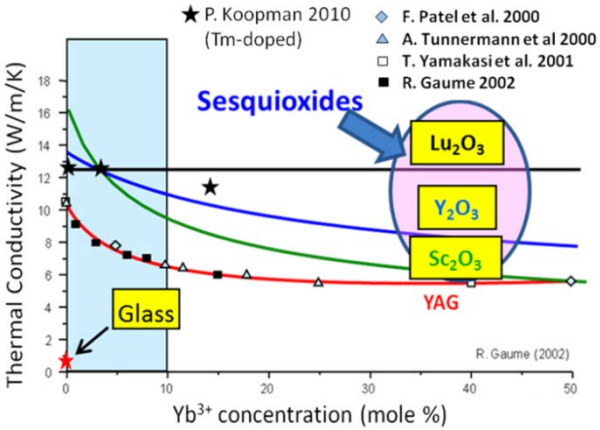
Yamamoto, R. M. et al. in *Proc. ASSP, Nara, Japan,* ***WC5*** *(**2008**).*



Ikesue, A.; Aung, Y. *Nat. Photonics* ***2008, 2, 721–727***

… sesquioxide ceramic …

- The relatively high thermal conductivity
- High absorption and emission cross-sections of trivalent rare-earth doped ions



J. Sanghera, et al. *Materials* ***2012, 5, 258-277***

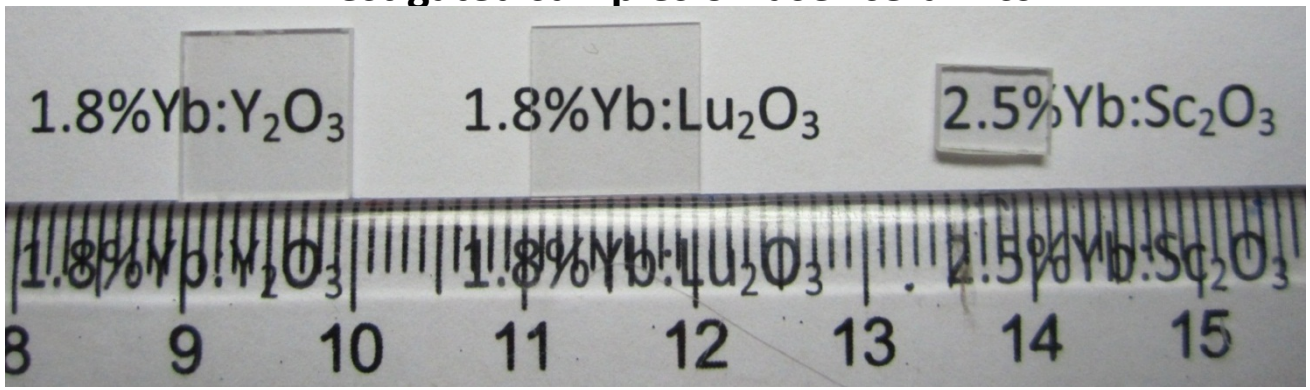
Introduction

Thermo-optical constants which are responsible for thermal lens and thermally induced depolarization in sesquioxide ceramics are remain poorly studied

	Y_2O_3 ceramic	Lu_2O_3 ceramic	Sc_2O_3 ceramic	YAG monocrystal
n_0	1.89	1.907	1.98(1.965)	1.82
κ [W/m·K] for 3%Yb	7.2 [4]	10.6 [4]	6.5 [4]	5
$1/L*dL/dT\cdot10^{-6}$ [1/K]	6.7[1] 8.5 [2]	6.1 [1] 8 [2]	6.3 [1] 9 [2]	6.6[1] 7.5 [2]
$dn/dT\cdot10^{-6}$ [1/K]	9.04 (633 nm [1]) 8.5e [3]	8.18 (633 nm [1]) 8.6 [3]	-21.46 (633 nm [1]) 9.6[3]	8.98 (633 nm [1]) 9.9[3]
ξ	---	---	---	3.2
ν Poisson's ratio	0.307	---	---	0.25

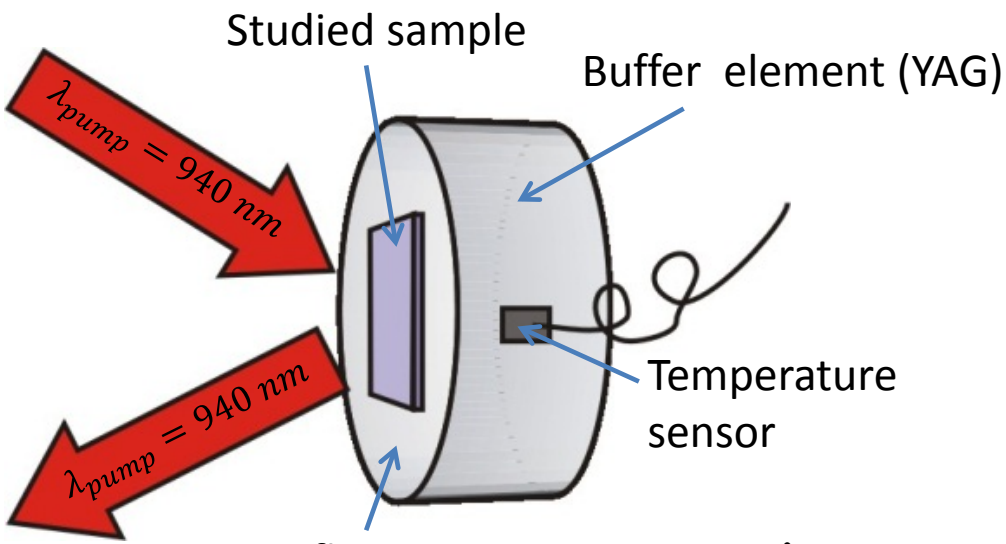
[1] V. Cardinali et al., Optical Materials **34**, 990–994 (2012)
[2] V. Petrov et al., Proc. of SPIE, Vol. **6216**, 62160H-1, (2006)
[3] T. Sudmeyer et al., Appl. Phys. B **97**: 281–295 (2009)
[4] J. Sanghera, et al. *Materials*, **5,** 258-277 (2012)

Investigated samples of laser ceramics



Measurements of heat load

Investigated samples of laser ceramics have small absorption coefficient on λ=1076 nm ($\alpha_0 < 10^{-4}$ cm^{-1})

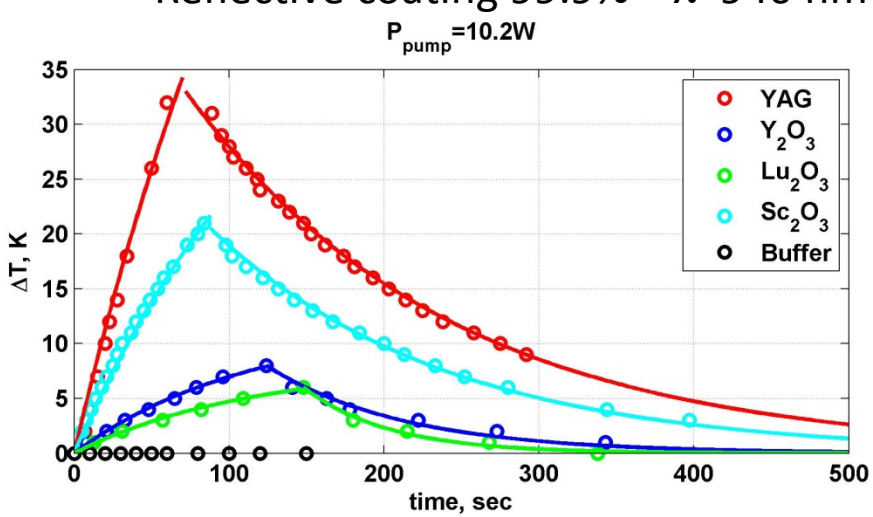


$$P_{pump\ abs} = P_{abs} + \mu P_{lum}$$

$0 < \mu < 1$ not all luminescence leaves the optical element

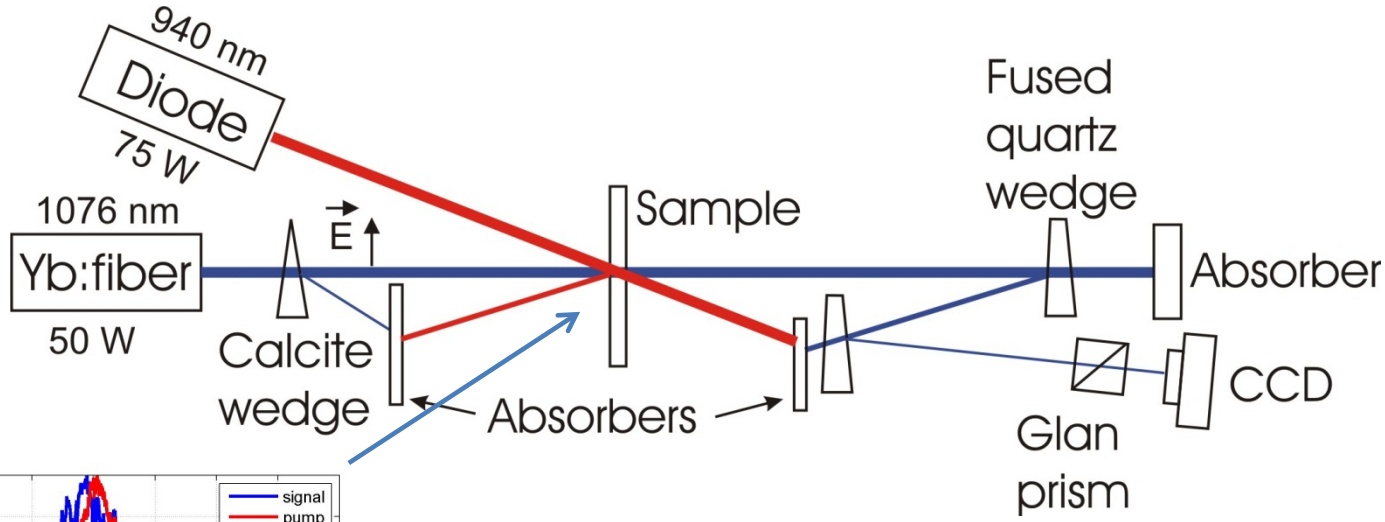
Assumptions:

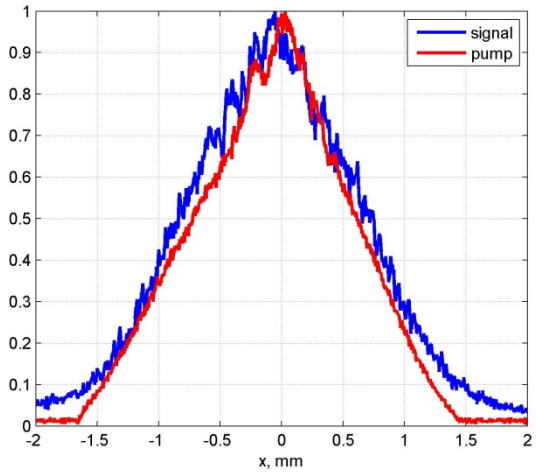
1. Temperature settling time << time of measurements
2. The main flow of heat goes to the buffer element

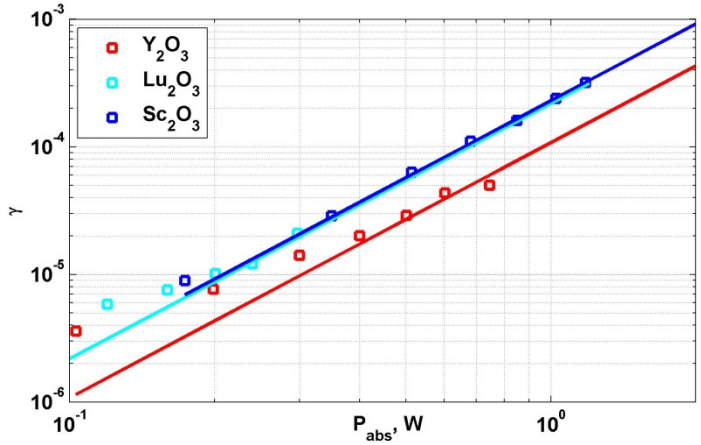


Material	P_{abs}/P_{laser}	$\alpha_{0\ eff}$, [1/cm]
Y_2O_3	0.01	0.1
Lu_2O_3	0.004	0.08
Sc_2O_3	0.034	0.28
YAG	0.14	0.75

Thermally induced depolarization measurements







For ceramic element and Gauss beam:

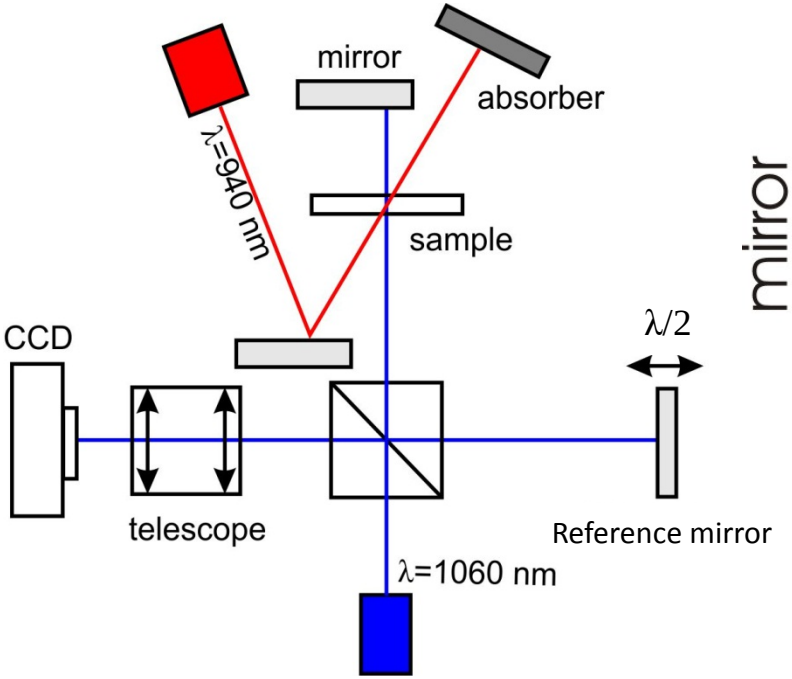
$$\gamma = 0.0171\left(\frac{Q}{\lambda\kappa}\left[\frac{2+3\xi}{5}\right]\right)^2 P_{abs}^2$$

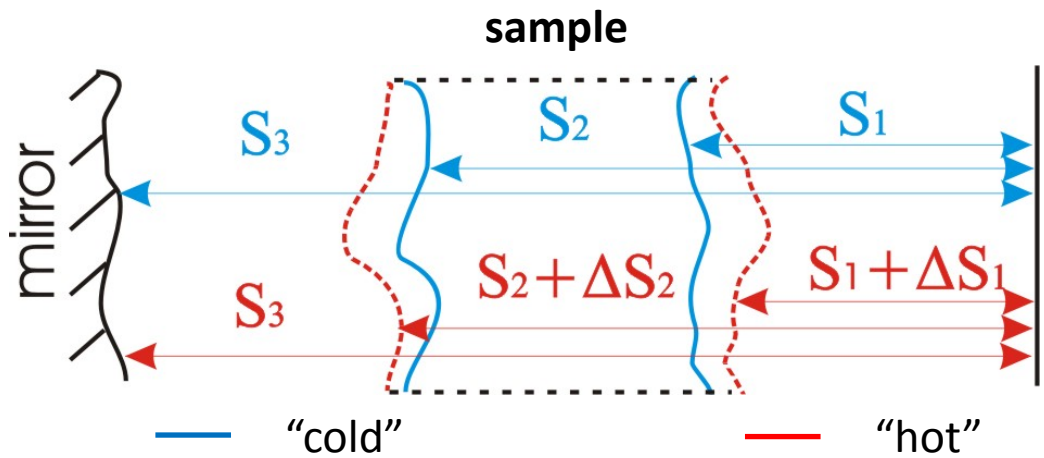
$$Q\left[\frac{2+3\xi}{5}\right]$$

	Y_2O_3	Lu_2O_3	Sc_2O_3	YAG literature
Q·(2+3ξ)/(5κ)	-5.7e-8	-7.3e-8	-1.25e-7	-2.9e-7
Q·(2+3ξ)/5	-4.2e-7	-7.8e-7	-8.0e-7	-1.47e-6

M. A. Kagan and E. A. Khazanov, Quantum Electronics **33**, 876-882 (2003).

Thermal lens measurements





We measured the interference of radiation from the reference mirror and:

1. first surface of the sample
2. second surface of the sample
3. mirror behind the sample

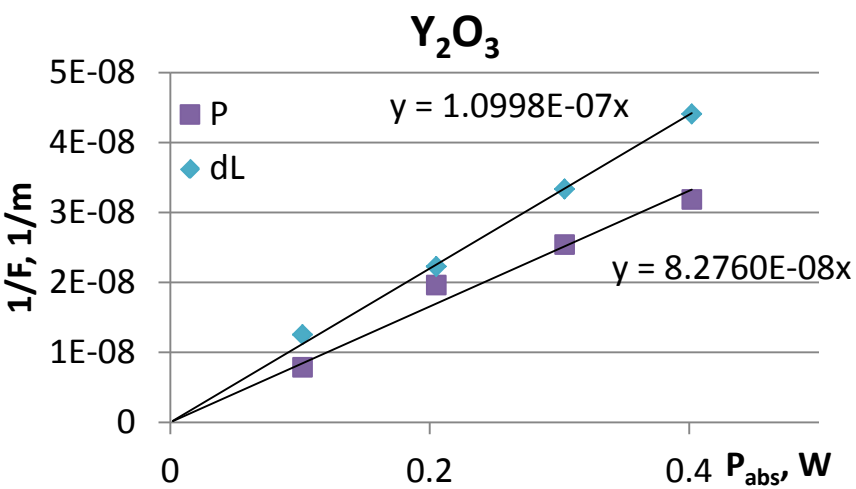
$$\begin{cases} \Delta L = \dfrac{1}{L}\dfrac{dL}{dT}\dfrac{1}{2\pi\kappa r_h^2}\dfrac{P_{abs}r^2}{2} \\ \Delta n = \dfrac{P}{4\pi\kappa r_h^2}\dfrac{P_{abs}r^2}{2} \end{cases}$$

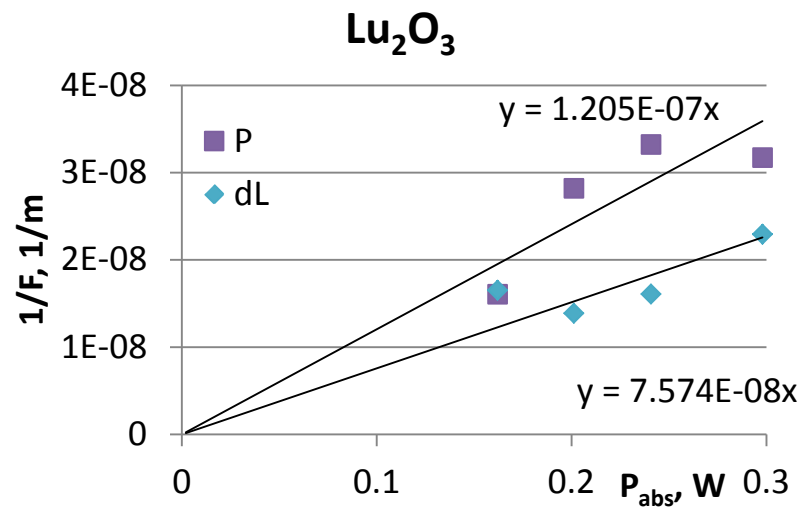
Later we found the phase distribution and strength of thermal lenses arising from thermal expansion of the sample and the refractive index dependences from the temperature and stress

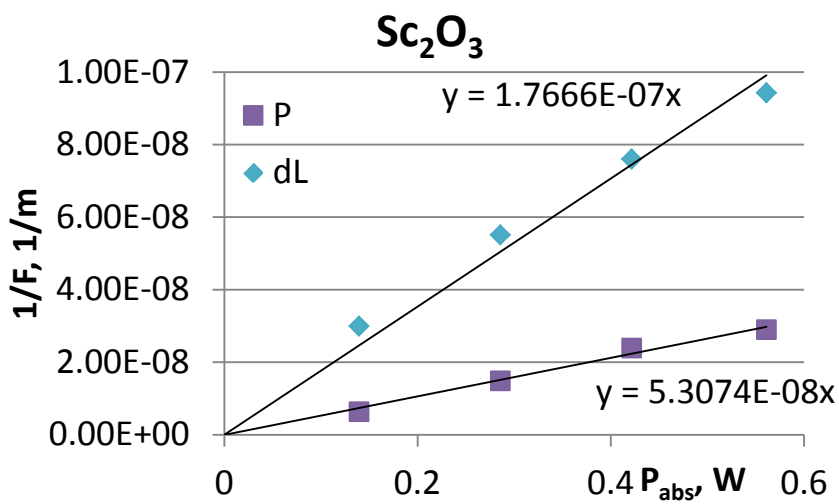
V. V. Zelenogorsky et al., Applied Optics **45**, 4092-4101 (2006)

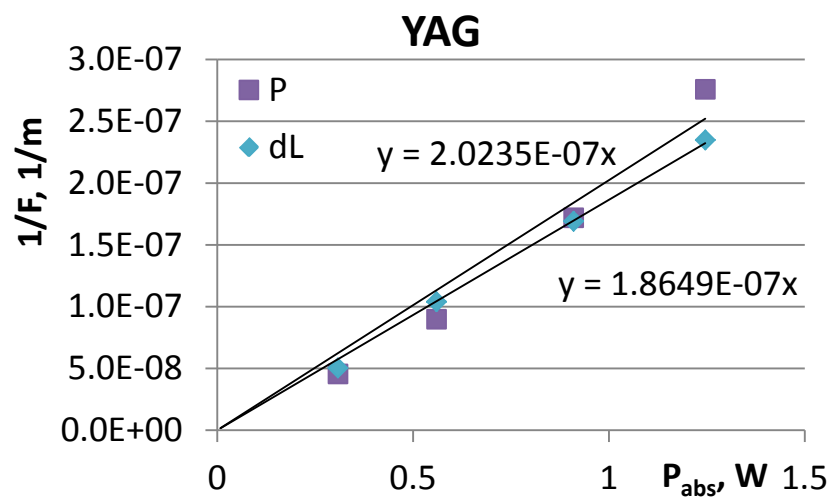
Thermal lens measurements

$$\begin{cases} \Delta L = \dfrac{1}{L}\dfrac{dL}{dT}\dfrac{1}{2\pi\kappa r_h^2}\dfrac{P_{abs}r^2}{2} \\ \Delta n = \dfrac{P}{4\pi\kappa r_h^2}\dfrac{P_{abs}r^2}{2} \end{cases}$$









Thermal lens measurements

	$Yb:Y_2O_3$ (ceramic)	$Yb:Lu_2O_3$ (ceramic)	$Yb:Sc_2O_3$ (ceramic)	Yb:YAG (crystal)
P	8.98e-6	19.2e-6	4.98e-6	14.6e-6
P/κ	1.21e-6	1.77e-6	7.78e-7	2.93e-6
$P_{literature}$	---	---	---	9.4e-6 [4]
$\frac{1}{L}\frac{dL}{dT}$	5.97e-6	5.99e-6	8.3e-6	6.8e-6
$\frac{1}{L}\frac{dL}{dT}_{literature}$	6.7e-6[1] 8.5e-6 [2] 6.56e-6 [4] 6.5e-6 [5]	6.1e-6 [1] 8e-6 [2]	6.3e-6 [1] 9e-6 [2]	6.6e-6[1] 7.5e-6 [2] 8.2e-6 (VLOC)
$\frac{dn}{dT}_{literature}$	9.04e-6 (633 nm [1]) 8.5e-6 [3] 5.5e-6 (1064nm [5])	8.18e-6 (633 nm [1]) 8.6e-6 [3]	-21.46e-6 (633 nm [1]) 9.6e-6[3]	8.98 (633 nm [1]) 9.9e-6[3] 8.9e-6 (VLOC)

[1] V. Cardinali et al., Optical Materials **34**, 990–994 (2012)
[2] V. Petrov et al., Proc. of SPIE, Vol. **6216**, 62160H-1, (2006)
[3] T. Sudmeyer et al., Appl. Phys. B **97**: 281–295 (2009)
[4] M. Weber, Handbook Of Optical Materials, CRC Press, (2003)
[5] T.Y. Fan, IEEE J. Sel. Top. Quant. Electron. **13** (3) 448–459 (2007).

Summary

- Thermo-optical properties of the three samples of laser ceramics made of sesquioxides Y, Lu and Sc studied.

- Thermo-optical constants P and Q(2+3ξ) respectively responsible for thermal lens and thermally induced depolarization in ceramic element and part of optical power transferred into heat are defined for all samples at room temperature.

- Comparison of thermo-optic constants of sesquioxide ceramics with similar characteristics of YAG are made. Ceramics from sesquioxides show better thermal-properties than YAG, which makes them more promising materials for lasers with high average power.

Thank you for your attention