National Academy of Sciences
Institute of Physics
Minsk, Belarus
E-mail:ivakin@ifanbel.bas-net.by

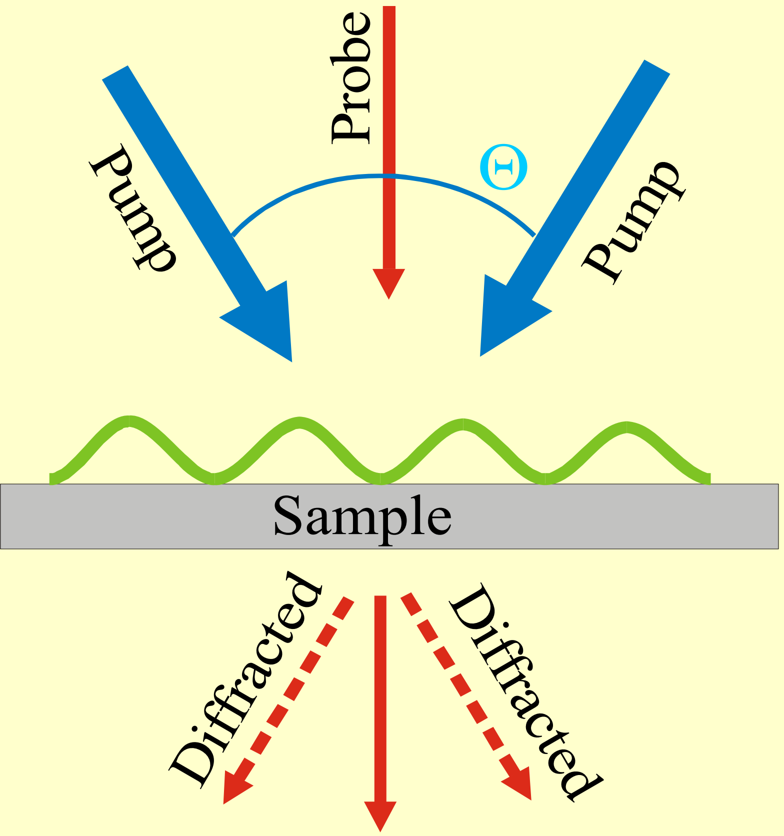
E.V. Ivakin, V.V. Kabanov, I.G. Kiseliov

Spatial migration of energy excitation between Yb^{3+} ions in highly doped $Gd_3Ga_5O_{12}$ laser crystal

18 Lithuanian-Belarusian seminar
“Lasers and optical nonlinearities”

Vilnius, September, 2009

TG technique and features



The method **IS BASED** on the fundamental physical law: the laser light action upon substance gives rise to refraction index changes.

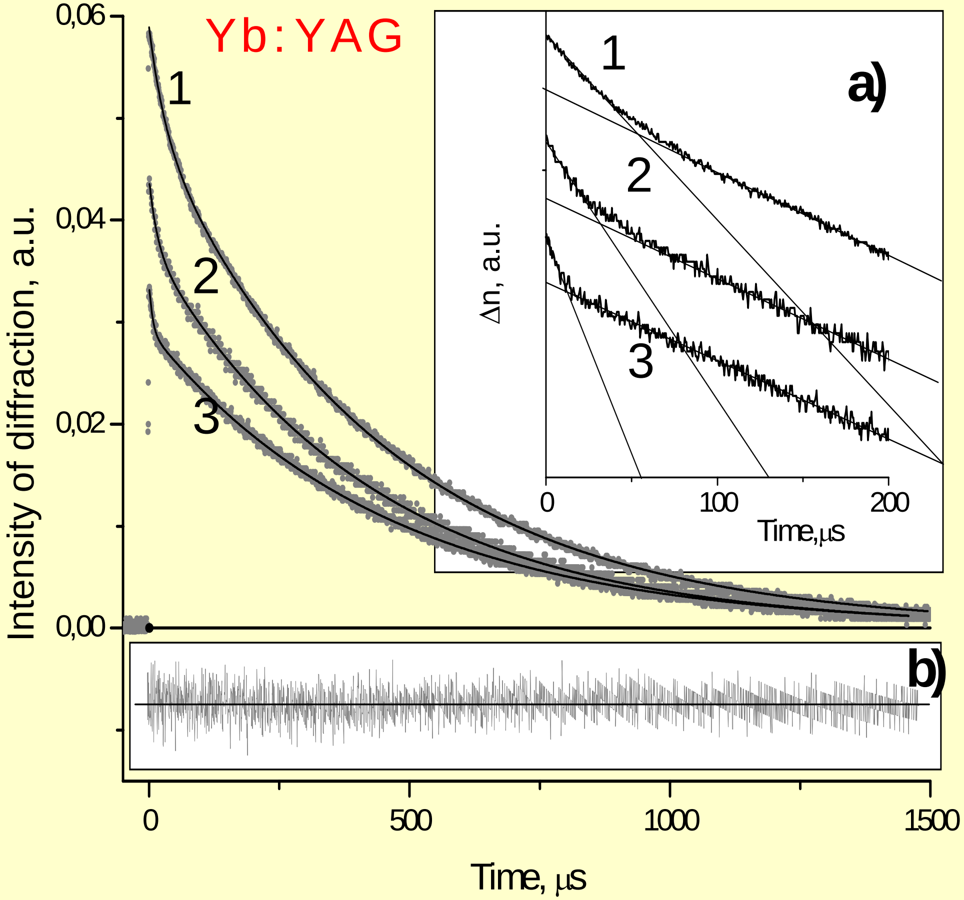
FEATURES:

- spatial periodicity of the excitation spot
- diffractional response followed by pumping beam action.
- coherent character of the signal

ADVANTAGES

- applicability to large variety of material and physical parameter to measure.
- a possibility to distinguish one mechanism of Δn from another by the amplitude, temporal or phase analysis of the diffraction signal
- no background signal before pumping flux is on.

Prehistory : low frequency TG excitation in laser crystal Yb^{3+}(9 at. %):YAG (Thermal and population density gratings)

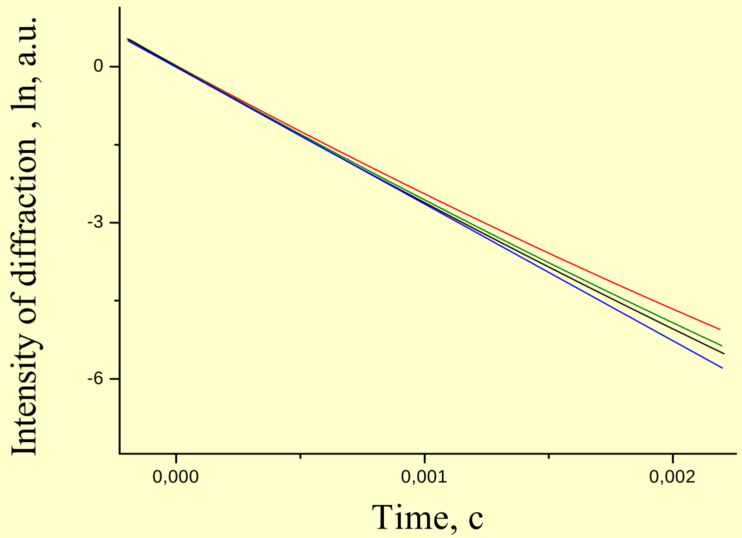


Intensity of diffracted signal as a function of time.

Λ = 52(1), 39(2) and 26(3) μm. Inset (a) – light induced refractive index in semi-logarithmic presentation. Inset (b) - residual

No dependence of electronic grating lifetime on grating spacing is observed in a case large-scaled TG is written!

High frequency TG recording in laser crystal gives rise to different outcome



The crystal $Yb^{3+}:Gd_3Ga_5O_{12}$ characteristics

Dopant concentration - 21 at %

Absorption lines - 932 , 944 and 971 nm

Ref. value of luminescence lifetime - 800 μs

Wavelength of emission – 1 025 nm

The sample thickness - 1 mm

The temporal behavior of diffracted signal at Λ = 11.7 (-----), 1.76 (-----), 1.1 (-----), 0.87 (------) μm

The lifetime of electronic component of diffraction appears to be dependent on grating spacing, so the diffusion phenomena (excited state migration) can be observed

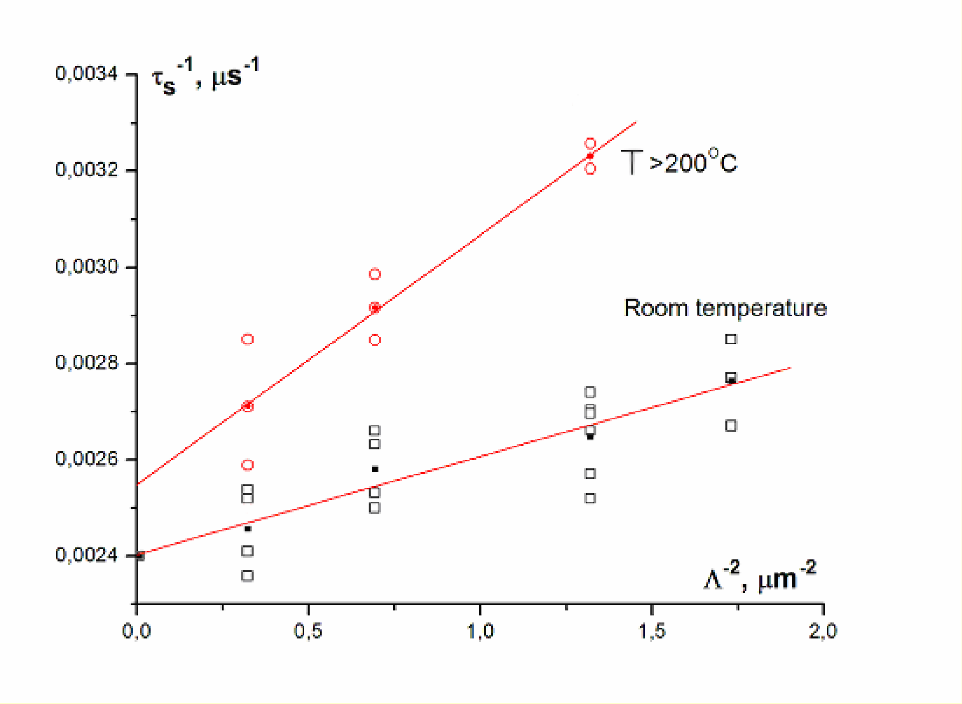
The problem of the excited state migration study in laser crystals. Brief review

H.J. Eichler, J.Eichler, J. Knof, Ch. Noack. Lifetimes of Laser-Induced Population Density Gratings in Ruby / // Phys. Stat. Sol. (a). – 1979.– 52.– P. 481–486.	The first proposal to use transient gratings for direct measurement of D in ruby. The parameter D is not measured.
L. Meilhak, G. Pauliat, G. Roosen Determination of the energy diffusion and of the Auder upconversion constants in a $Nd:YVO_4$ standing wave laser/ // Opt. Communs. – 2002. - V. 203. - P. 341-347.	Nondirect estimation of the parameter D via intensity of emission control of CW laser with one mirror of resonator being moved. D= $(0,7\pm0,3)\cdot10^{-7}$ cm^2/s
Danielmeyer, N.G. Fluorescence quenching in Nd:YAG/ // J.Appl. Phys. – 1971. – Vol. 42(8). - P. 3125 – 3128.	The parameter D for Nd:YAG crystal has been calculated from the study of threshold of single-mode operation. D= $(5\pm2)\cdot10^{-7}$ cm^2/s

Positive and negative role of the effect of energy migration

Laser crystal Yb: $Gd_3Ga_5O_{12}$

Excited state lifetime and excited energy migration determining



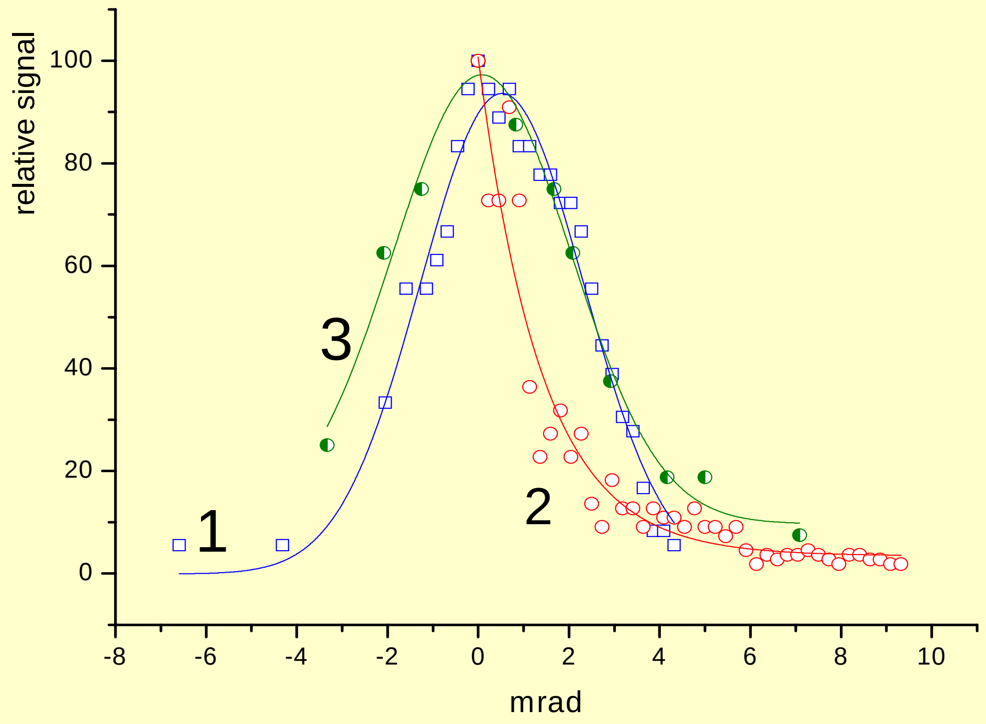
$$\frac{1}{\tau_{diffr.}} = \frac{2}{\tau_R} + 8\pi^2 D_E \cdot \frac{1}{\Lambda^2},$$

The plot for the excited state lifetime and coefficient of energy diffusion deriving

The sample temperature	Diffusion coefficient of excited state of Yb^{+3} ions	Lifetime of excited state of Yb^{3+} ions
25 °C ± 3 °C	$2{,}4 \cdot 10^{-8}$ cm²/s	825 µs
200 °C ± 10 °C	$6{,}6 \cdot 10^{-8}$ cm²/s	785 µs

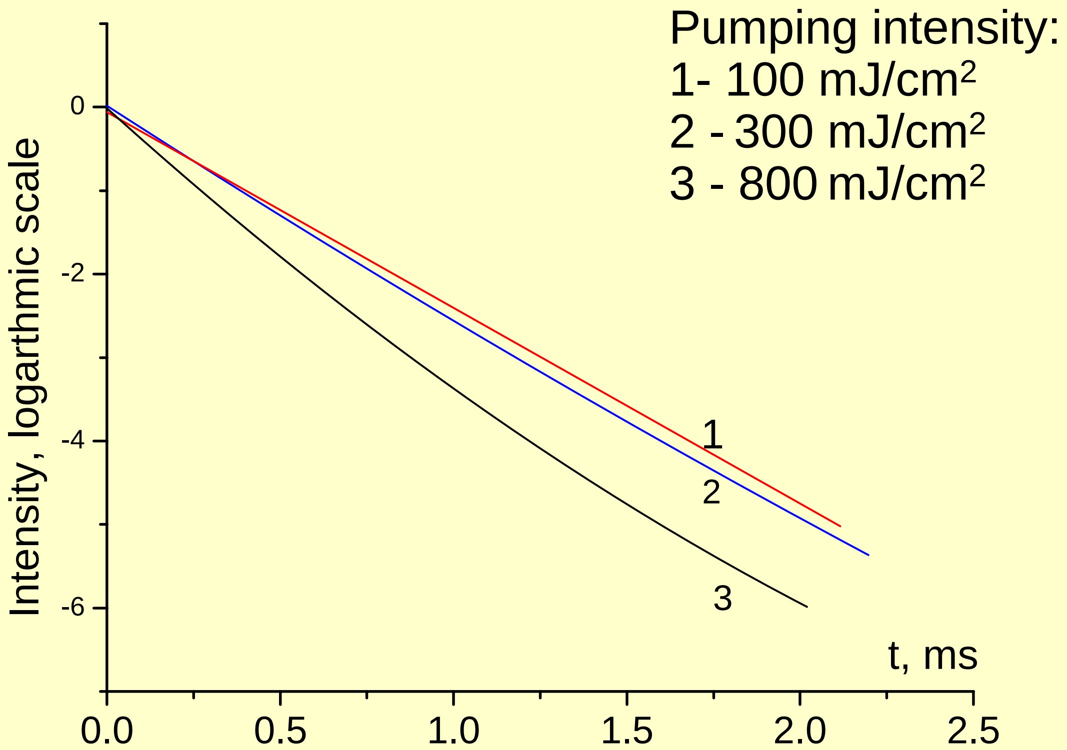
Attendant problems and effects that we are faced with

Angular selectivity of three- dimensional transmitting grating in $Yb{:}\ Gd_3Ga_5O_{12}$



Intensity of diffraction as a function of angle of readout for grating spacing 1,76 (1), 1,1 (2) , 0,87 (3) μm

Up-conversion: the TG lifetime depends on intensity of crystal excitation



Effects of up-conversion gives rise to grating lifetime shortening as the intensity of excitation becomes larger

PHASE SENSITIVE DETECTION

Time dependent light intensity diffracted by transient grating under condition of signal-scattered light interference

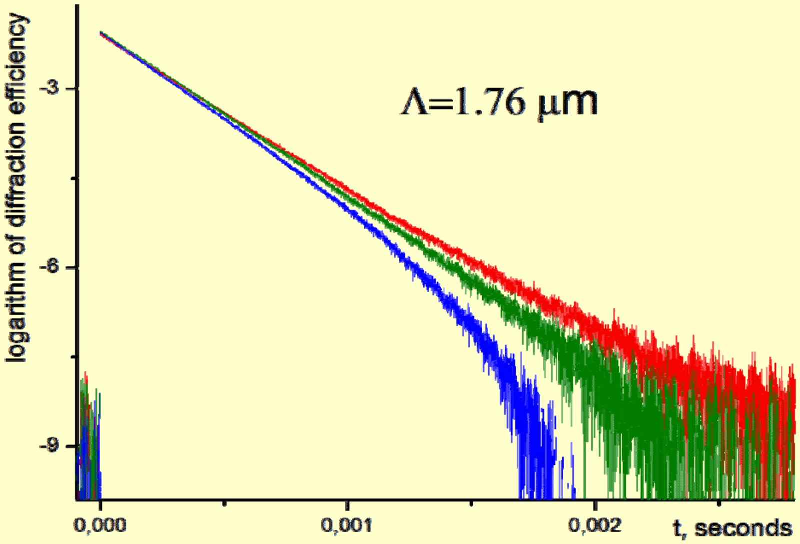
$$I_D(t,\varphi) = I_B + I_D(0)\exp\left(-\frac{2t}{\tau}\right) + 2\gamma\sqrt{I_B I_D(0)}\exp\left(-\frac{t}{\tau}\right)\cos\varphi$$

I_D – diffracted intensity , I_B – intensity of scattered light, γ – degree of coherence, φ - random phase difference between two coherent fields

Summation or subtraction of two π-shifted scans gives

$$I_D(t,\varphi_0) + I_D(t,\varphi_0+\pi) = 2I_B + 2I_D(0)\exp\left(-\frac{2t}{\tau}\right)$$

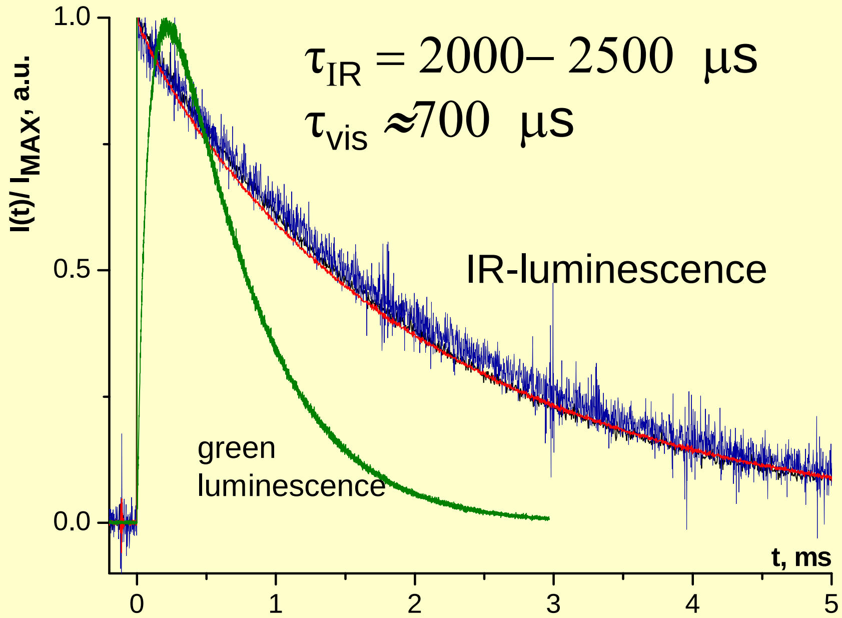
$$I_D(t,\varphi_0) - I_D(t,\varphi_0+\pi) = 4\gamma\sqrt{I_B I_D(0)}\exp\left(-\frac{t}{\tau}\right)$$



Kinetics distortion caused by the scattered light interference for three values of phase difference between two fields.

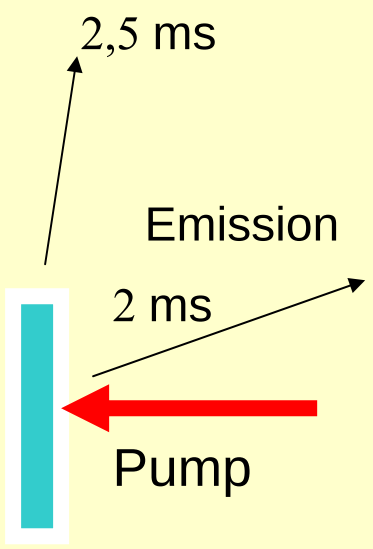
Note: the phase difference φ is not controllable

Spontaneous emission of Yb: $Gd_3Ga_5O_{12}$ in IR and visible under sample pumping at 971 nm



Intensities of IR and vis. emission are found to be linearly and quadratically dependent on the intensity of excitation respectively

The emission re-absorption leads to the time constant increase



Unforeseen product of our studies: the TG method is more reliable for lifetime of excited state measurement in laser crystal in comparison with conventional luminescence study.