Nonlinear optics spectroscopy in glasses doped with nanoparticles

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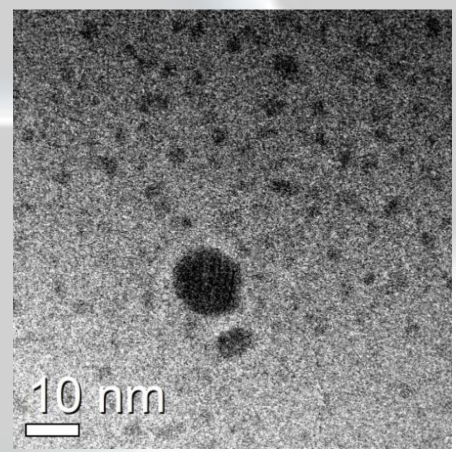
Outline

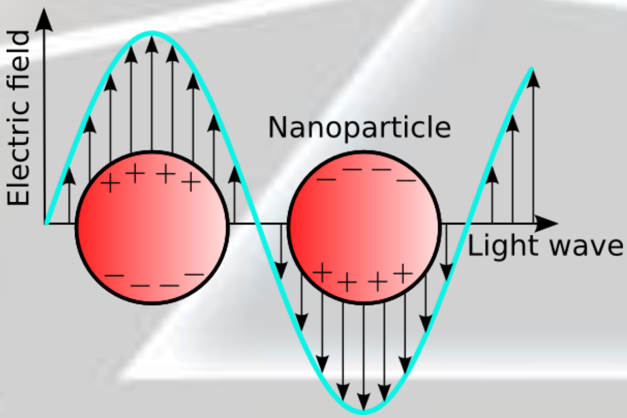
- Motivation
- Background (Nonlinear Optics effect)
- Experimental setup (Z-Scan and WLCZ-Scan and Optical Kerr Gate)
- Experimental results
- Conclusion

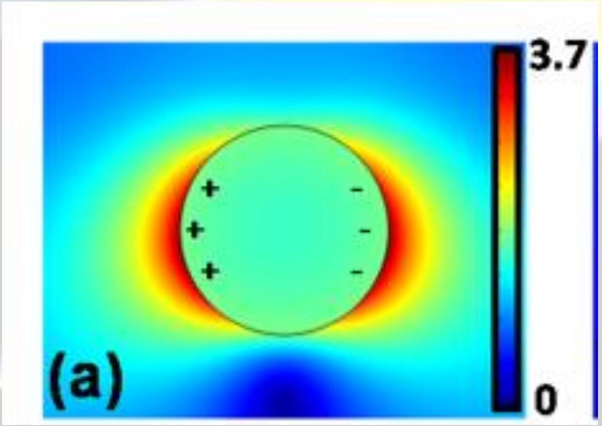


Motivation

Why study nonlinear effect in glasses with nanoparticles ?

• Local field enhancement effect





•They are promising materials for photonic applications: ultrafast response times and high third order nonlinearities

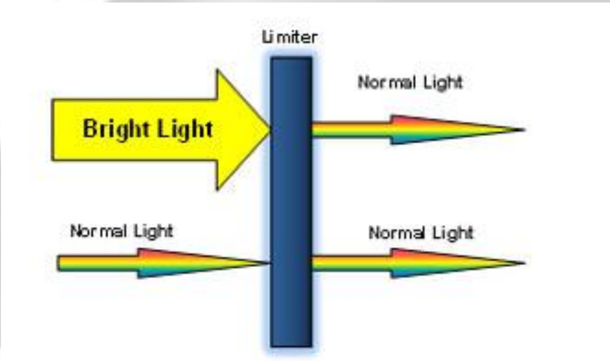
http://physics.aalto.fi/groups/comp/msp/research/plasmonics/

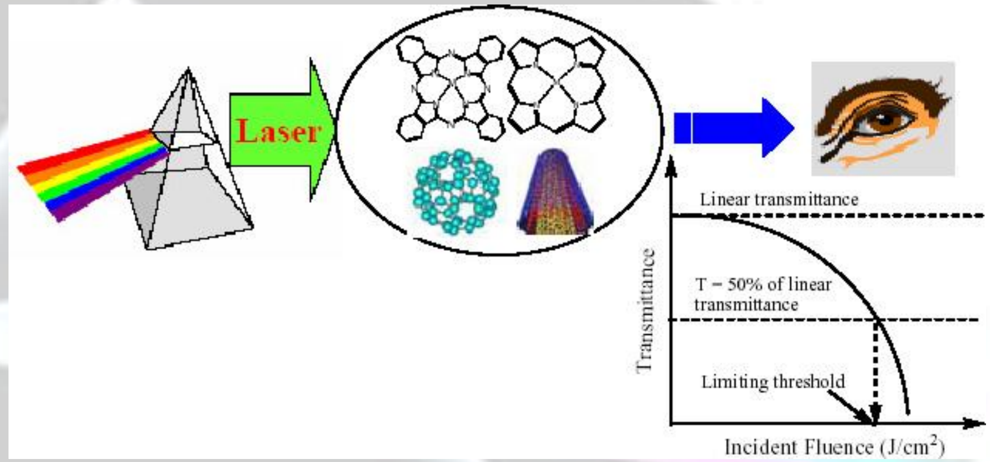
http://www.cpg.ch.cam.ac.uk/Research/StudyOfNearFieldPlasmonicInteractionsForSERS.php

Motivation

- Find new materials with Multi-photon absorption

Optical Limiters



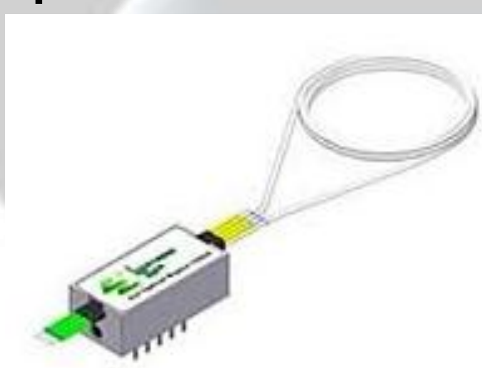


http://www.lightwavelogic.com/applications_optical_filters_limiters.html

http://spie.org/x14682.xml

- Find new materials for telecom

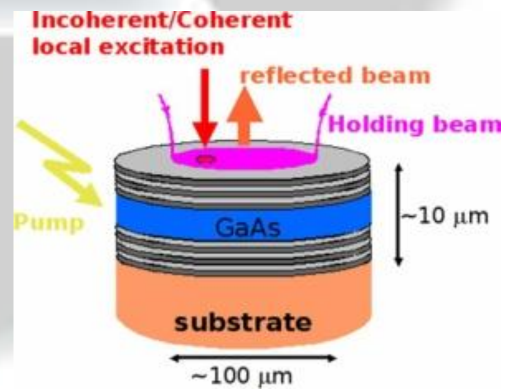
All-Optical Switches



http://www.directindustry.com/prod/lightwavelink/industrial-fiber-optic-switches-36007-718873.html

- Excited state life time

Saturable absorbers



http://www.lpn.cnrs.fr/en/PEQ/AutoOrg_SC.php

Nonlinear Optics

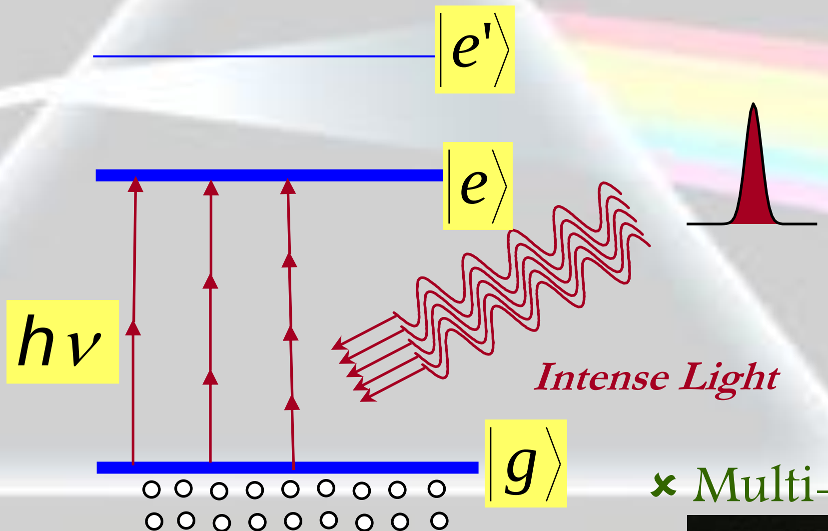
✓ Nonlinear Polarization (transparent midium)

$$P = \chi^{(1)}E + \chi^{(2)}EE + \chi^{(3)}EEE + \chi^{(4)}EEEE + \chi^{(5)}EEEEE \ldots$$

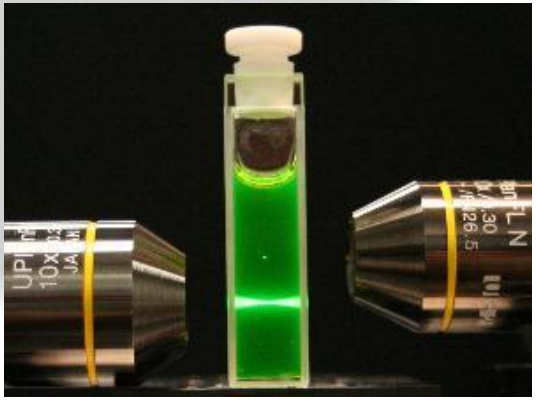
$$\mathrm{Im}\,\chi^{(3)}$$

$$\mathrm{Im}\,\chi^{(5)}$$

$$\mathrm{Im}\,\chi^{(7)}$$



× Multi-photon absorption



Nonlinear absorption

$$\alpha(I) = \cancel{\alpha_0} + \alpha_2 I + \alpha_3 I^2 + \alpha_4 I^3$$

Nonlinear Optics introduction

✓ **Nonlinear Polarization (transparent medium)**

$$P = \chi^{(1)}E + \chi^{(2)}EE + \chi^{(3)}EEE + \chi^{(4)}EEEE + \chi^{(5)}EEEEE \ldots$$

Optical Kerr effect

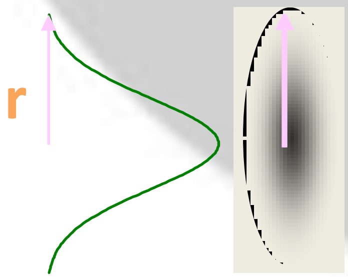
$$\mathrm{Re}\ \chi^{(3)}$$

$$n(I) = n_0 + \Delta n = n_0 + n_2 I$$

$$n_2 = \frac{3\chi^{(3)}}{4n^2\varepsilon_0^2 c}$$

→ Nonlinear refraction

Nonlinear medium



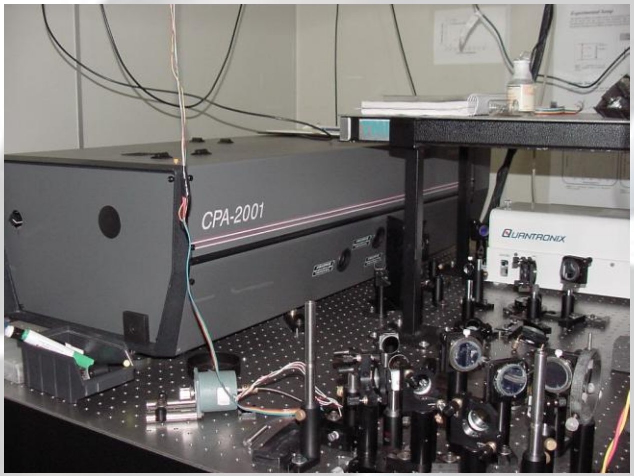
$$\Delta\phi = kn_2 I(r) L$$

Electronic effects

IFSC-USP
Fotônica

Experimental setup

Laser System

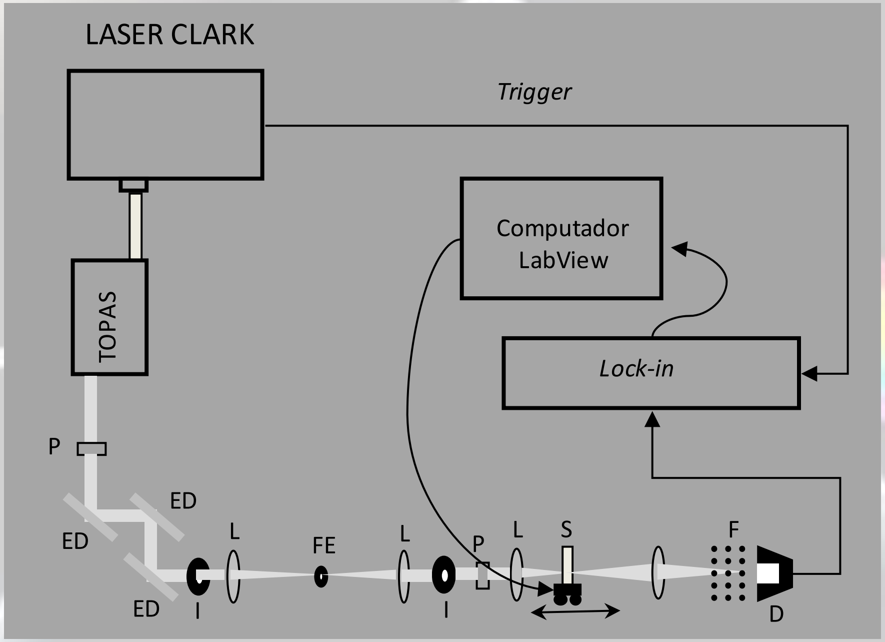


- ✓ *Ti:sapphire chirped pulse amplified system (CPA-2001)*
  - ✓ *775 nm*
  - ✓ *150 fs*
  - ✓ *800 μJ*

- ✓ *Optical parametric amplifier (TOPAS)*
  - ✓ *460 - 2600 nm*
  - ✓ *≈120 fs*
  - ✓ *20-60 μJ*

Experimental setup

Z-scan technique



To obtain the spectrum of the nonlinear effect

$$T = \frac{1}{\sqrt{\pi} q_0(z,0)} \int_{-\infty}^{\infty} \ln[1 + q_0(z,0) e^{-\tau^2}] d\tau$$

$$q_0(z,t) = \frac{\beta I_0(t) L}{1 + z^2 / z_0^2}$$

$$T(z, \Delta\phi_0) = 1 + \frac{4\Delta\phi_0 x}{(x^2+9)(x^2+1)}$$

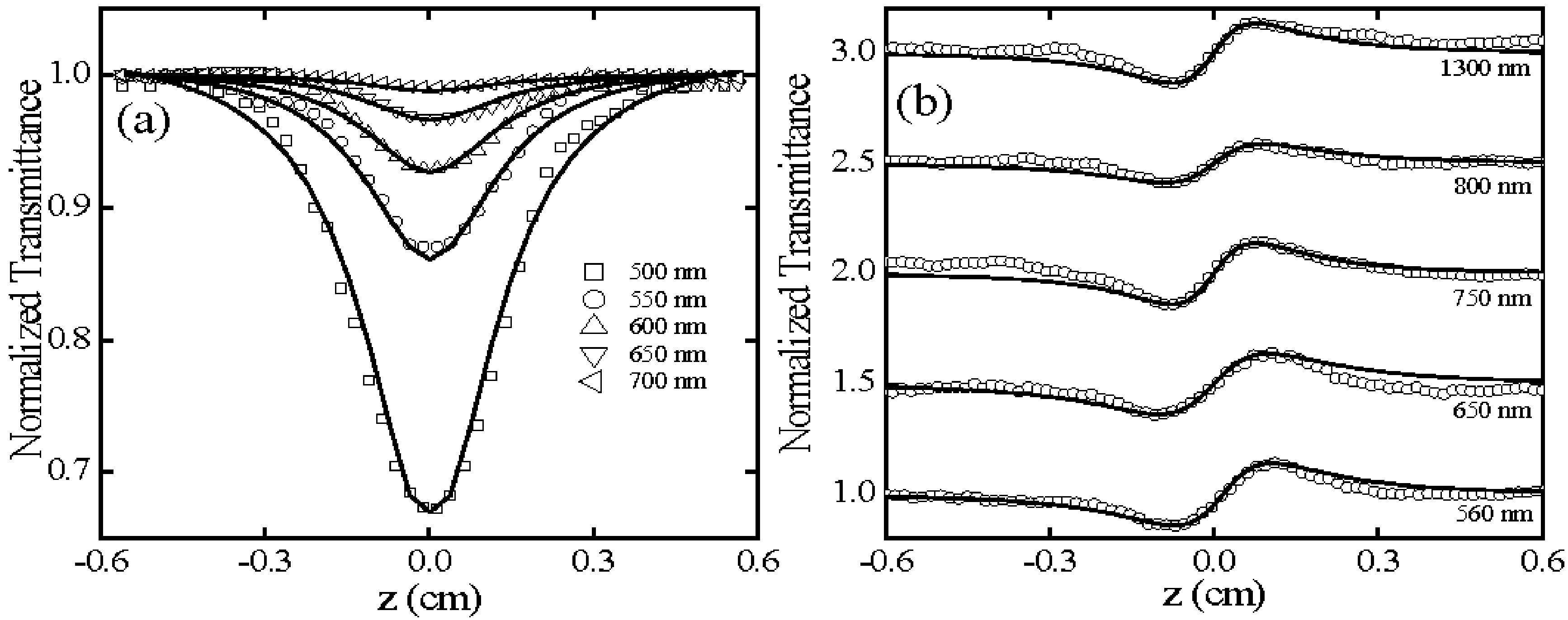
$$\Delta\phi_0 = k n_2 I_0 L.$$

Sheik-Bahae, M. et al.., IEEE J. Quantum Elect. 1990, 26, 760-769

De Boni L *et al* Optics Express, Opt. Express, 12, 3921-3927 (2004)

Z–scan Results

Traditional Z-scan



WLC Z-scan

Typical (a) open- and (b) closed-aperture Z-scan curves obtained at several wavelengths. The solid lines represent fittings.

The pulse energy and the beam waist used in the open aperture Z-scan are 34 nJ and 16 µm for 500 nm, 29 nJ and 17 µm for 550 nm, 27 nJ and 18 µm for 600 nm, 23 nJ and 19 µm for 650 nm, 19 nJ and 20 µm for 700. The pulse energy and the beam waist used in the closed aperture Z-scan are 8 nJ and 16 µm for 560 nm, 16 nJ and 17µm for 650 nm, 16 nJ and 18 µm for 750, 17 nJ and 18.5 µm for 800 nm and 62 nJ and 20 µm for 1300 nm.

De Boni L *et al* Optics Express, 20, 6844- 6850 (2012)

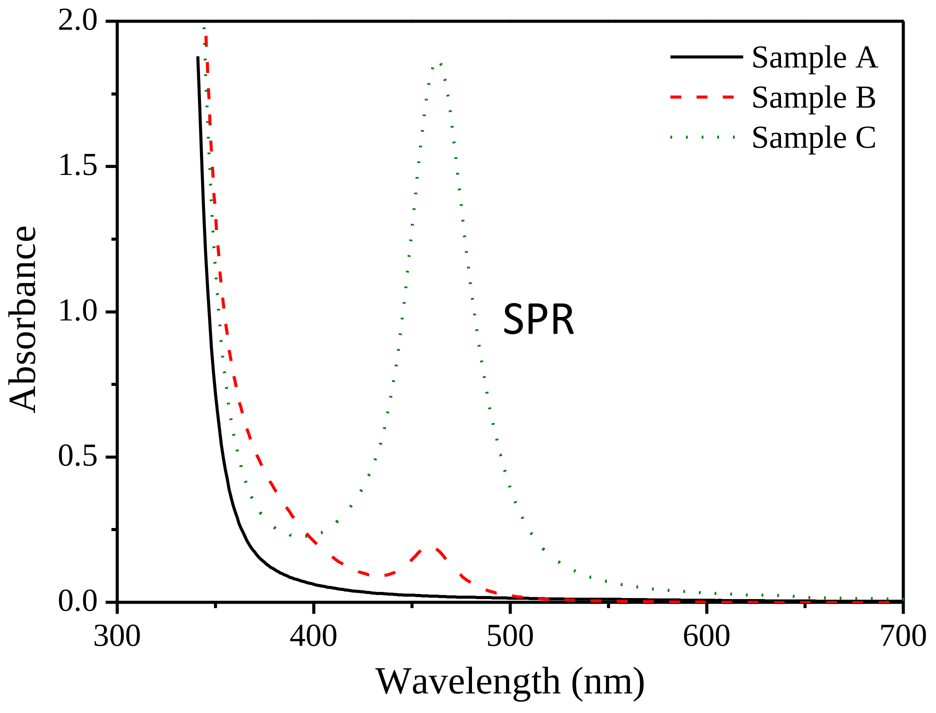
Lead–germanium oxide glasses + Ag

59PbO-41GeO$_2$ (in wt. %) for glass host (sample A)

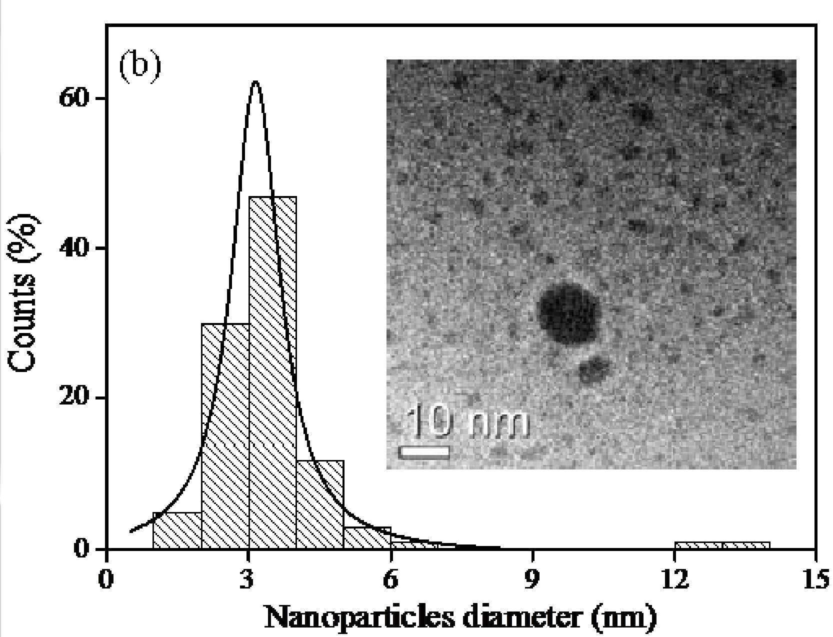
+

AgNO$_3$ (5.0 wt. %)

Annealed:
- 420 °C for 1 h (sample B)
- 480°C for 3 h (sample C)



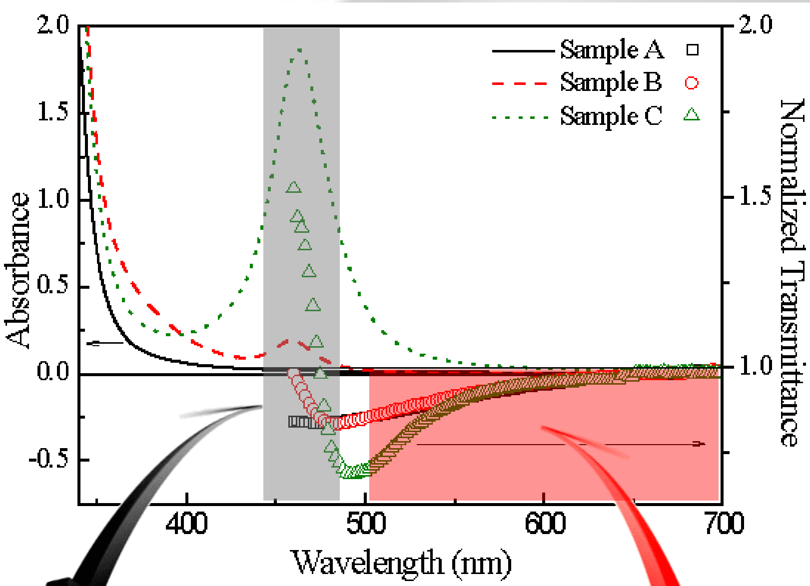
Filling factor of about **2%** for sample C



The inset shows the image of Ag NPs investigated with a high resolution TEM

De Boni L *et al* Optics Express, 20, 6844- 6850 (2012)

Two-photon absorption spectra

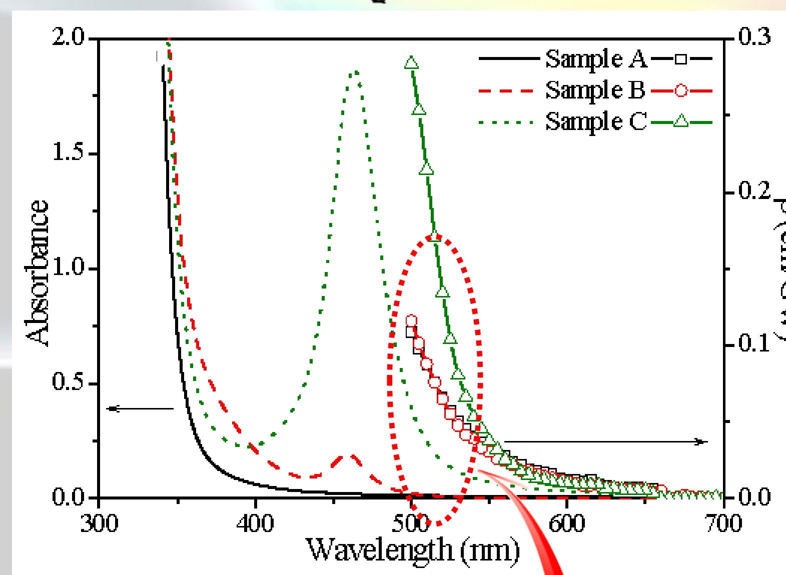


$$T = \frac{1}{\sqrt{\pi} q_0(z,0)} \int_{-\infty}^{\infty} \ln[1+q_0(z,0)e^{-\tau^2}]d\tau$$

$$q_0(z,t) = \frac{\beta I_0(t)L}{1+z^2/z_0^2}$$

Saturable absorption

Two-photon absorption



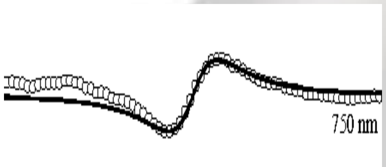
Enhancement effect

This increment is *attributed to an interband transition in the Ag nanoparticles, also mediated by a 2PA excitation.*

Qu S. *et al* Opt. Mater. **28(3), 259–265 (2006).**

De Boni L *et al* Optics Express, 20, 6844- 6850 (2012)

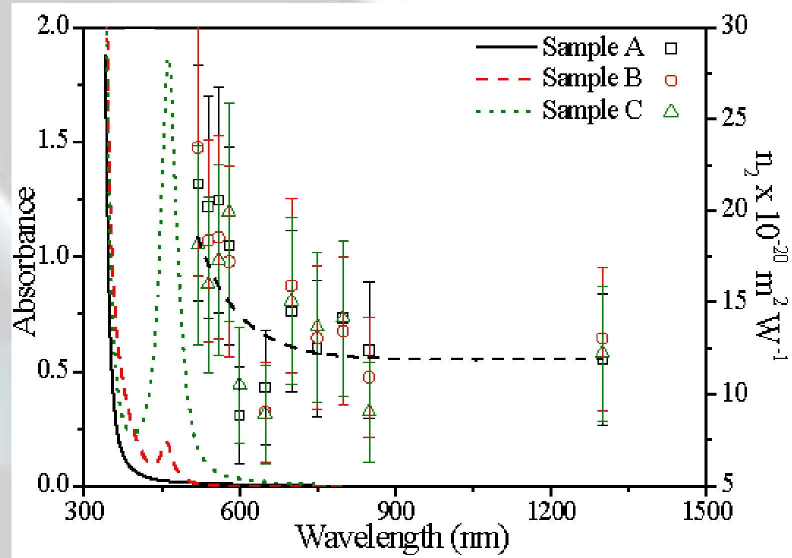
Nonlinear refraction spectra



$$T(z,\Delta\phi_0) = 1 + \frac{4\Delta\phi_0 x}{(x^2+9)(x^2+1)}$$

$$\Delta\phi_0 = k n_2 I_0 L.$$

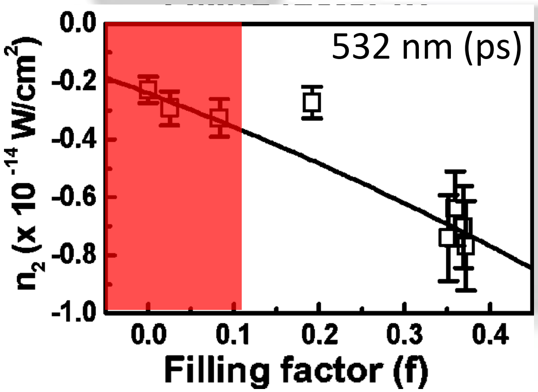
De Boni L *et al* Optics Express, 20, 6844- 6850 (2012)

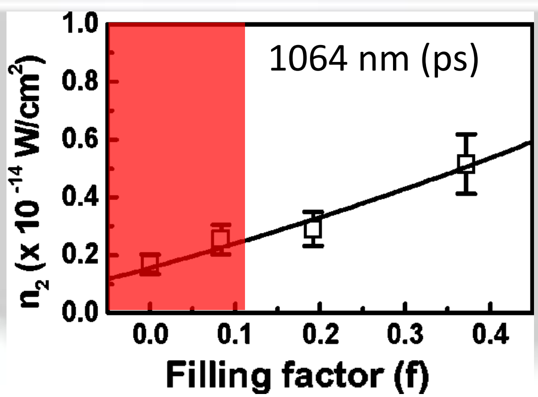


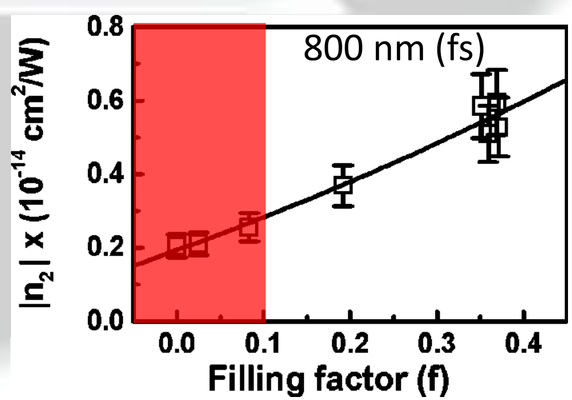
Same value → glass host

Transparent glass ceramic containing sodium niobate nanocrystals.

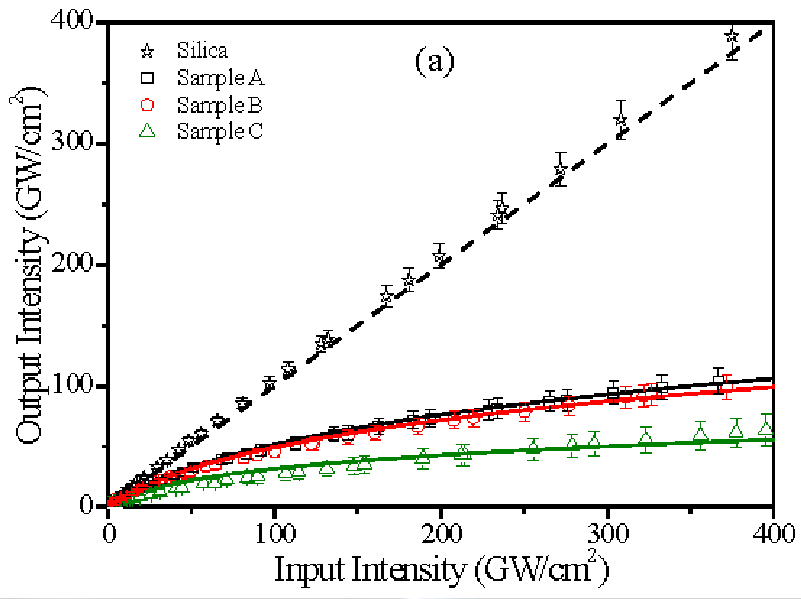
Falcão-Filho E *et al* Phys. Rev. B **69(13), 134204 (2004).**







Optical limiting effect



$$W = \Delta n_{max} / \lambda \alpha_0$$

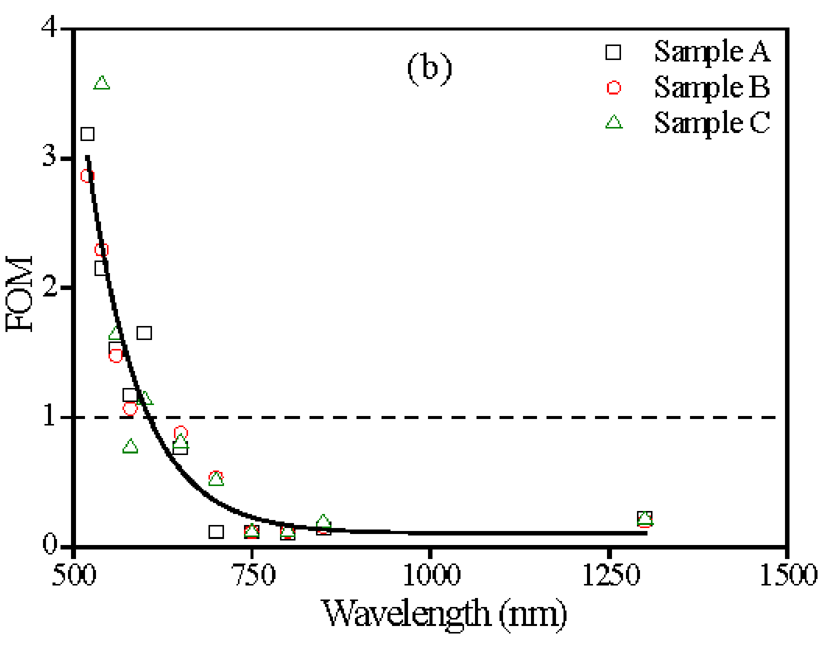
$$FOM = 2\beta\lambda / n_2$$

α_0 is very small

W>2

→ All-optical switch
GOOD

$$FOM < 1$$



De Boni L *et al* Optics Express, 20, 6844- 6850 (2012)

Tungsten Lead–Pyrophosphate + Cu

$70Pb_2P_2O_7$-$30WO_3$ (in wt. %) for glass host

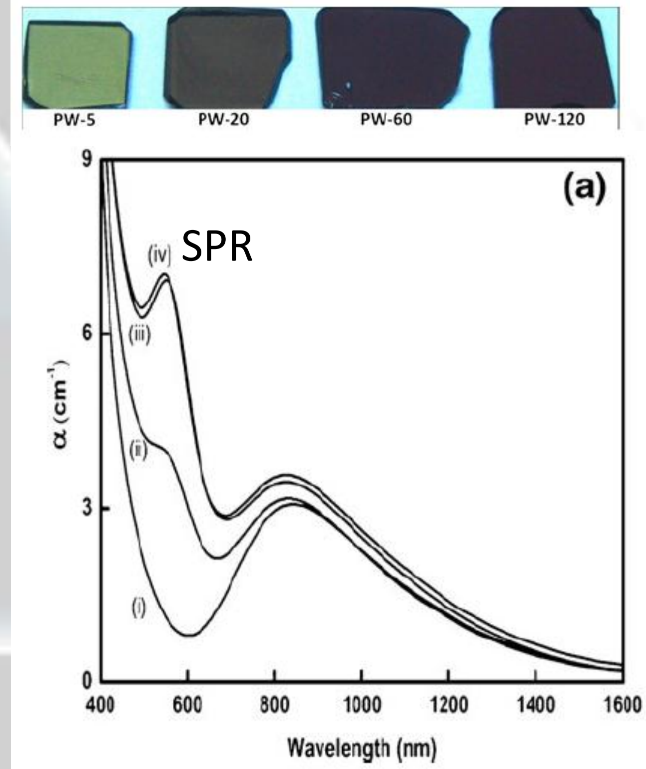
+

CuO (0.5 wt. %)

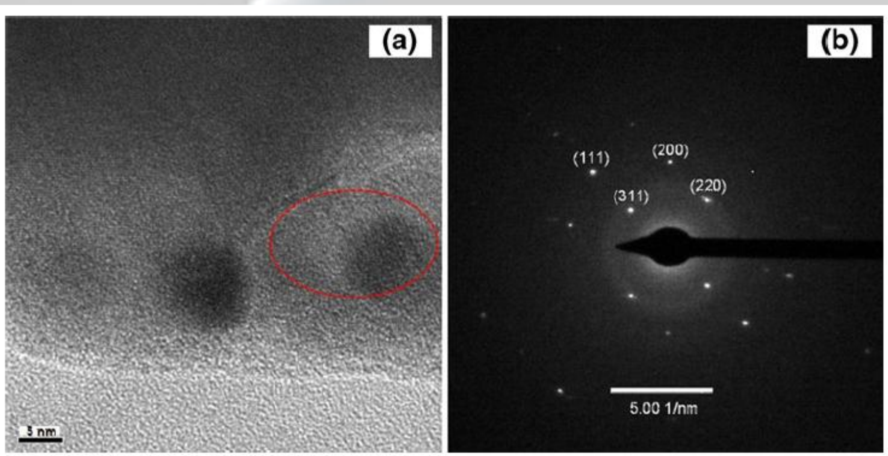
Table 1 Sample labels, synthesis conditions, and characteristic temperatures of PW glasses doped with CuO

	Sample labels	Annealing conditions		Characteristic temperatures	
		T_{ht} (°C)	t_{ht} (min)	T_g (°C)	T_x (°C)
(i)	PW-0		0		
(ii)	PW-5		5		
(iii)	PW-20	410 +	20	410	575
	PW-60		60		
(iv)	PW-120		120		

Changes in color



(a) Cu NPs investigated with a high resolution TEM



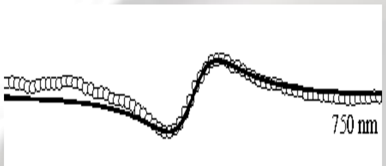
(b) Crystallographic planes of cubic Cu structure NPs

Manzani *et al* , Plasmonics, (2013)

Nonlinear refraction and Absorption

IFSC-USP
Fotônica

$$T(z,\Delta\phi_0) = 1 + \frac{4\Delta\phi_0 x}{(x^2+9)(x^2+1)}$$

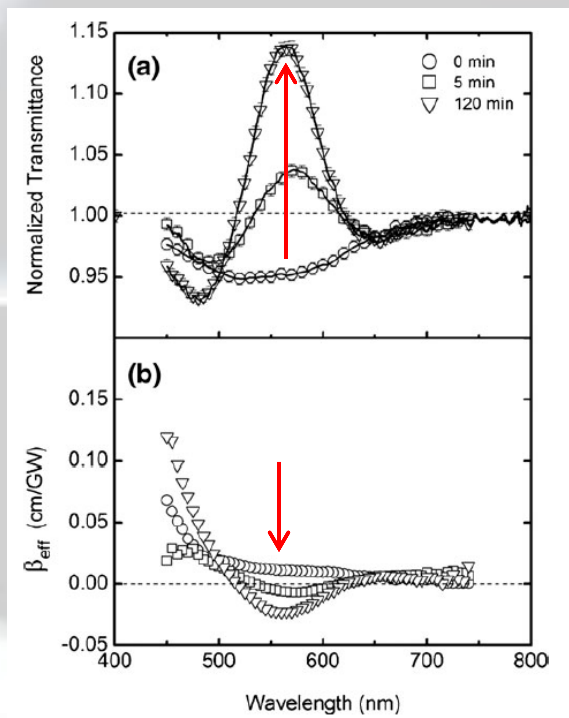


$$\Delta\phi_0 = kn_2I_0L.$$

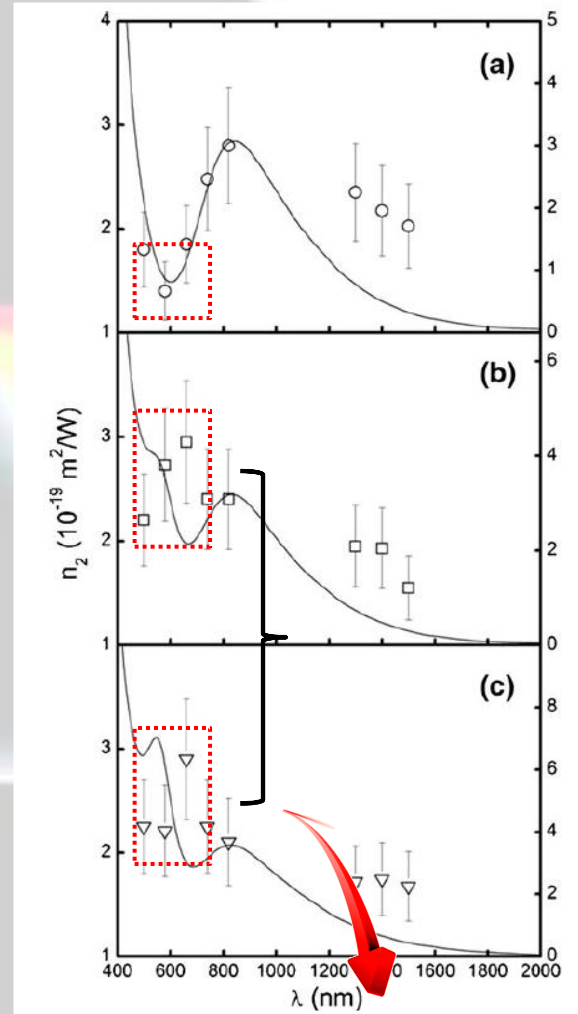
Nonlinear Absorption spectra

$$T = \frac{1}{\sqrt{\pi}q_0(z,0)}\int_{-\infty}^{\infty}\ln[1+q_0(z,0)e^{-\tau^2}]d\tau$$

$$q_0(z,t) = \frac{\beta I_0(t)L}{1+z^2/z_0^2}$$



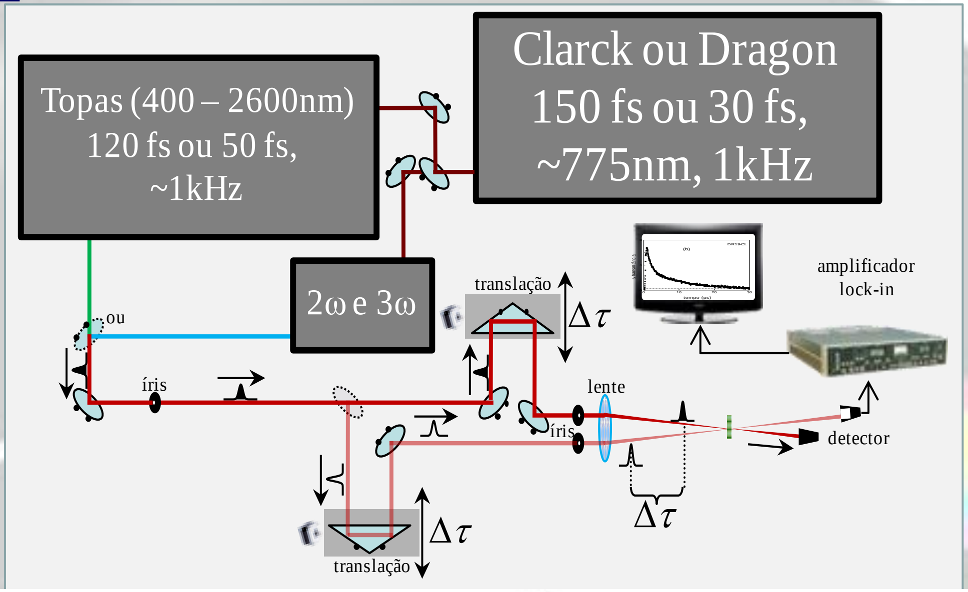
Inversion of the effect



Enhancement effect

Manzani *et al* , Plasmonics, (2013)

Optical Kerr Gate effect



Outside of the Plasmon band

780 nm

200 fs

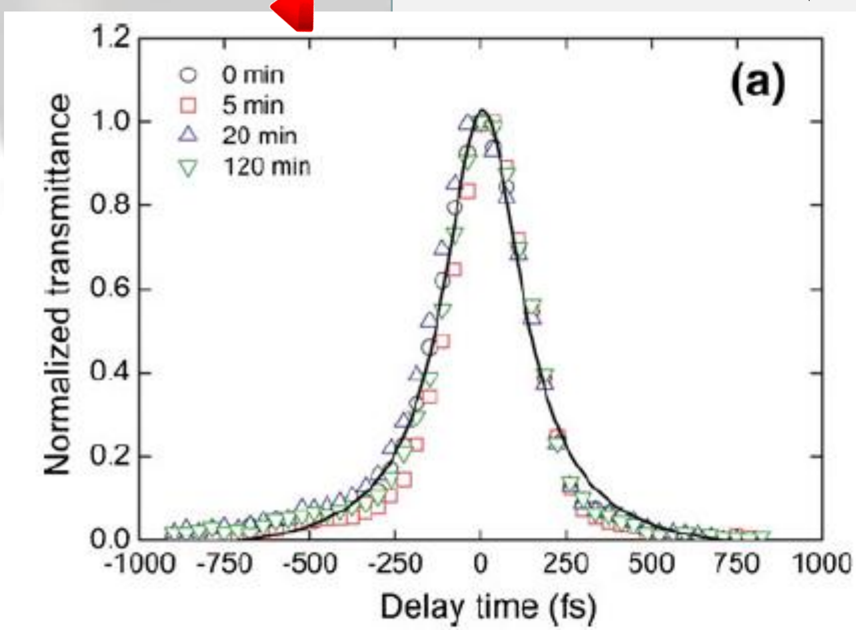
FAST

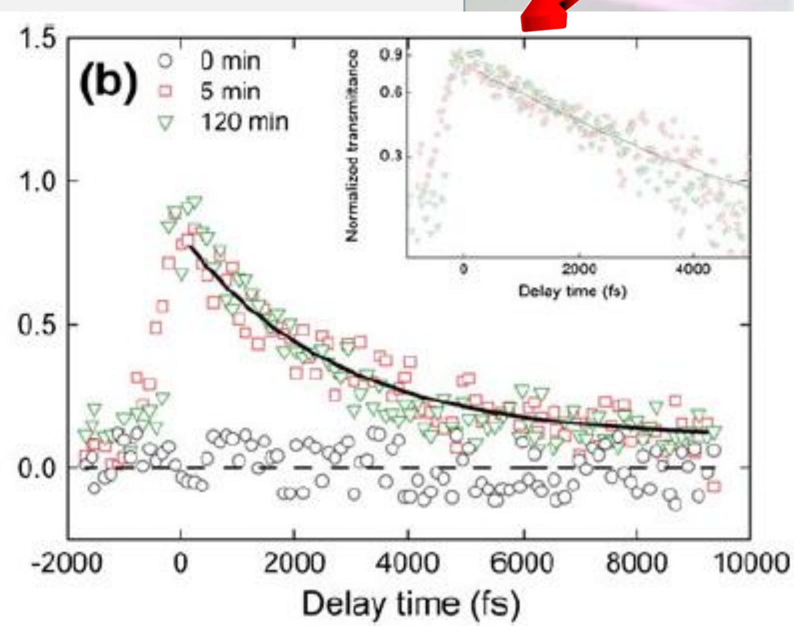
Inside of the Plasmon band

560 nm

2.3 ps

SLOW





Manzani *et al* , Plasmonics, (2013)

Heavy metal oxide glasses + Au

58.4 GeO_2–41.6 Bi_2O_3 (in wt. %) for glass host

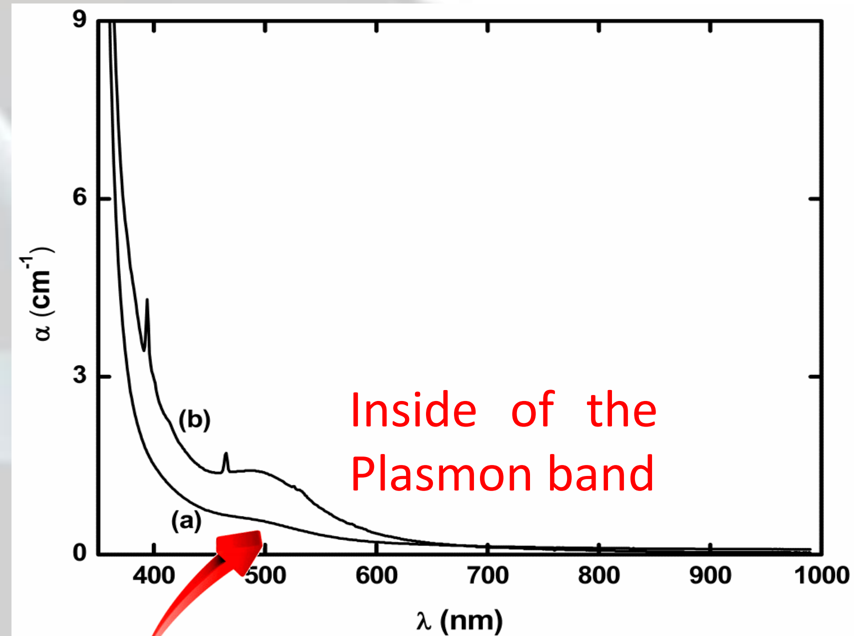
+

$3Au_2O_3 - 0.5Eu_2O_3$ (wt%)

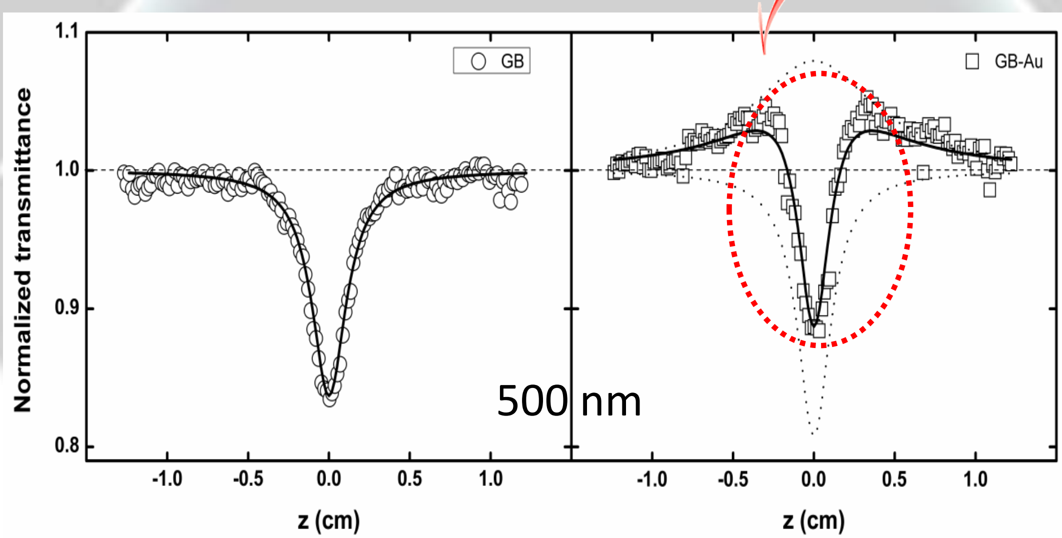
Nonlinear Absorption spectra

$$T = \frac{1}{\sqrt{\pi} q_0(z,0)} \int_{-\infty}^{\infty} \ln[1 + q_0(z,0) e^{-\tau^2}] d\tau$$

$$q_0(z,t) = \frac{\beta I_0(t) L}{1 + z^2 / z_0^2}$$



Inside of the Plasmon band



Two-photon Absorption

Two-photon Absorption + Saturable absorption

Manzani *et al* , Plasmonics, (2013)

Heavy metal oxide glasses + Au

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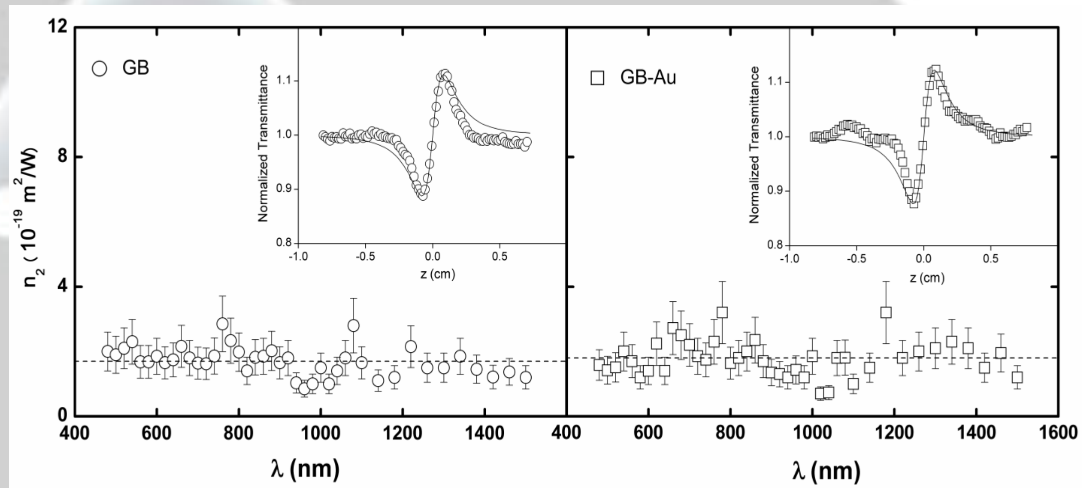
+

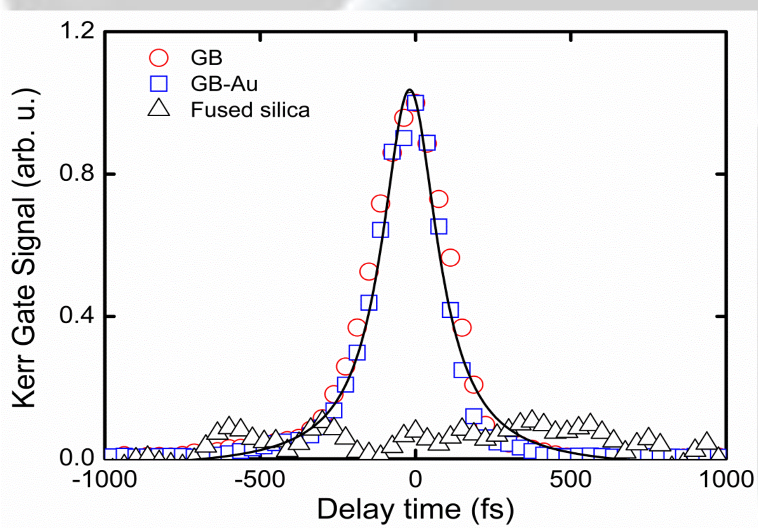
3Au_2O_3 – 0.5Eu_2O_3 (wt%)

$$T(z,\Delta\phi_0) = 1 + \frac{4\Delta\phi_0 x}{(x^2+9)(x^2+1)}$$

$$\Delta\phi_0 = k n_2 I_0 L.$$

Nonlinear refraction spectra





Outside of the Plasmon band

780 nm

~200 fs

FAST

Manzani *et al* , Plasmonics, (2013)

Conclusion

- **Saturable** and **two-photon** absorption were observed

plasmon band

Increased because of *an* ***interband transition*** *in the case of Ag nanoparticles*

- **Nonlinear refraction** was observed to be the **same**

10 times higher *than fused silica*

low filling factor Ag and Au

- **Optical limiting effect** was observed to increase a factor of **2** due to the AgNP

- Samples can be used as **optical limiters**, **all-optical switches** and **saturble absorbers** because of the distinct response times

FAST SLOW

Acknowledgements

FAPESP

CNPq

CAPES

Thank you