



HAL
open science

2D/3D Optical Data Storage in Polymers with Nonlinear Microscopy

Denis Gindre

► **To cite this version:**

Denis Gindre. 2D/3D Optical Data Storage in Polymers with Nonlinear Microscopy. 3rd International Workshop on Nano and Bio-Photonics (IWNBP 2015), 2015, Cabourg, France. hal-02564173

HAL Id: hal-02564173

<https://univ-angers.hal.science/hal-02564173>

Submitted on 19 Nov 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



2D/3D Optical Data Storage in Polymers with Nonlinear Microscopy

Denis Gindre

**Laboratoire MOLTECH-Anjou,
UMR CNRS 6200
Université d'Angers
France**

Introduction

Two-photon processes for Optical Data Storage

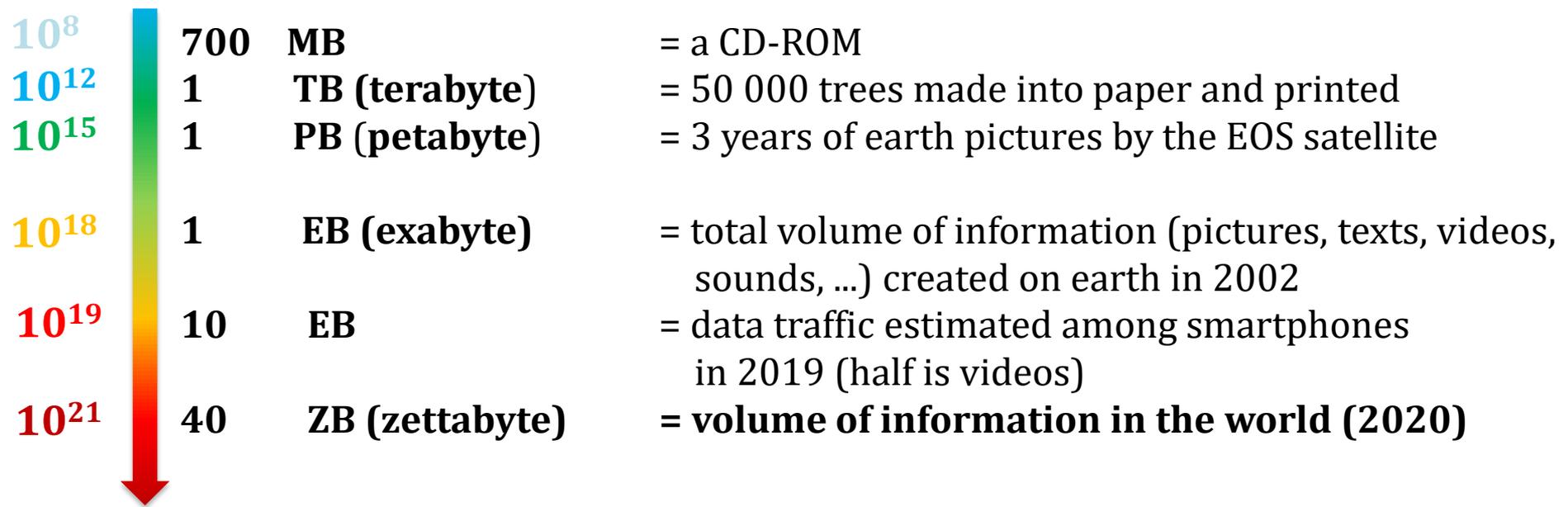
Data storage by photoinduced isomerization of azobenzenes

Data storage by photoinduced cross-linking of coumarins

Image and 3D storage / tagging

Conclusion

The digital revolution



7 TB/day
(2013)



10 TB/day
(2013)



50 TB/day
Radio telescope Square
Kilometer Array (2020)



Story of Data Storage

1,44 MB



1982

Flask Disk 8 MB



2000

Hard Drive
1 TB



2006

iPhone
16 GB



2007

SSD
Solid State Drive
1 TB



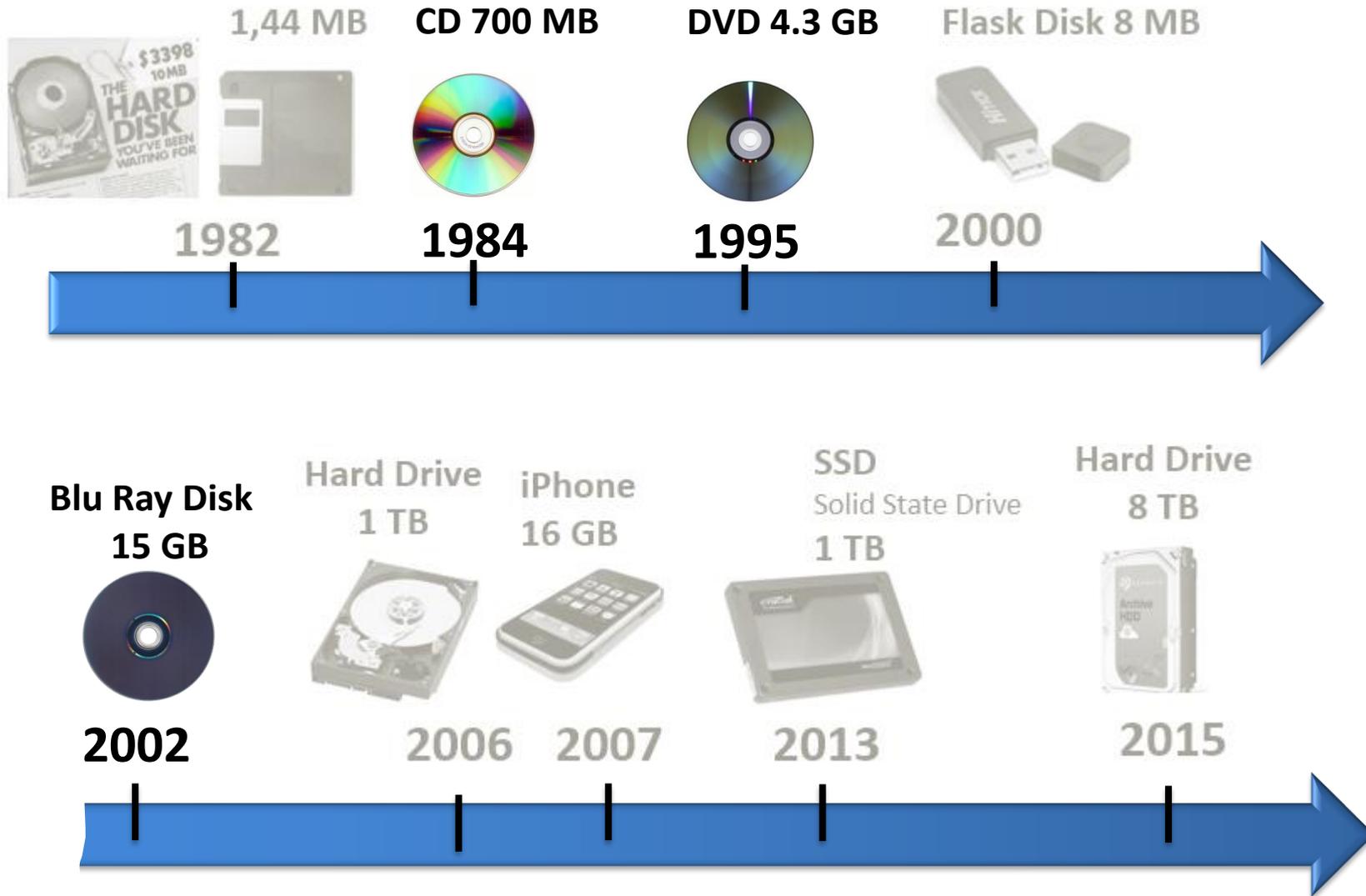
2013

Hard Drive
8 TB

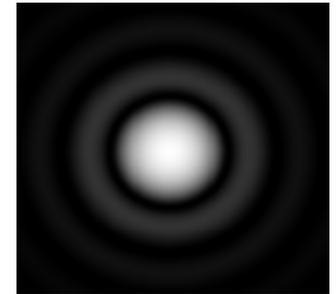


2015

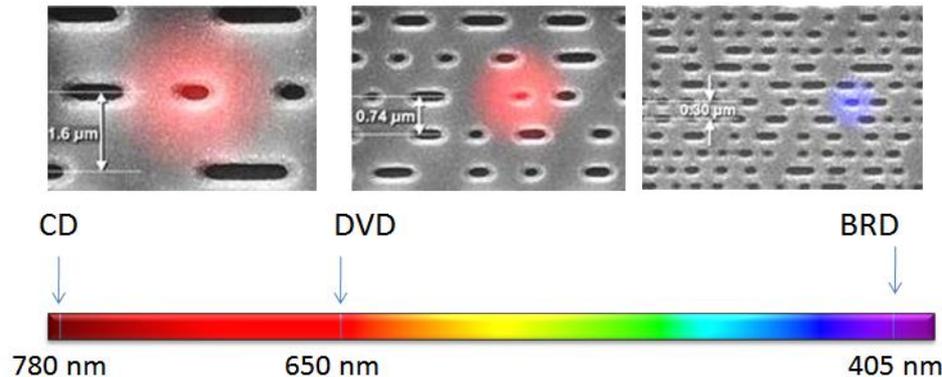
Story of **Optical** Data Storage



The size of the spot (Airy disk) is limited by the diffraction



$$\sin \theta = 1.22 \frac{\lambda}{d}$$



**The
(potential)
future of
optical data
storage**

- **Near Field Optics**

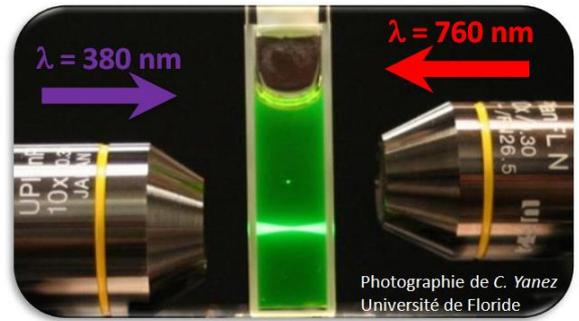
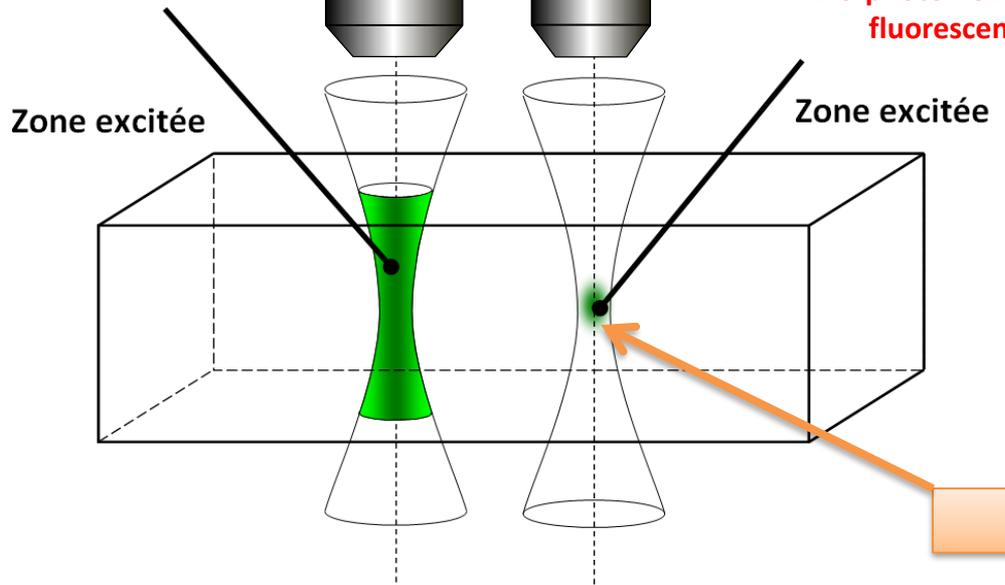
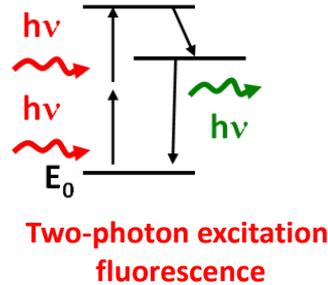
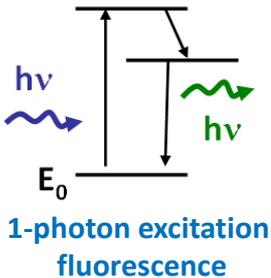
to avoid the diffraction limit with evanescent waves

- **Volume storage**

Holographic disks

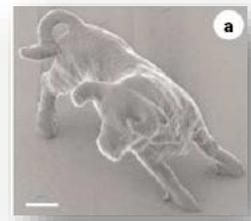
Multi-photonic and non linear optical processes

With the help of nonlinear optical processes, data bits can be recorded in the deep volume of the material.

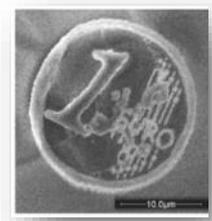


Voxel with sub- λ size

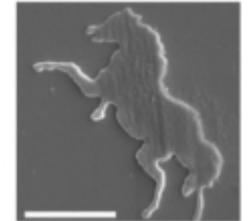
Application :
Nanofabrication by polymerization induced by 2-photon absorption



S. Kawata, *Nature*, 2001

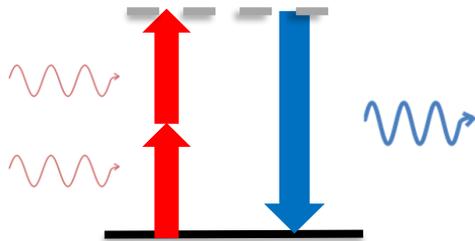


P. Baldeck, *Optics Letters*, 2002



K. S. Lee, *Prog Polym Science*, 2008 (review)

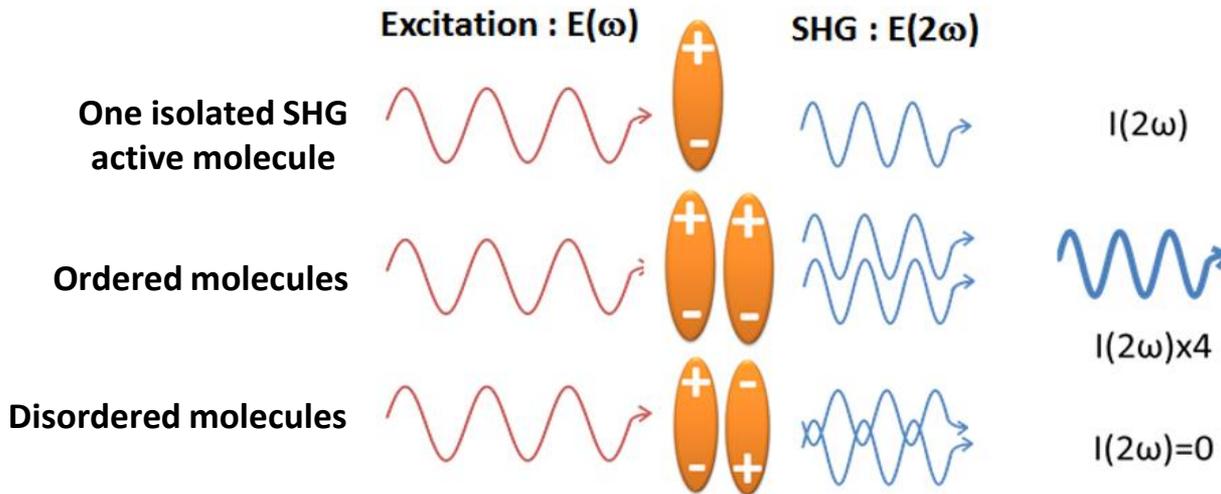
Second Harmonic Generation (SHG)



Induced polarization : $\vec{p} = \alpha \vec{E} + \beta \vec{E}\vec{E} + \dots$

linear nonlinear

SHG $\neq 0 \Rightarrow \beta \neq 0 \Rightarrow$ non centro-symmetry of the material
 SHG efficiency \Rightarrow density of the molecules

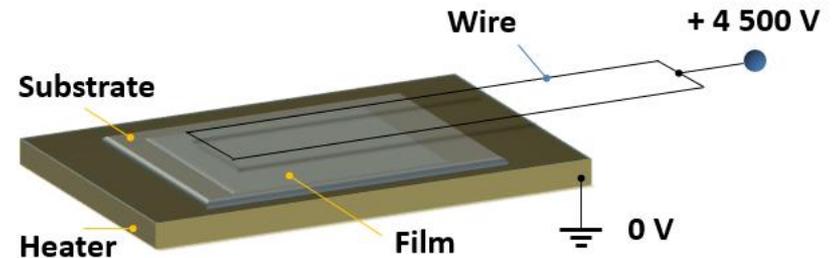
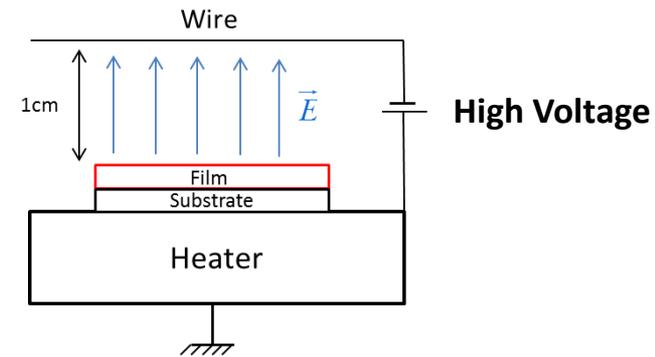


Necessity of molecular orientation

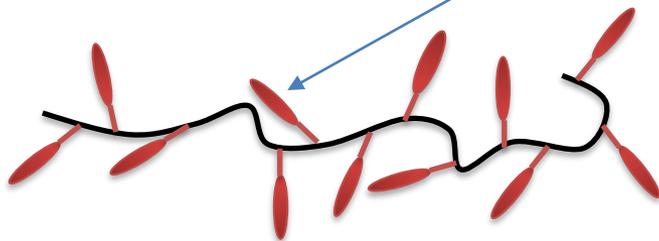
Chromophores orientation

Corona poling

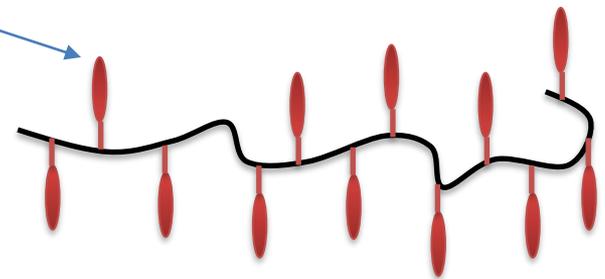
A high static electric field is applied into the film of copolymers. The temperature of the film is just below the glass transition temperature (T_g)



Drafted chromophores



Corona poling



Data storage with azobenzenes

Optical Data storage by photoinduced isomerization of azobenzenes

Chromophores : Disperse Red 1 (DR1) **grafted** to PMMA

- ▶ photo-induced *cis-trans* isomerisation
- ▶ Photo-induced molecular movements
- ▶ Loss of the initial order

▶ photoinduced depoling

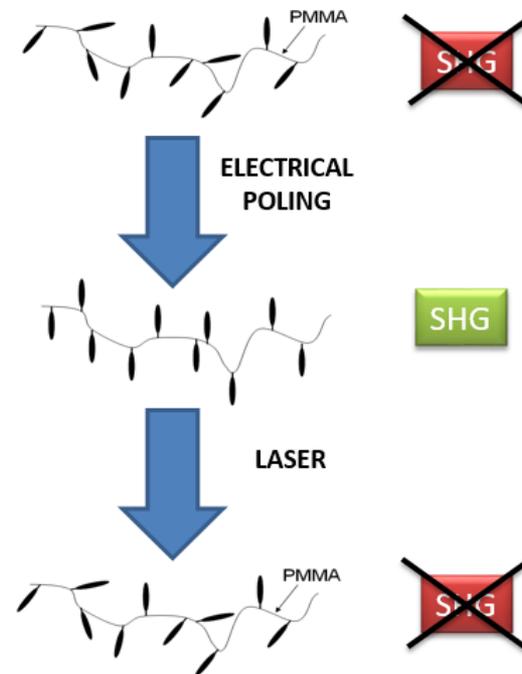
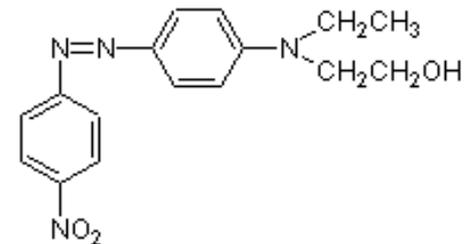
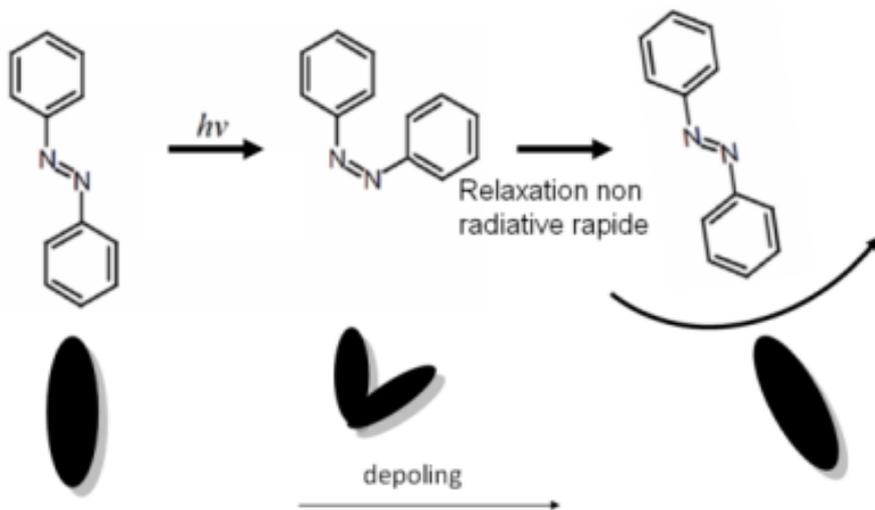
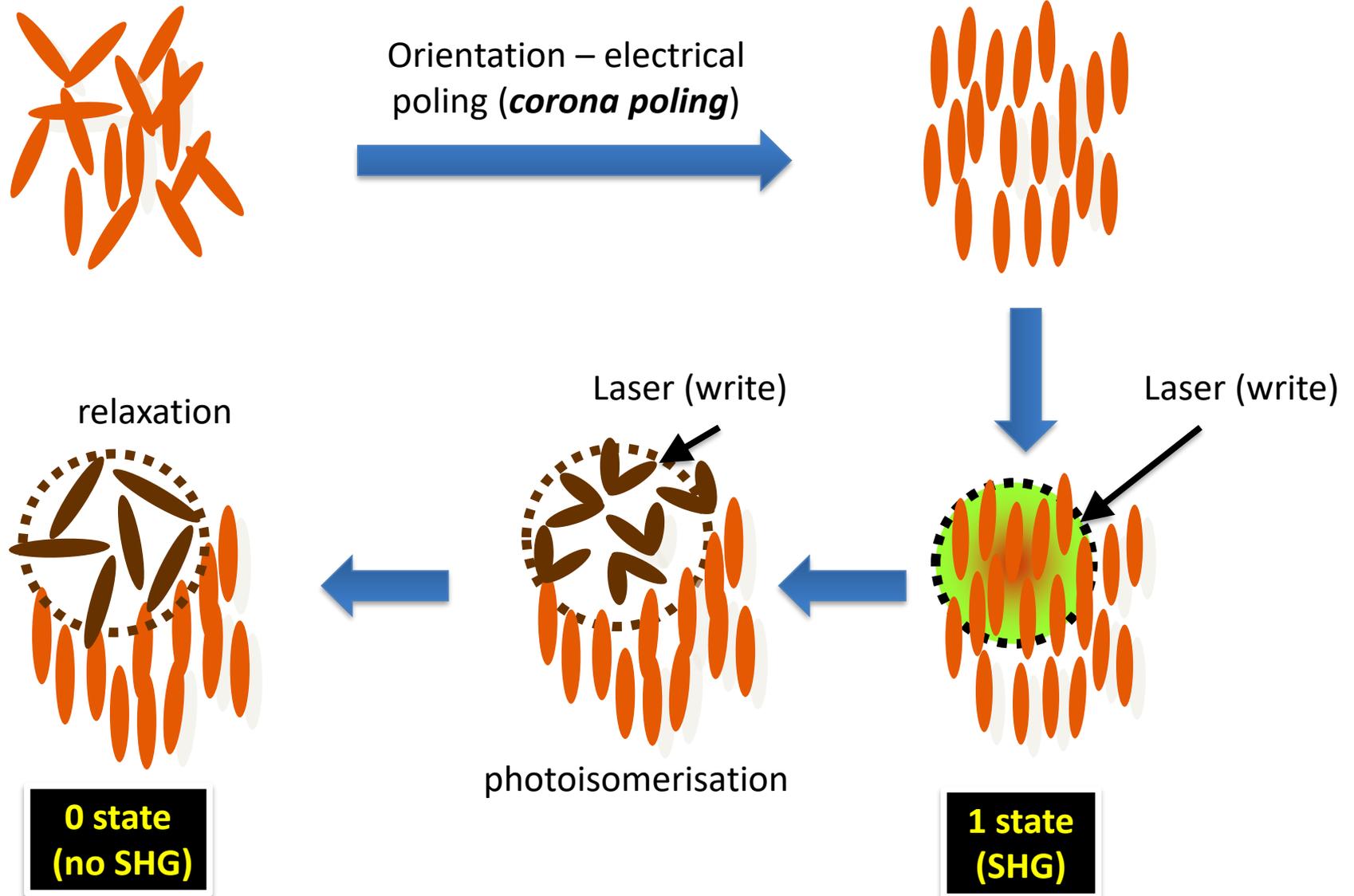
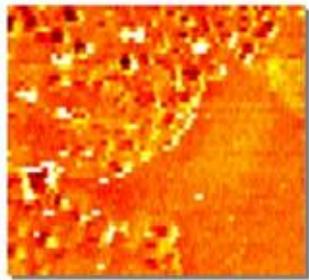


Photo-induced depoling principle



binary data storage by photoinduced depoling

Readout P = 2 mW

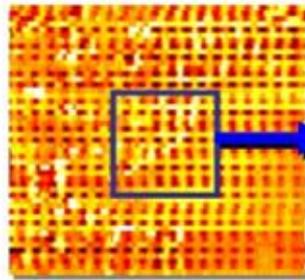


50 μm

Initial SHG scan

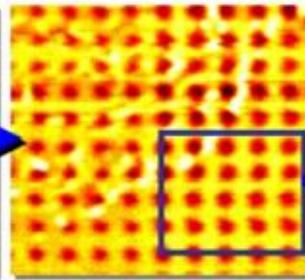


Readout P = 2 mW



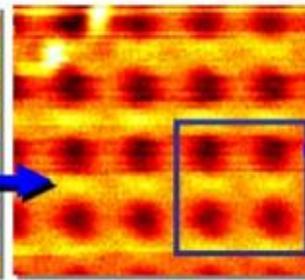
50 μm

1st SHG scan



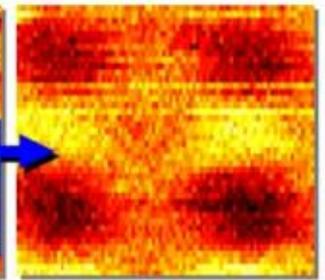
20 μm

2nd SHG scan



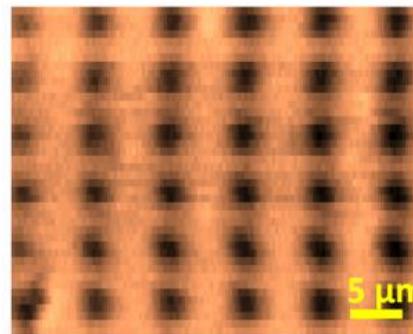
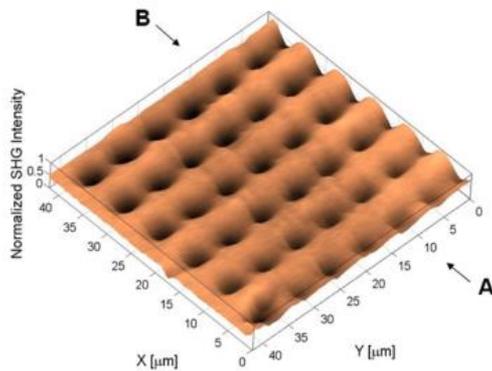
10 μm

3rd SHG scan



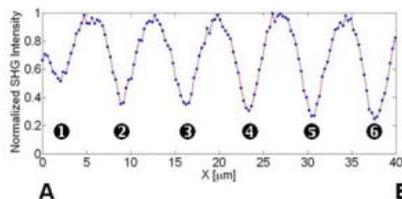
5 μm

4th SHG scan



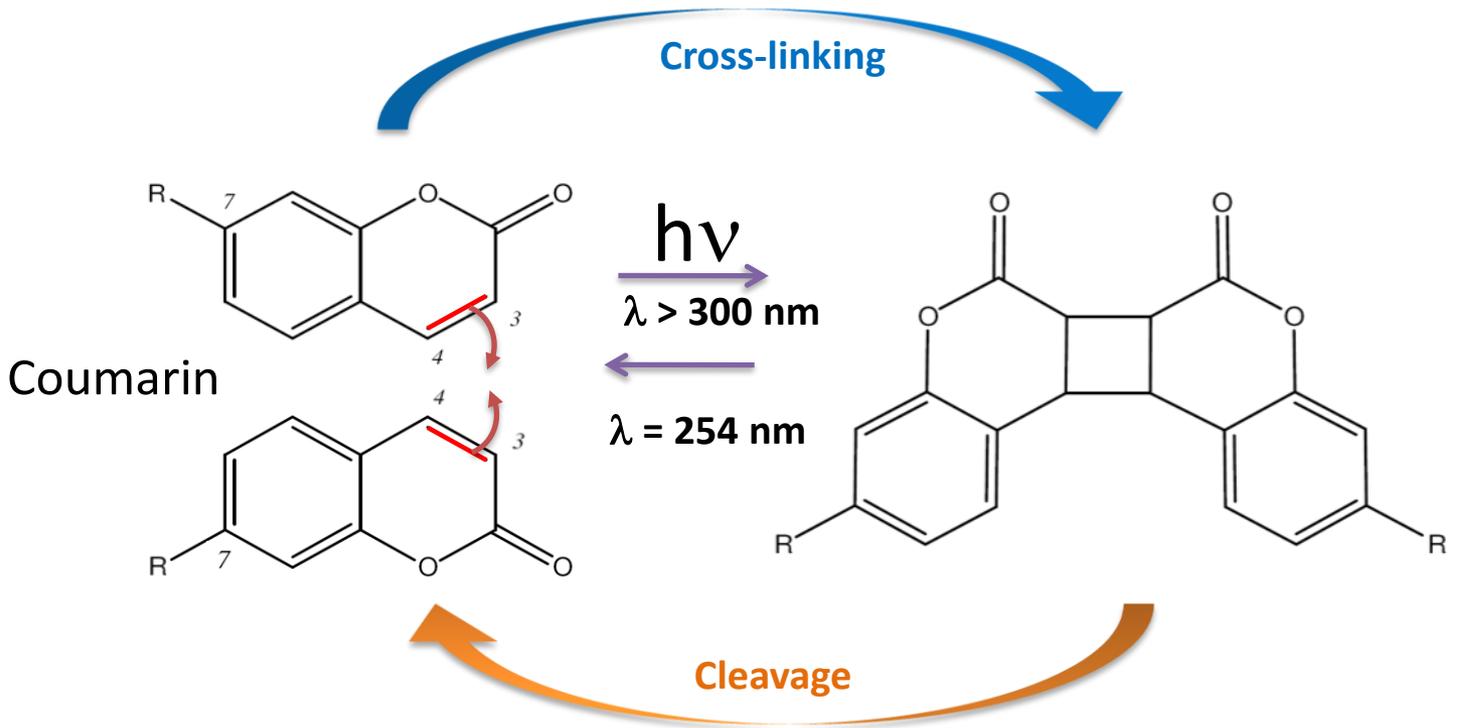
30 ms
60 ms
90 ms
120 ms
150 ms
180 ms

Write : $P_{\text{laser}} = 30 \mu\text{W}$
Read $P_{\text{laser}} = 4.5 \mu\text{W}$



- D. Gindre *et al* , App. Phys. Lett., 90, 9, 094103 (2007)
- D. Gindre *et al* , J. Opt. Soc. Am. B, 24, 532 (2007)
- D. Gindre *et al* , Opt. Exp., 14, 9896 (2006)
- A. Fort *et al* , Patent 0651627 (2006). US 12/226.980 (2008).

ODS by photoinduced dimerisation

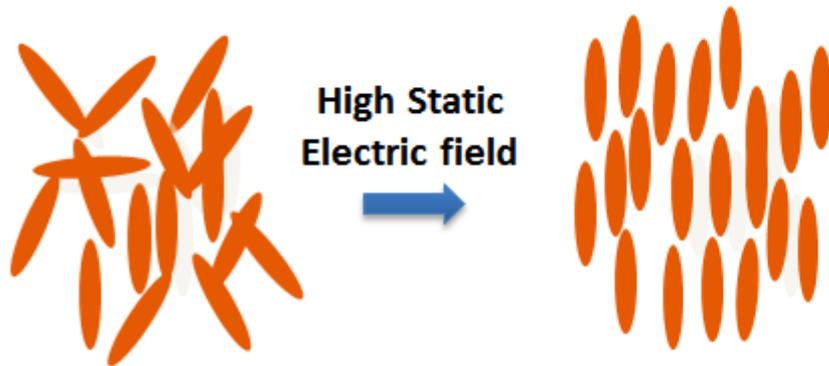
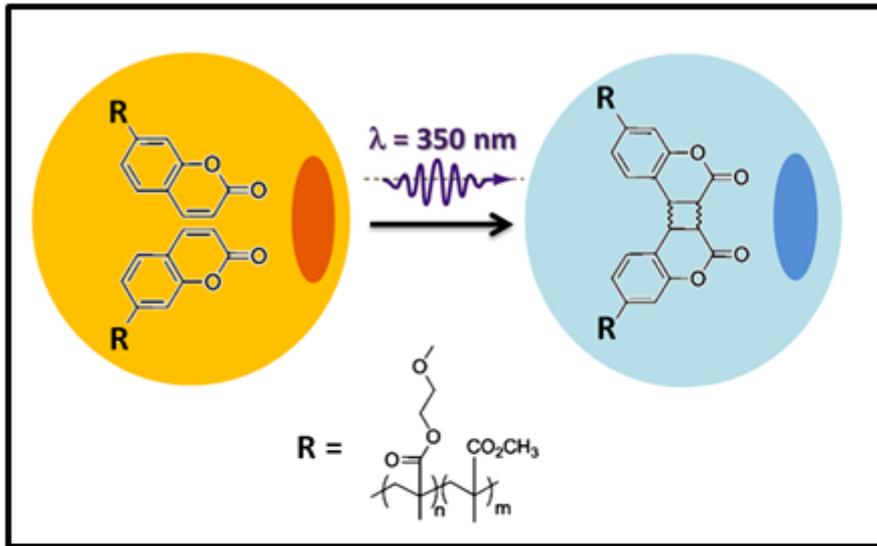


- High conjugaison
- High dipolar moment
- High SHG response

- Low conjugaison
- low dipolar moment
- low SHG response

Reversible process

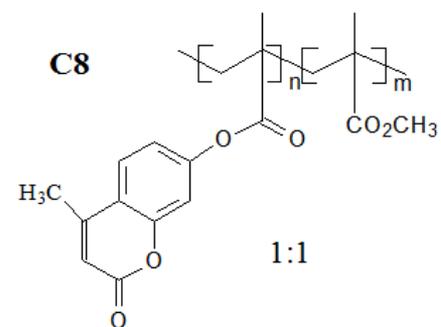
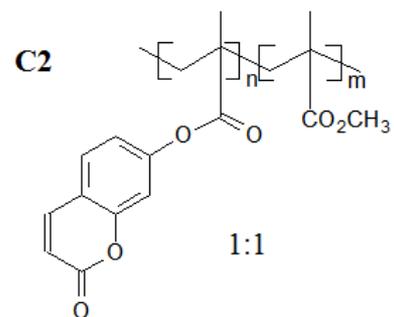
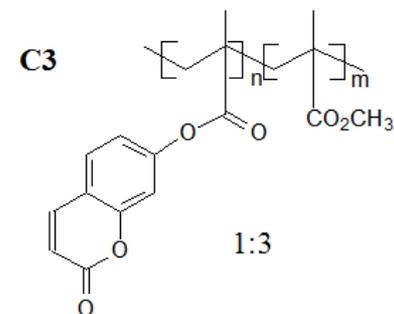
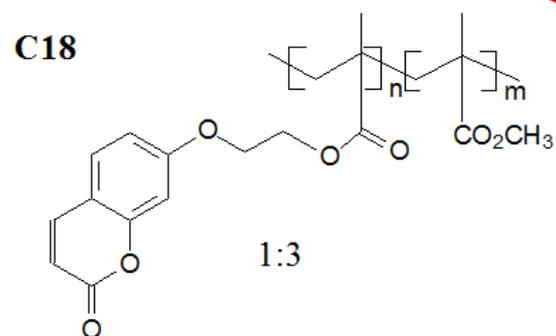
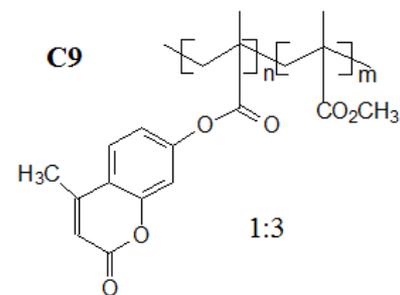
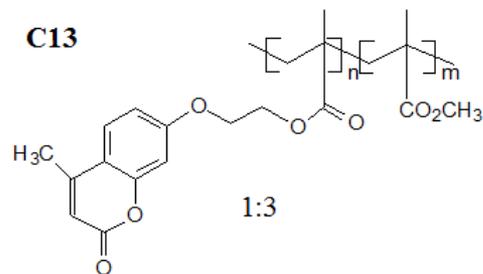
Photo-induced cross-linking of coumarins



Laser (high energy)

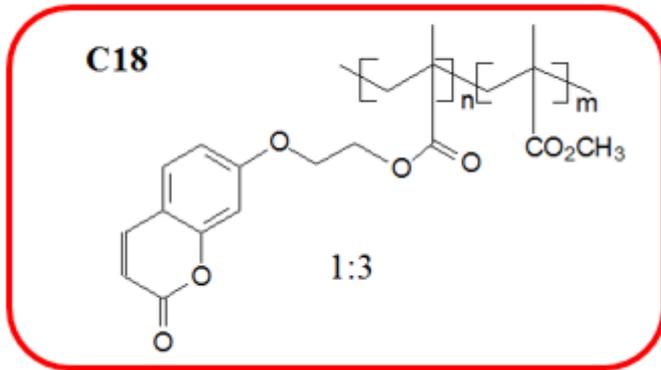
Laser (low energy)

The ratio between monomer / dimer is controlled by the power of the laser
→ Modulation of the SHG response



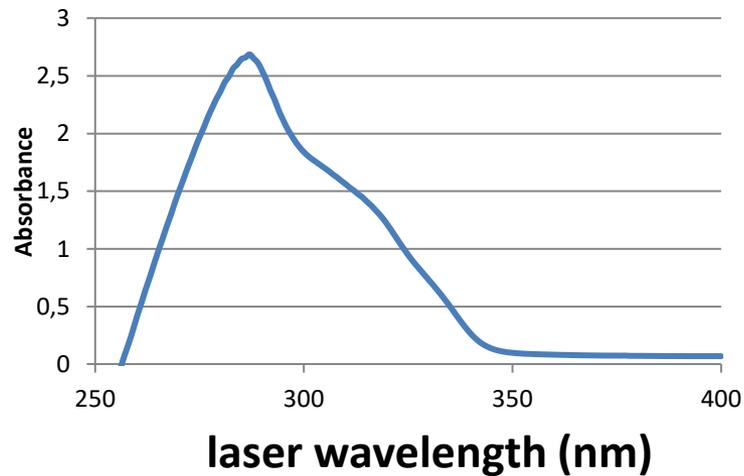
D. Gindre *et al*, submitted to *Molecules* (2016)

Absorption spectrum

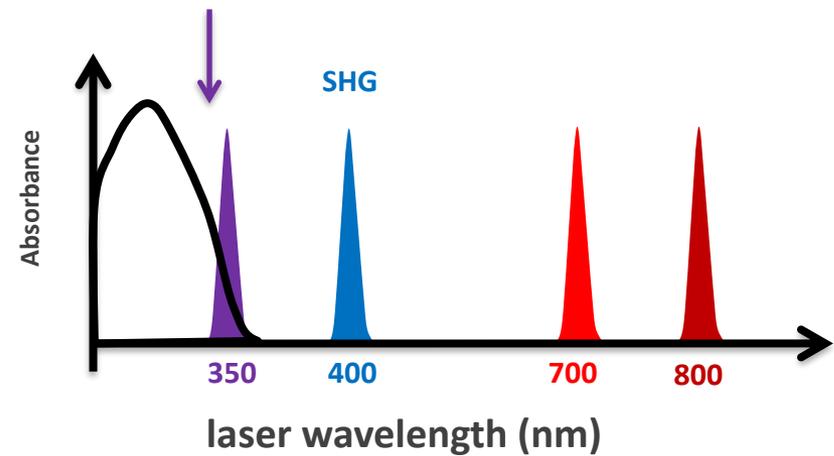


READ

WRITE

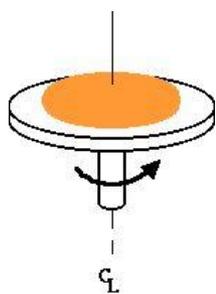
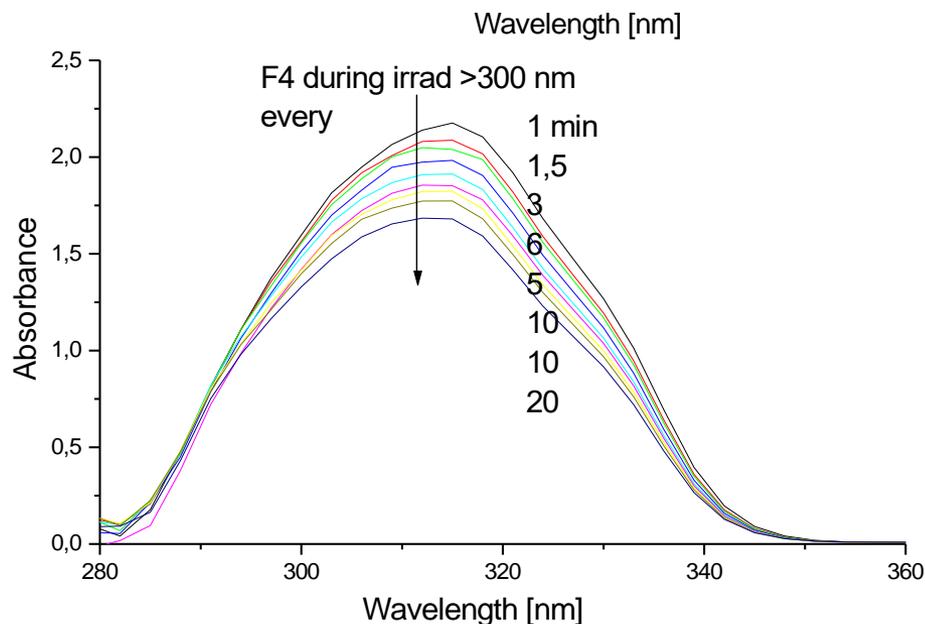
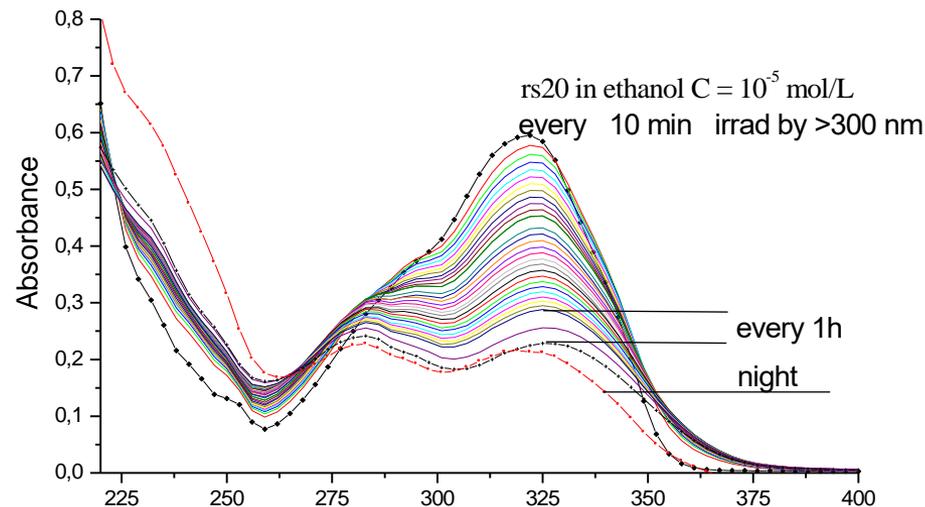
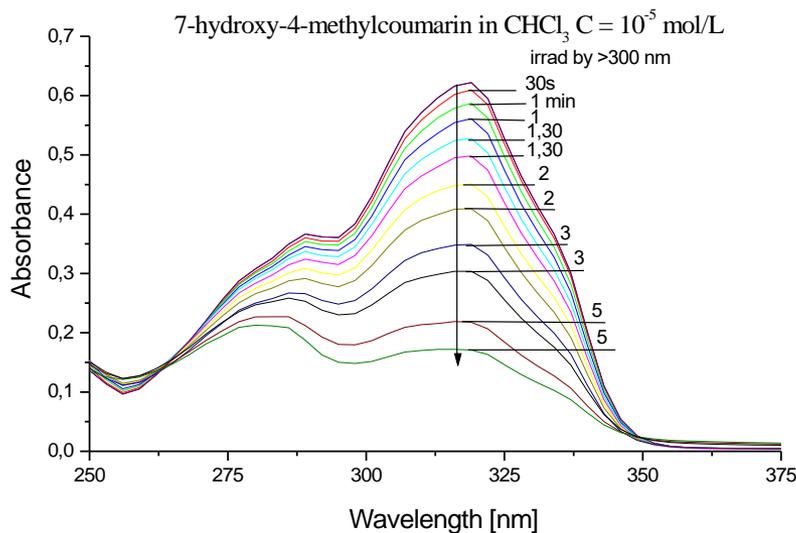


Two-photon Absorption



Chemistry study of coumarin based molecules

Photodimerisation in solution

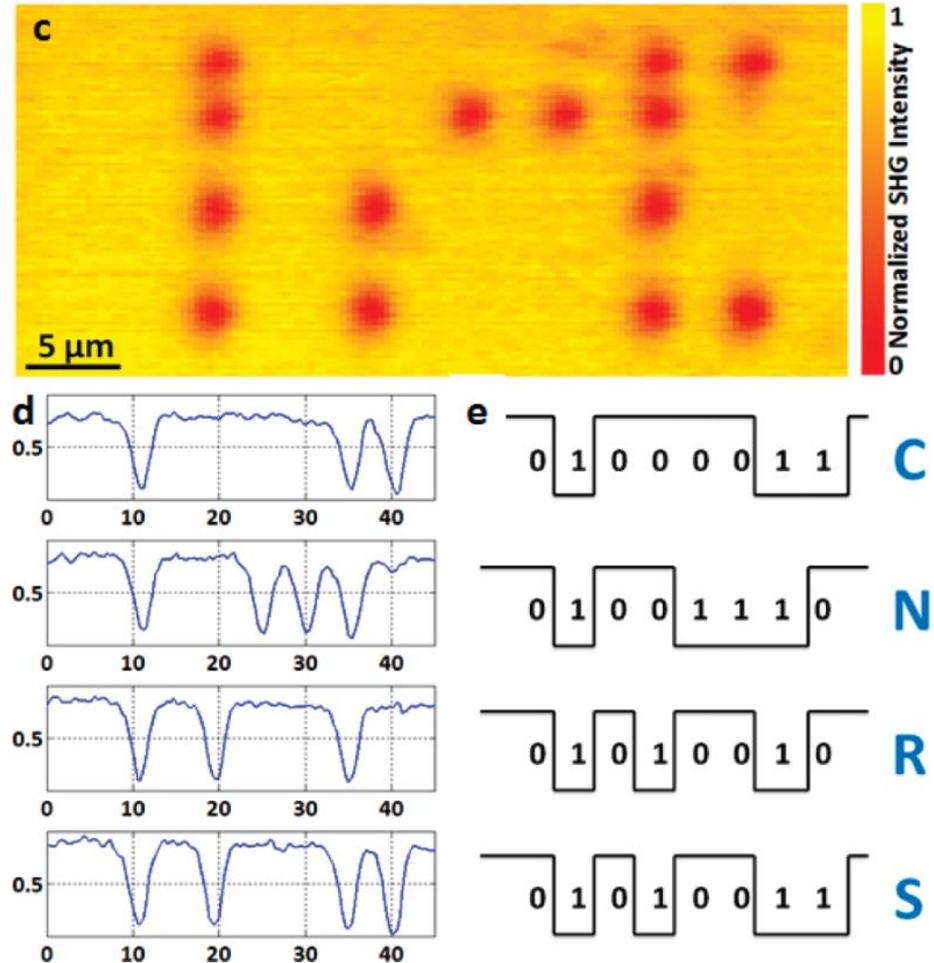
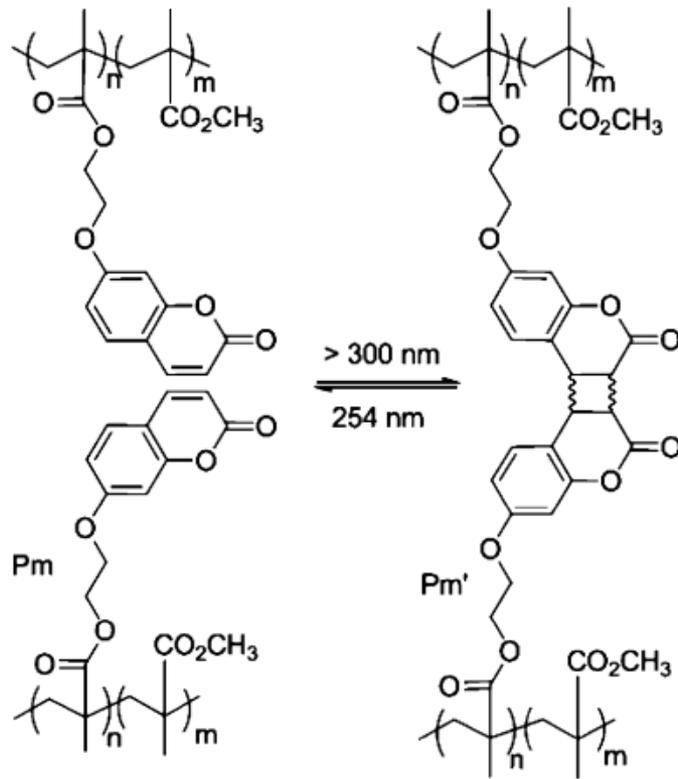


Spin coating

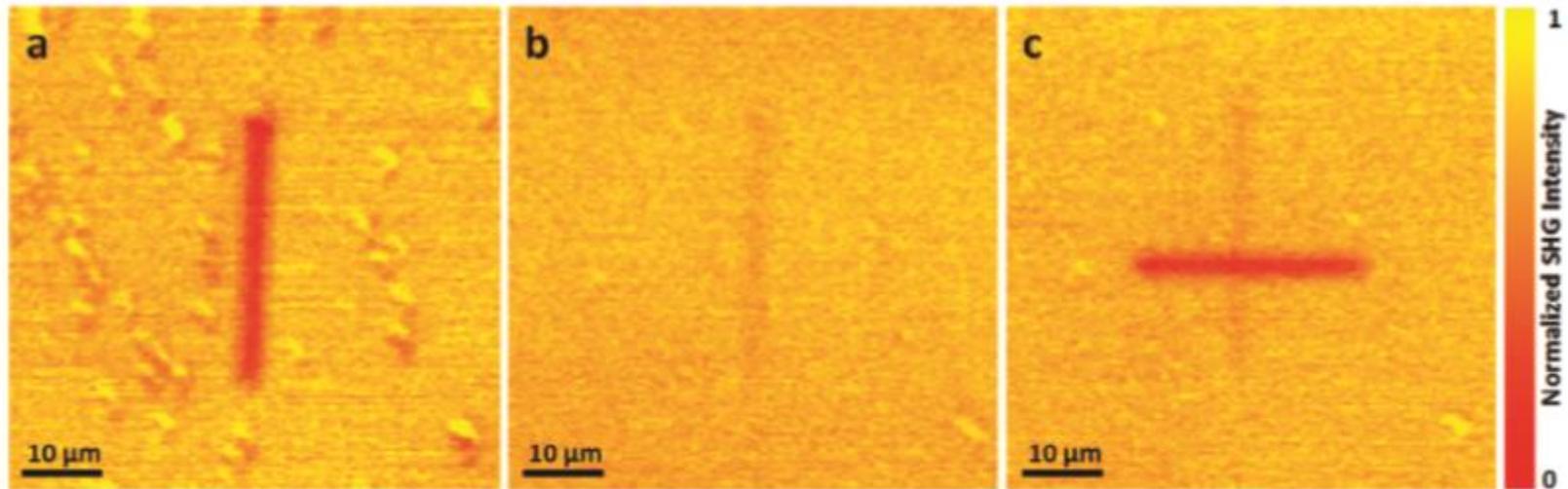
The spin-coating technique allows to make thin films with controlled thickness.

- glass slides BK7
- spin-coat at 1200 rpm
- 1 wt % 1,1,2- trichloroethane solution

binary optical data storage

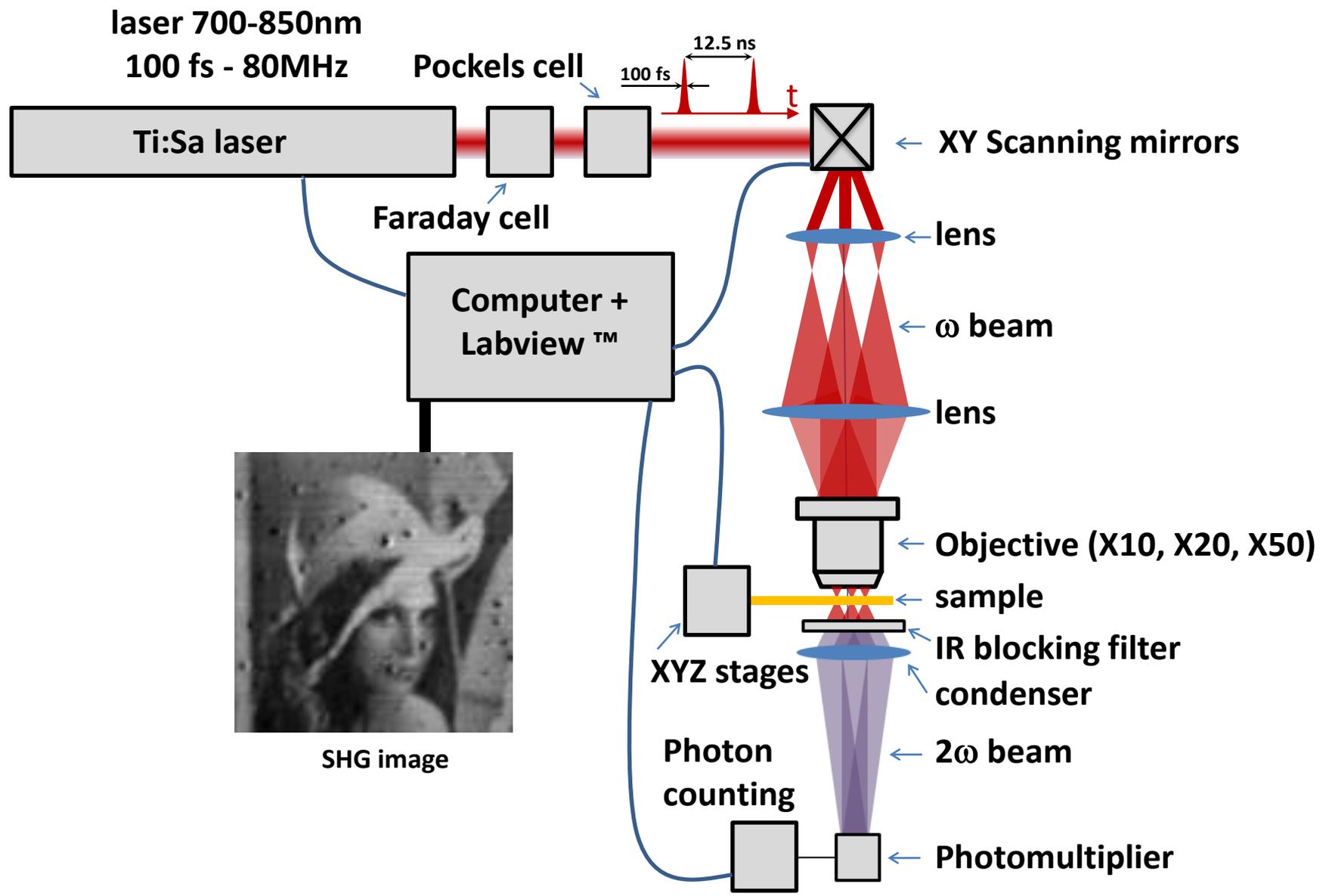


K. Iliopoulos et al, J. Am. Chem. Soc., 132, 14343 (2010)



- (a) SHG image (readout at $\lambda = 800$ nm) after a line was written at $\lambda = 700$ nm.
- (b) SHG image after irradiation of the area with a UV reactor ($\lambda = 250$ nm).
- (c) SHG image after a new line was written perpendicular to the first one.

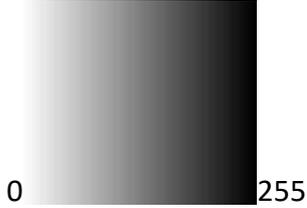
Multiphoton microscopy : setup



Principle of image storage

1. Calibration

Reference 8-bit image



Writing laser power

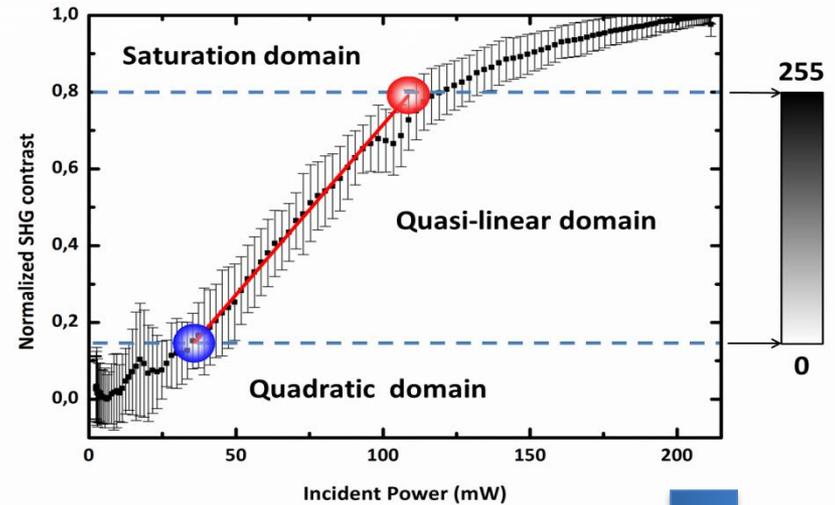
0 mW 210 mW

Read-out image



SHG microscopy scan

2. SHG read-out contrast as function of illumination power



3. Limits of illumination powers to write image in linear regime

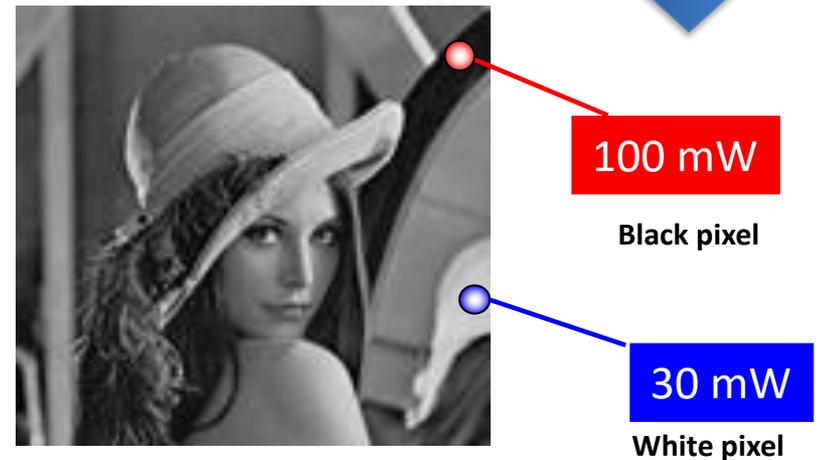


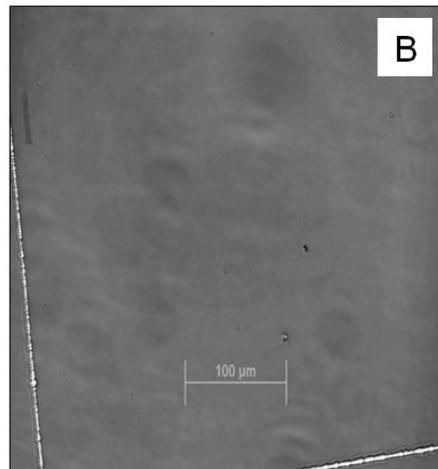
Image storage in azobenzenes

Writing image = variation of the laser power for each point

Grayscale reference image
100 x 100 pixels 8 bit



Optical Microscope
examination after image
writing



SHG imaging

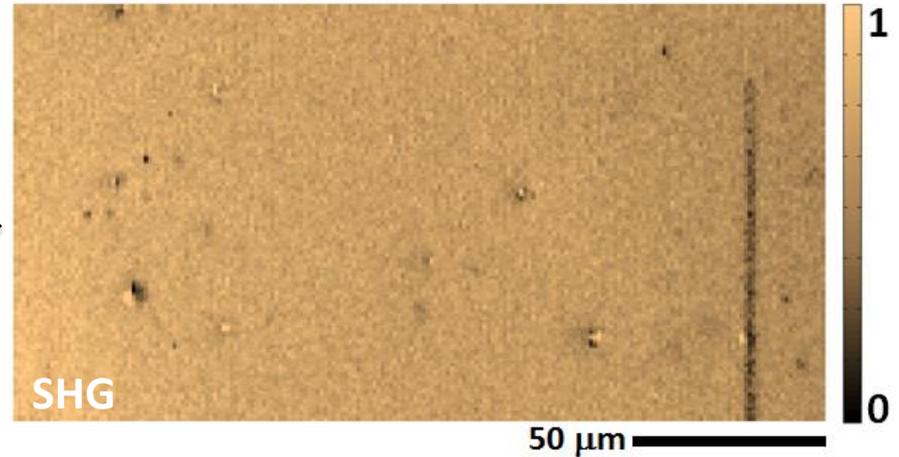


D. Gindre *et al*, *Opt. Exp.*, 14, 9896 (2006)

Image storage by controlled dimerization

1 – Calibration

2 - **Fast SHG reading** of poled area
 $\lambda = 800 \text{ nm}$, $P = 5 \text{ mW}$ before writing



3 - **Image writing**

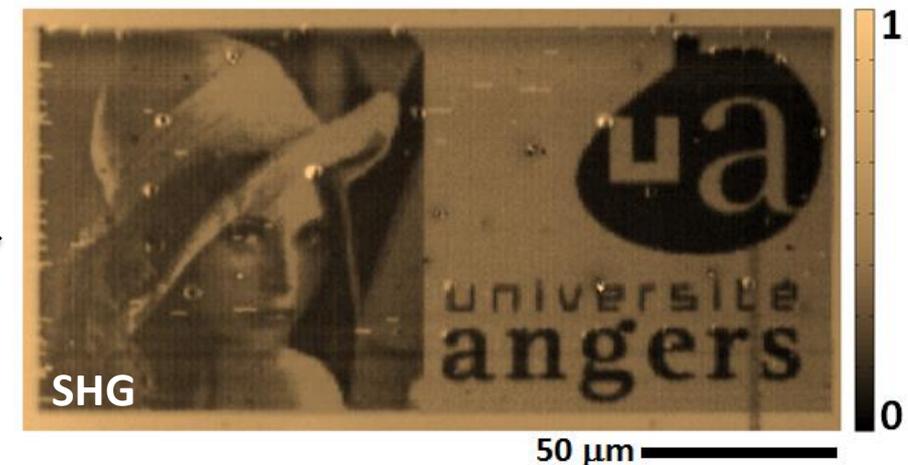
$\lambda = 695 \text{ nm}$, $P = 26 \text{ mW}$,

1 ms < Exp. Time < 1000 ms

I = Cste



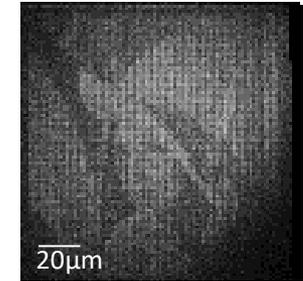
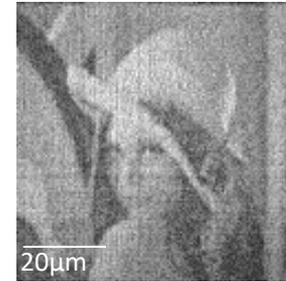
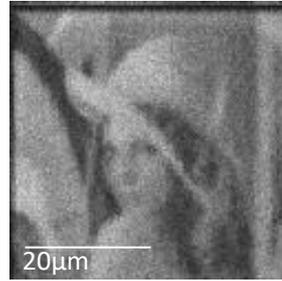
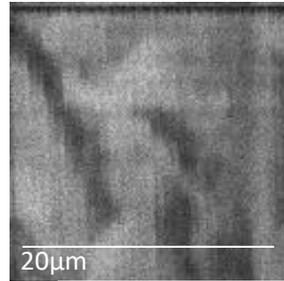
4 - **Slow SHG reading** of the
same poled area $\lambda = 800 \text{ nm}$,
 $P = 5 \text{ mW}$



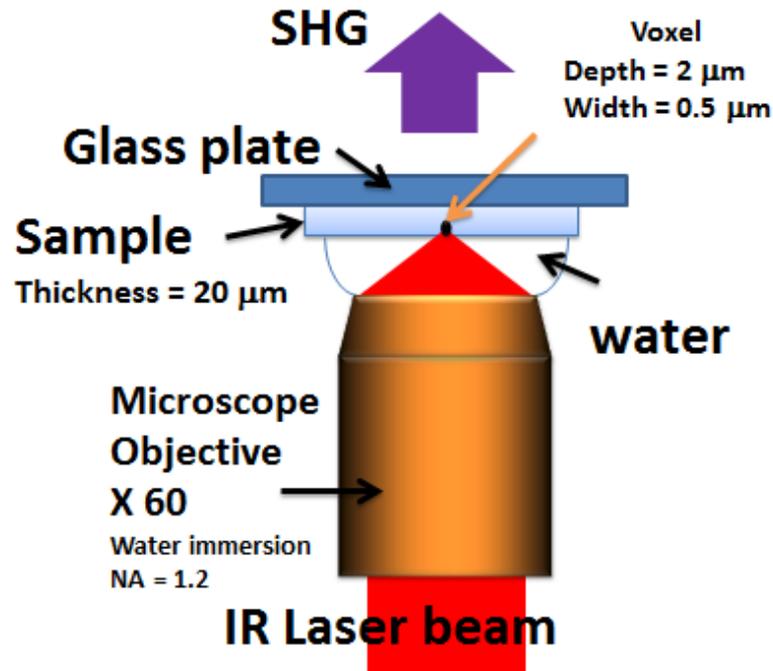
D. Gindre et al, Opt. Lett., 38, 4636 (2013)

Resolution optimization

$$\delta_{xy} = \frac{1,22\lambda}{2ON}$$



$$\delta_z = \frac{2n\lambda}{ON^2}$$



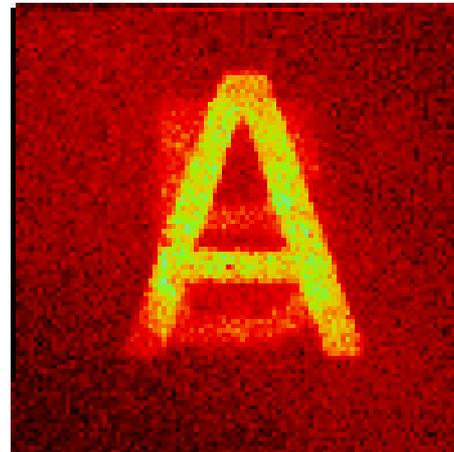
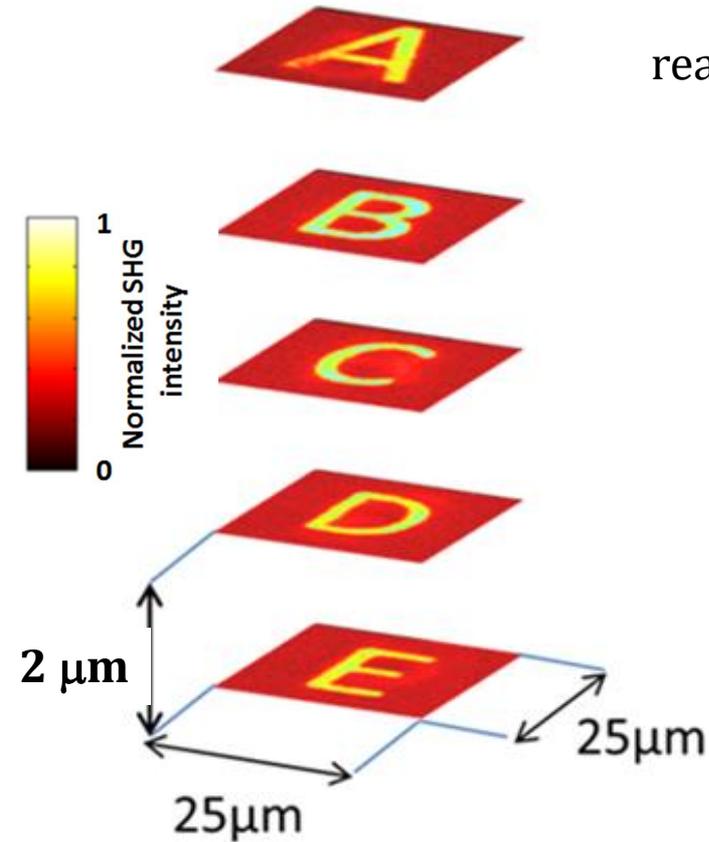
3D Binary storage

60 mW (700 nm) = white pixels

0 mW for the background

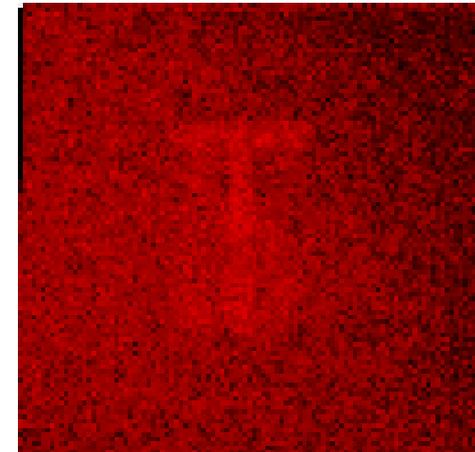
Space between letters :

read-out at 800nm (power **10mW**)



100x100 pixels/image
Depth increment = $1\ \mu\text{m}$.
Pixel time = $200\ \mu\text{s}$

50 scans



100x100 pixels/image
Depth increment = $1\ \mu\text{m}$.
Pixel time = $200\ \mu\text{s}$

45 scans

3D Image storage



Images 128x128 pixels recorded at **700 nm** and restored by SHG at 400 nm
Space between images = **5 μm**

Crosstalk between 2 images ↓



3D Image storage

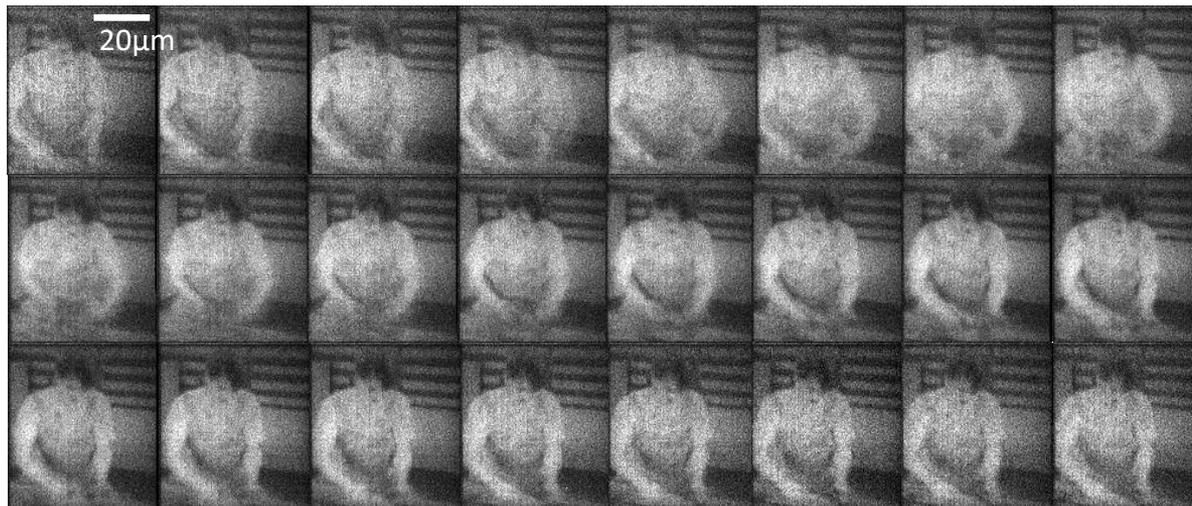


24 images 128x128 pixels
(corresponding to 1 second of the
movie *Modern Times*)

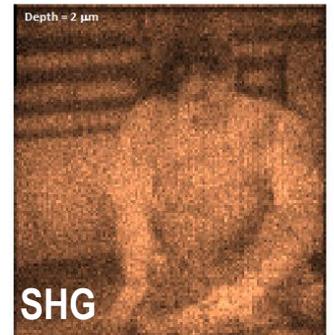
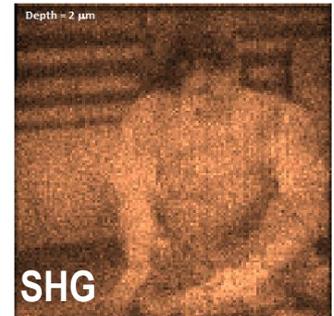
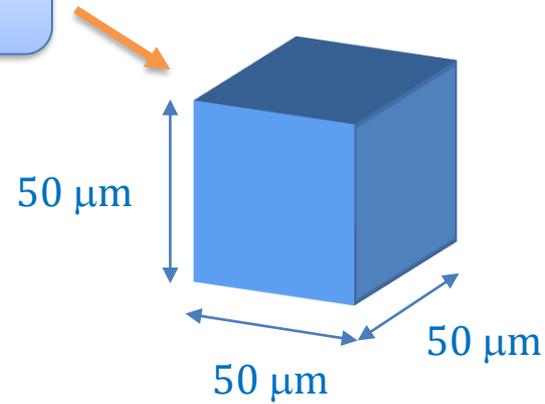
recorded at **700 nm** and restored by
SHG at **400 nm**

Space between images = **2 μm**

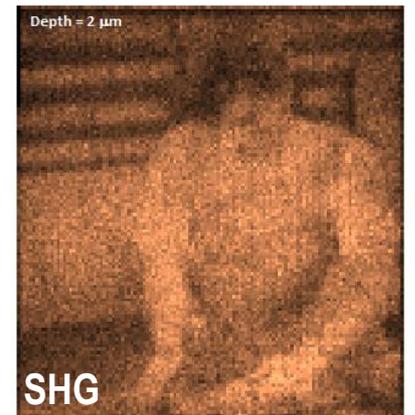
SHG
images



1 second of the movie
Modern Times



Poor quality bulk



Hidden tagging application



Invisible and Security TAG
Written with a focused laser beam



**IR laser +
scanning TPEF/SHG**



**The tag is invisible without non linear
optical measurements
(laser + TPEF or SHG)**

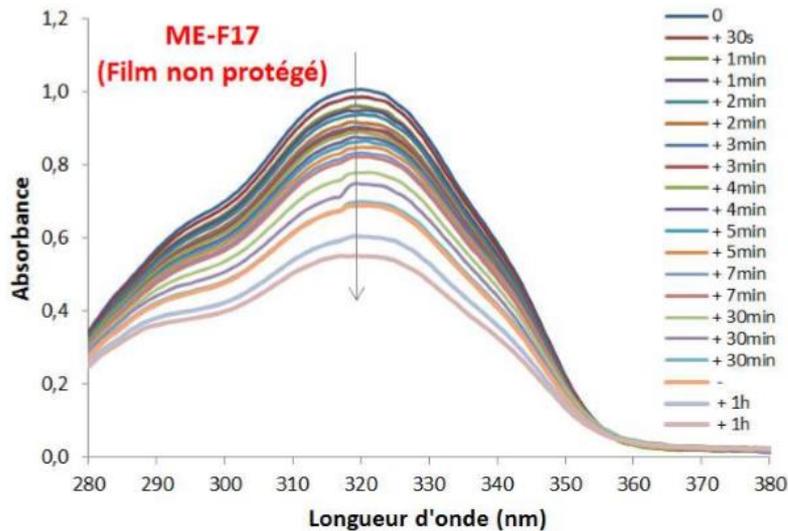
Hidden tagging application

For tagging applications, the (cleavage) should be prohibited.

→ Protection of the premarked polymer **with stop UV film**

Formulation from acrylic resin ENCOR-5126 + Solasorb UV200 + Tinuvin P

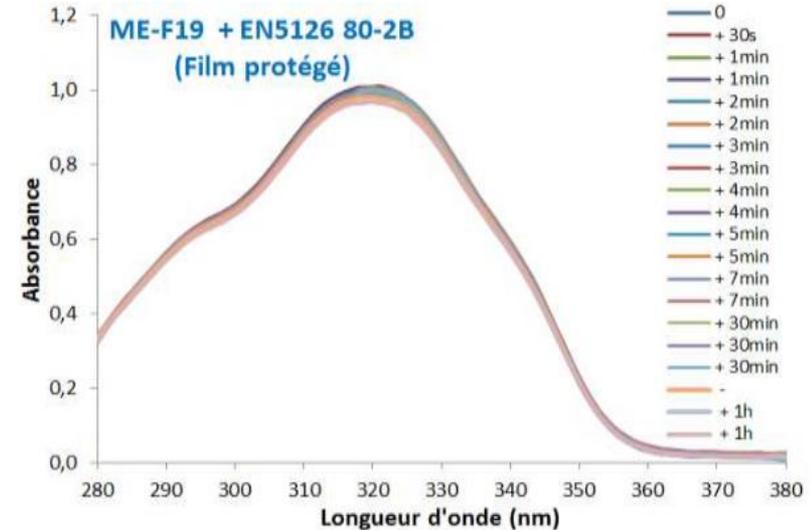
Without protection



UV lamp
(150W)
319 nm



With UV protection



- Possibility to store **information** into a copolymer thin film with **non linear optical processes**.
- **Image storage** by modulation of the power of writing laser. The read-out requires **SHG microscopy**
- Possibility to write information in the volume with high densities. The information is collected by two-photon imaging techniques (SHG or/and TPEF)
- Possible application to non linear hidden tagging

Acknowledgements



Marc Sallé

Pr. MOLTECH Anjou, Chemistry



Emilie Champigny

PhD, 3D Storage



Konstantinos Iliopoulos

Post-doc, Optics



Oksana Krupka

Post-doc, Synthesis



Bouchta Sahraoui

Pr MOLTECH-Anjou, NLO measurements



Yohann Morille

IE CNRS, Labview development

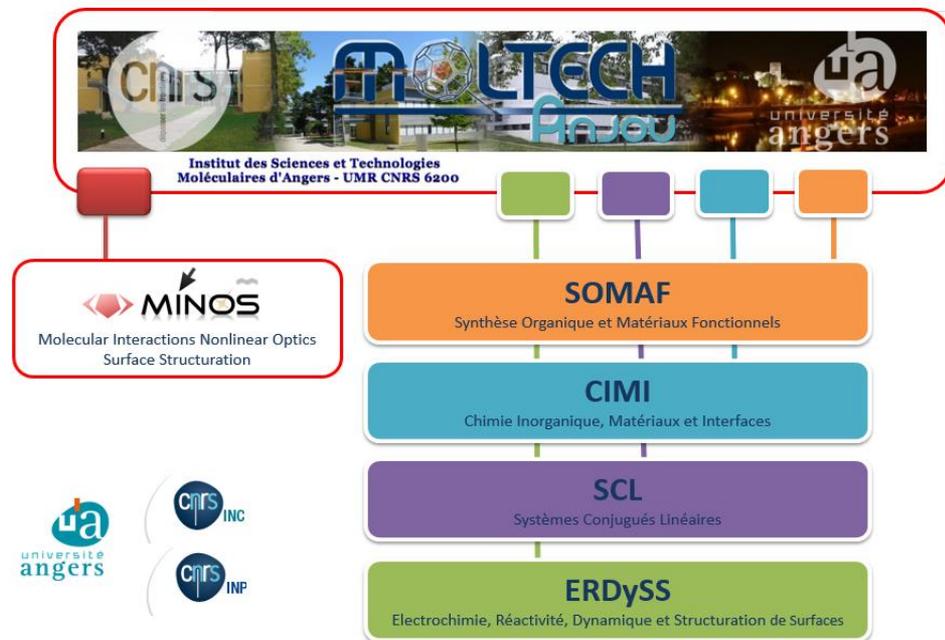


Marie Evrard

Valorisation engineer, aging/UV protection

Fundings

**Moltech Projet (pari scientifique)
Region Pays de la Loire**



Thank you for your attention