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-02564173v1

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

Outline

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

10^8	700	MB	= a CD-ROM
10^{12}	1	TB (terabyte)	= 50 000 trees made into paper and printed
10^{15}	1	PB (petabyte)	= 3 years of earth pictures by the EOS satellite
10^{18}	1	EB (exabyte)	= total volume of information (pictures, texts, videos, sounds, ...) created on earth in 2002
10^{19}	10	EB	= data traffic estimated among smartphones in 2019 (half is videos)
10^{21}	40	ZB (zettabyte)	**= volume of information in the world (2020)**

7 TB/day
(2013)

10 TB/day
(2013)

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

Story of Data Storage

1,44 MB

Flask Disk 8 MB

1982

2000

Hard Drive
1 TB

iPhone
16 GB

SSD
Solid State Drive
1 TB

Hard Drive
8 TB

2006

2007

2013

2015

Story of Optical Data Storage

1,44 MB

1982

CD 700 MB

1984

DVD 4.3 GB

1995

Flask Disk 8 MB

2000

Blu Ray Disk
15 GB

2002

Hard Drive
1 TB

2006

iPhone
16 GB

2007

SSD
Solid State Drive
1 TB

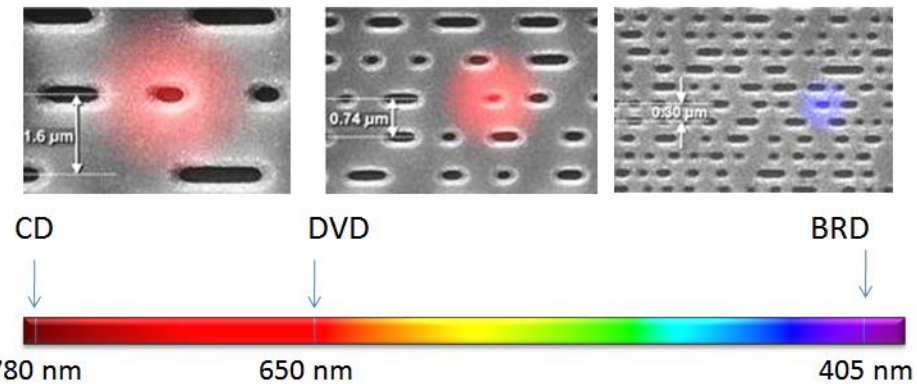
2013

Hard Drive
8 TB

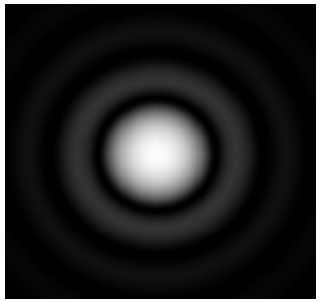
2015

Optical Data Storage

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



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

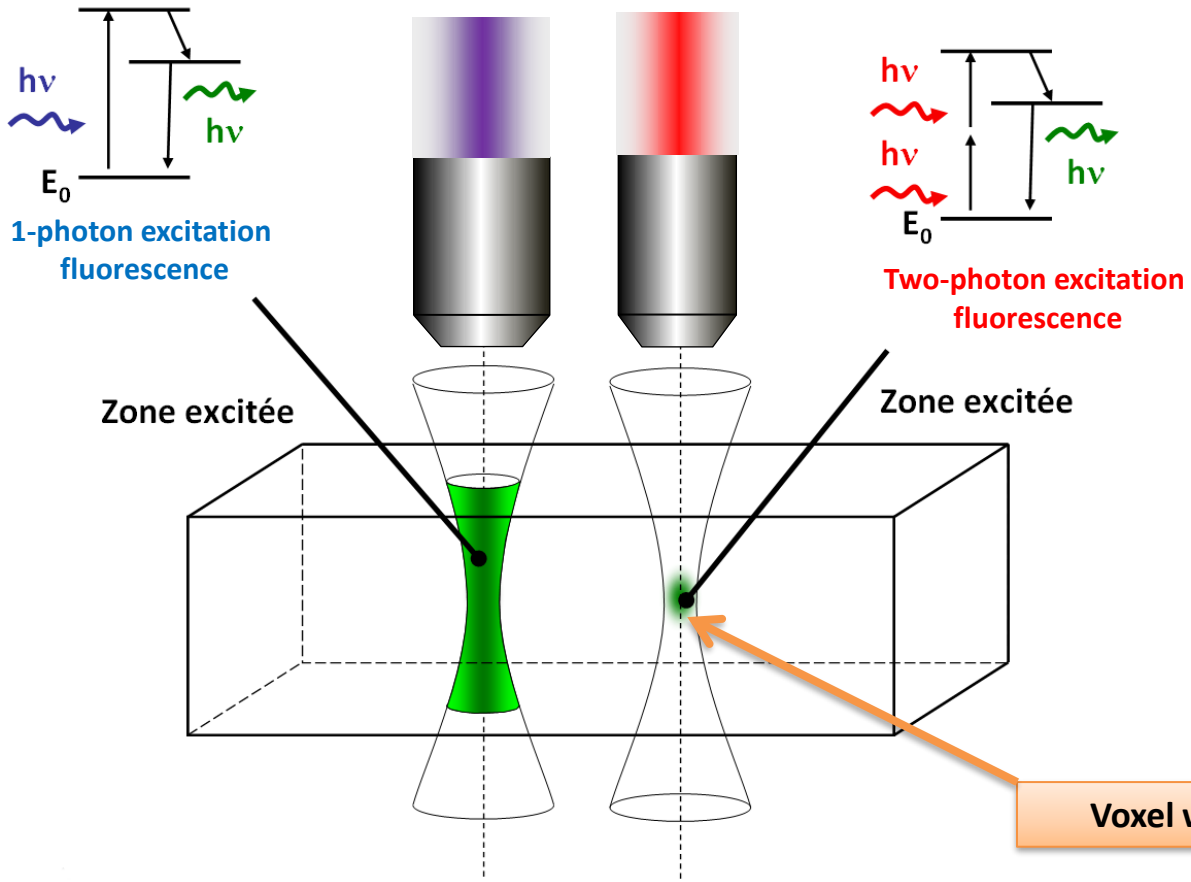


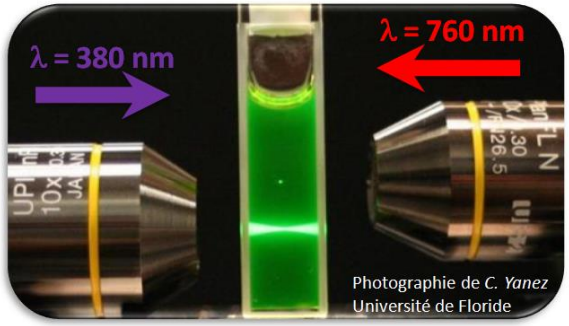
The (potential) future of optical data storage

- **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.

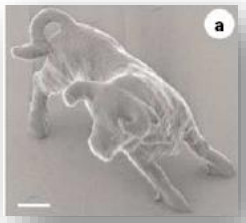
Two-Photon Absorption





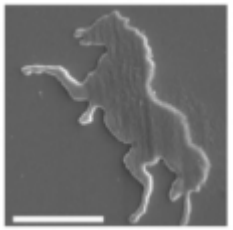
Application :

Nanofabrication by polymerization induced by 2-photon absorption



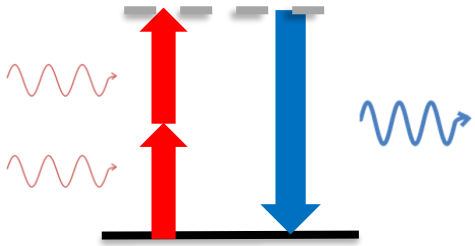
S. Kawata, **Nature**, 2001

P. Baldeck, **Optics Letters**, 2002



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

Second Harmonic Generation (SHG)

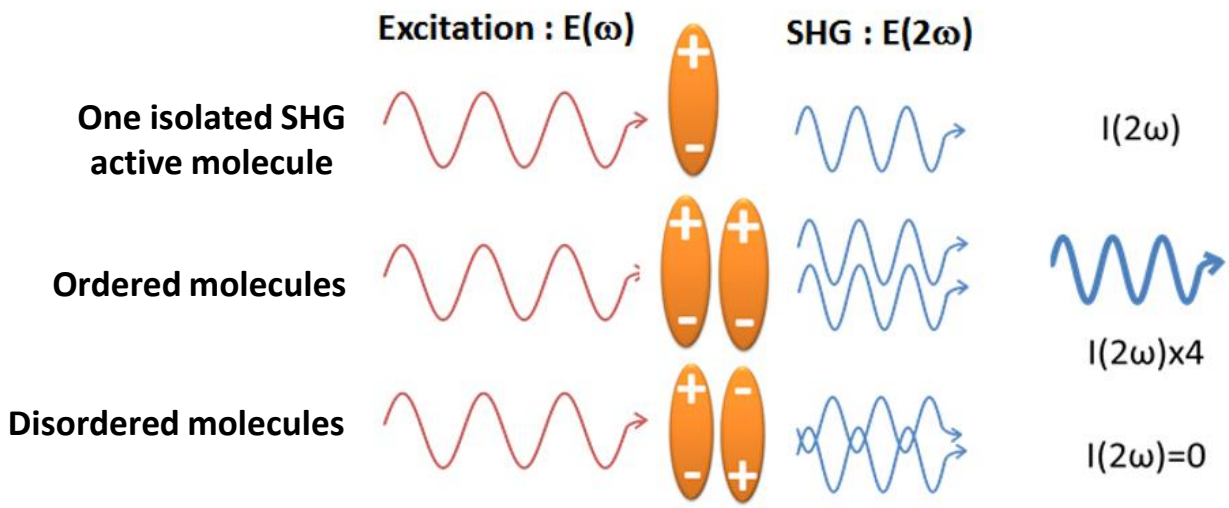


Induced polarization : $\vec{p} = \alpha \vec{E} + \beta \vec{E}\vec{E} + \ldots$

linear nonlinear

SHG $\neq 0$ ➡ $\beta \neq 0$ ➡ non centro-symmetry of the material

SHG efficiency ➡ density of the molecules

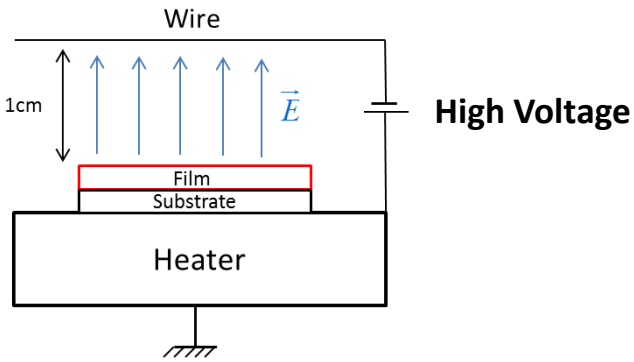


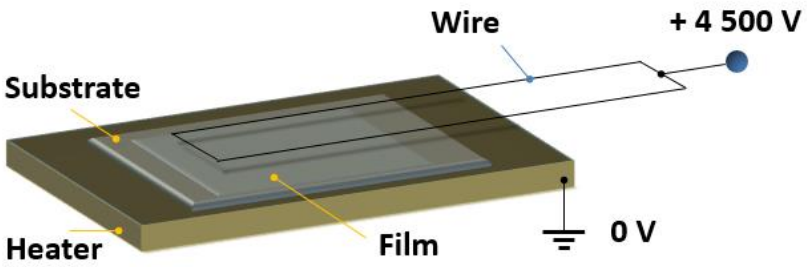
Necessity of **molecular orientation**

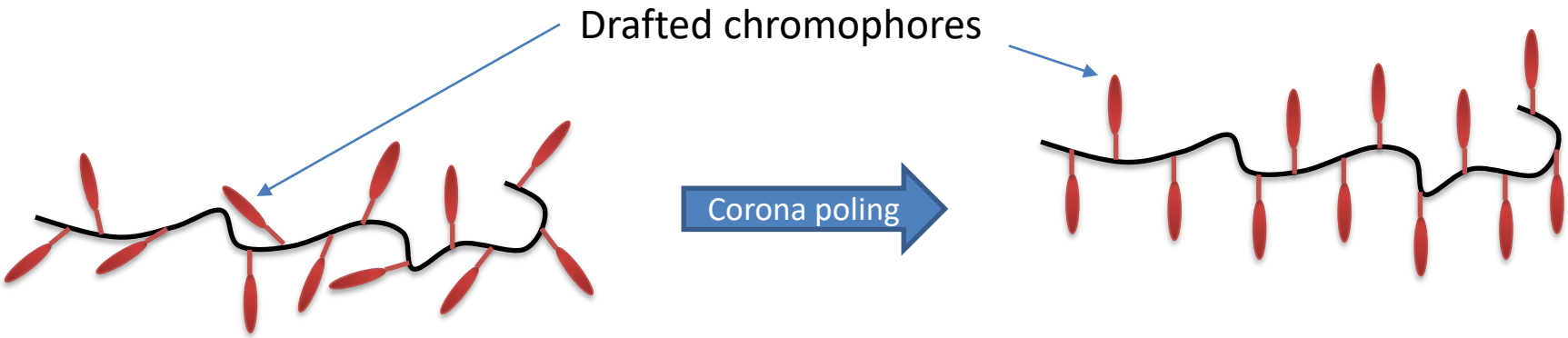
Chromophores orientation

Corona poling

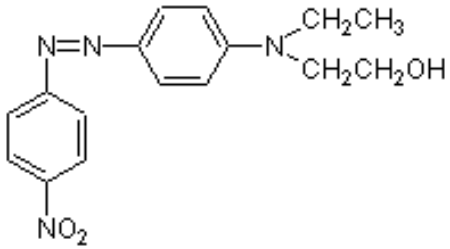
A high static electric field is applied into the film of copolymers. The temperature of the film is just below the glass transition temperature (Tg)







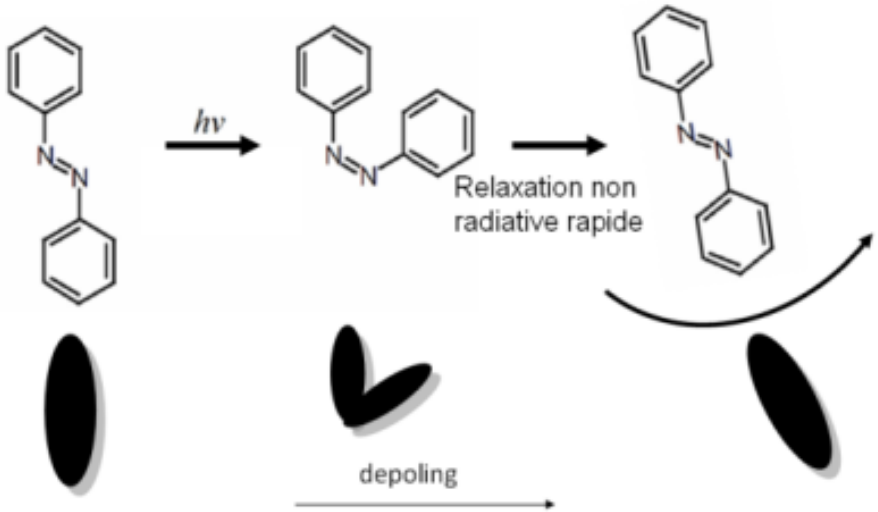
Data storage with azobenzenes



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

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

photoinduced depoling



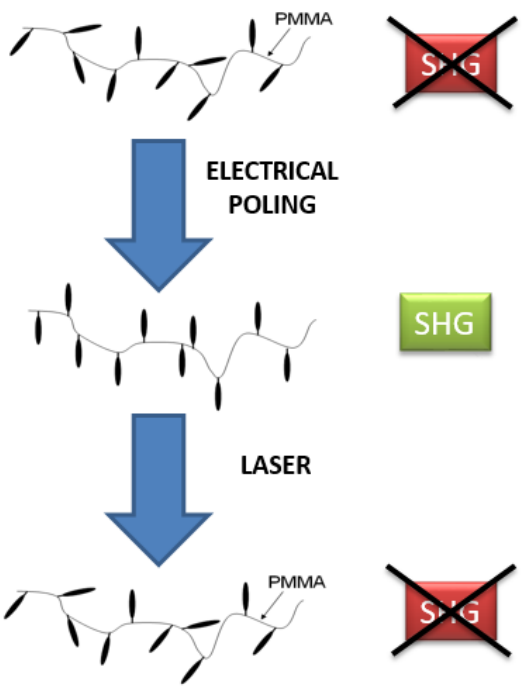
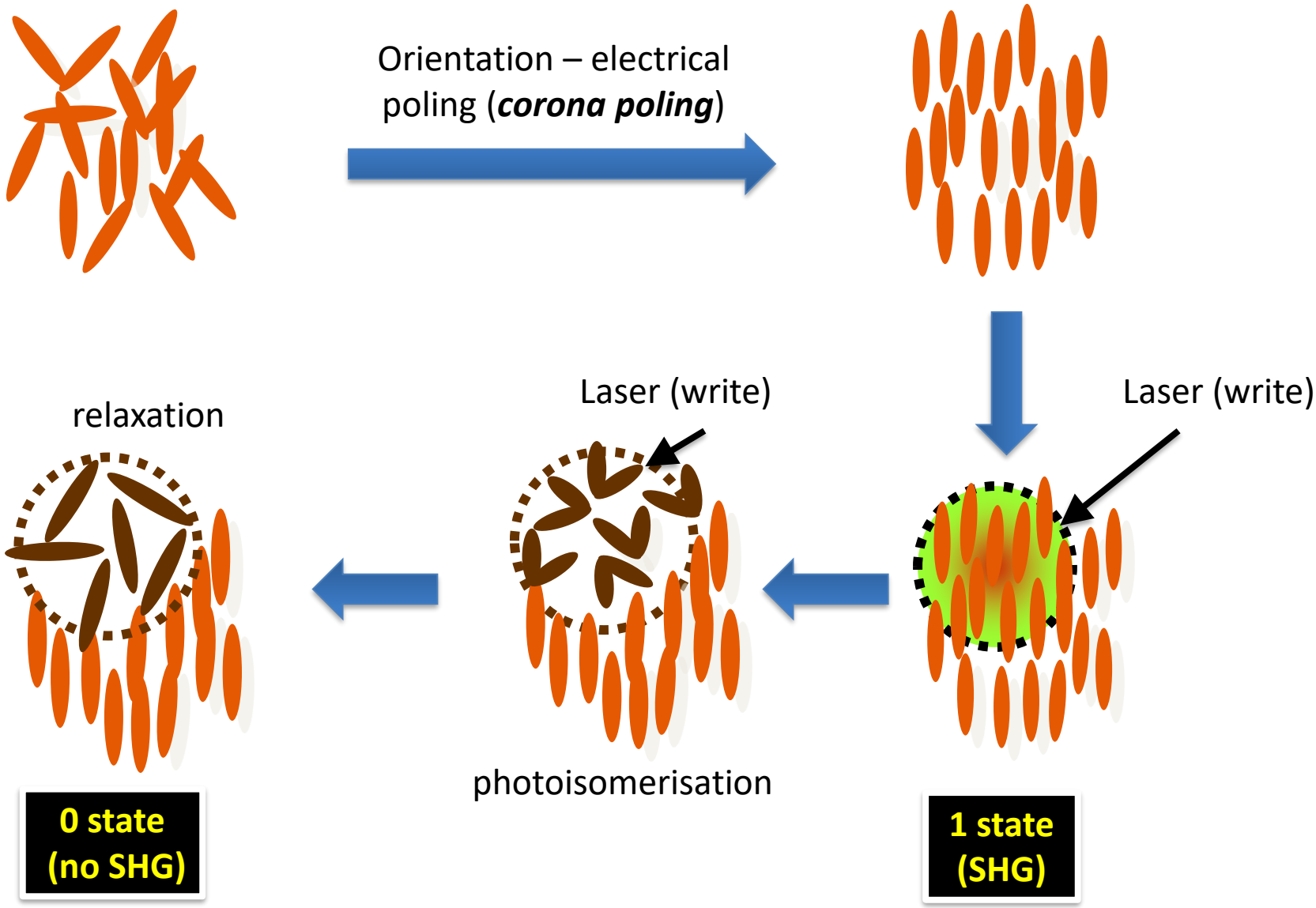
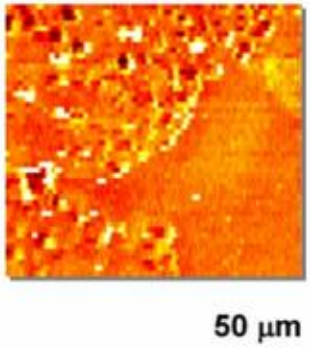


Photo-induced depoling principle



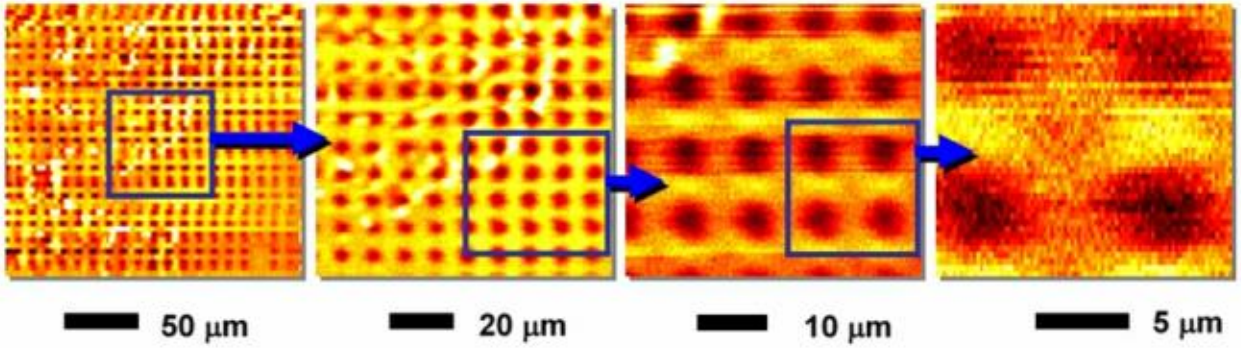
binary data storage by photoinduced depoling

Readout P = 2 mW

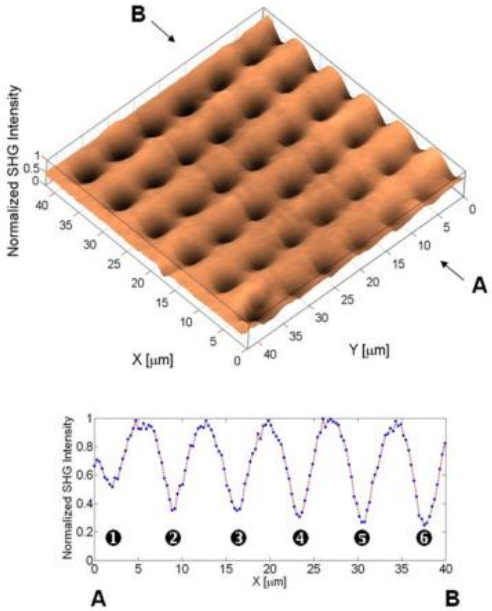


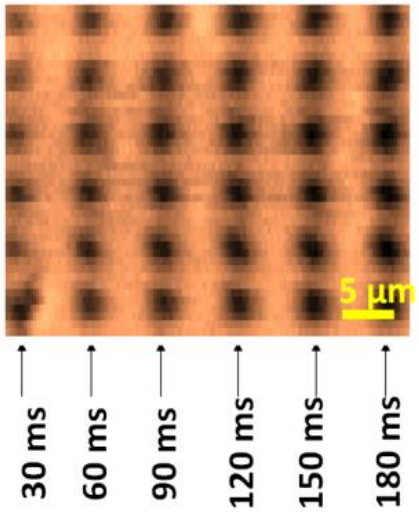
Initial SHG scan

Readout P = 2 mW



1st SHG scan 2nd SHG scan 3rd SHG scan 4th SHG scan

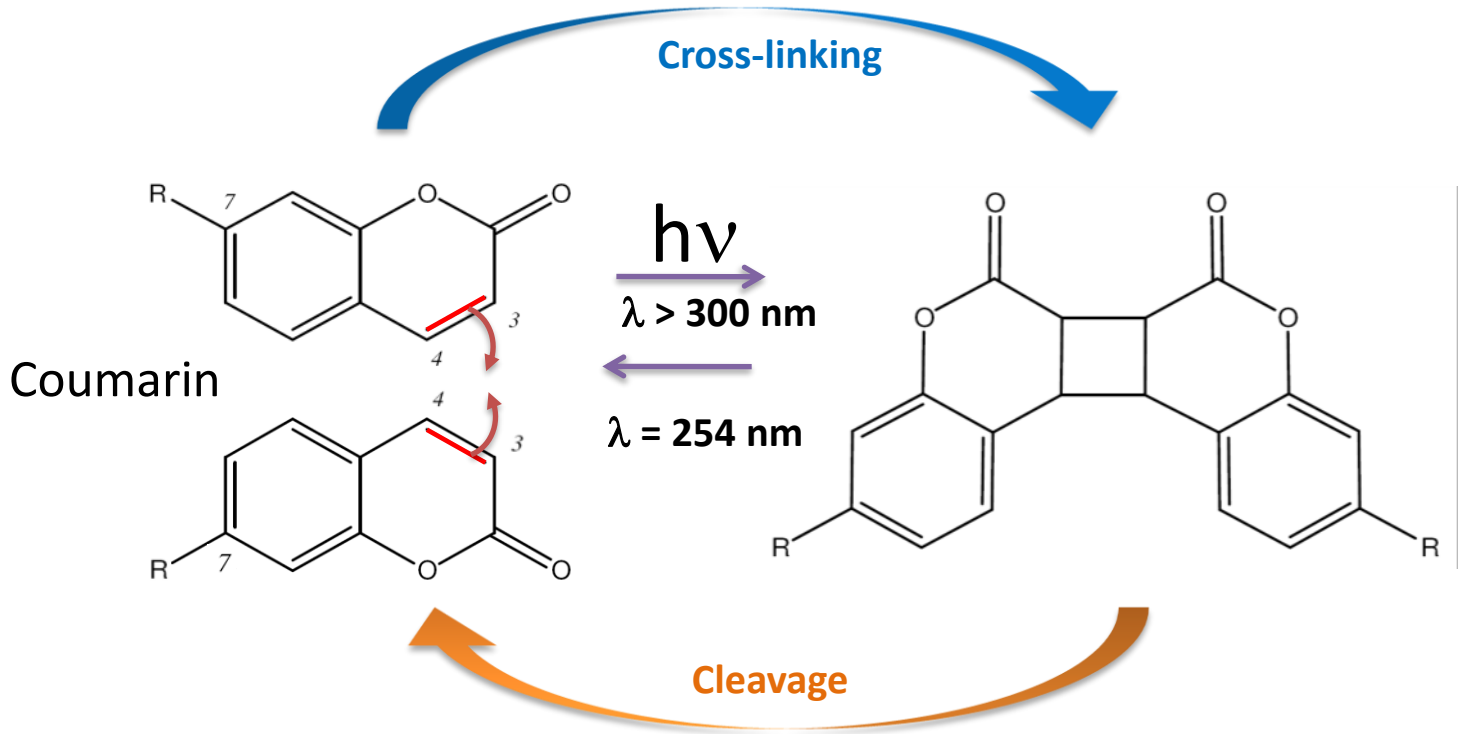




Write : P_{laser} = 30 µW
Read P_{laser} = 4.5 µW

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).

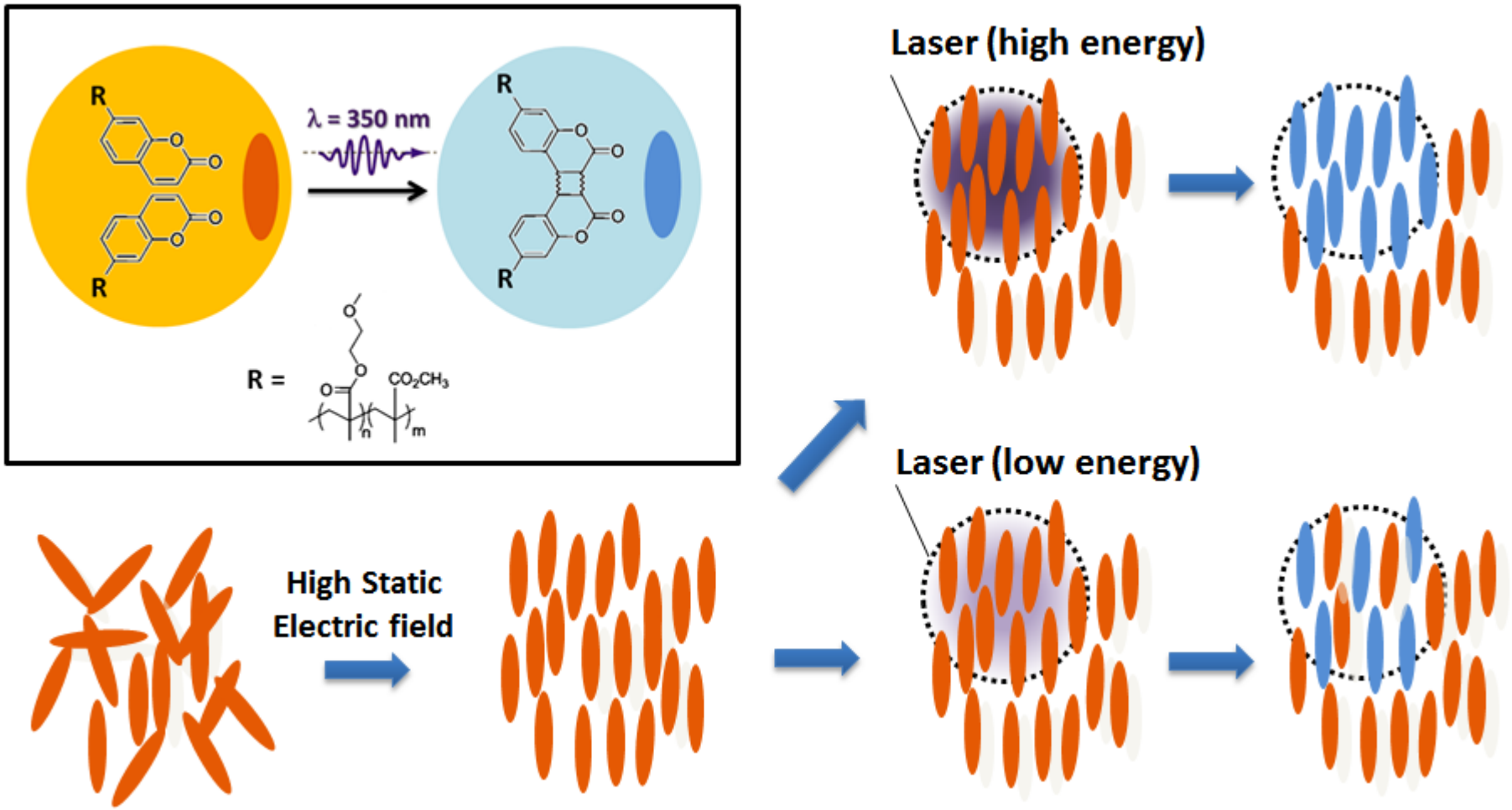
ODS by photoinduced dimerisation



High conjugaison	Low conjugaison
High dipolar moment	low dipolar moment
High SHG response	low SHG response

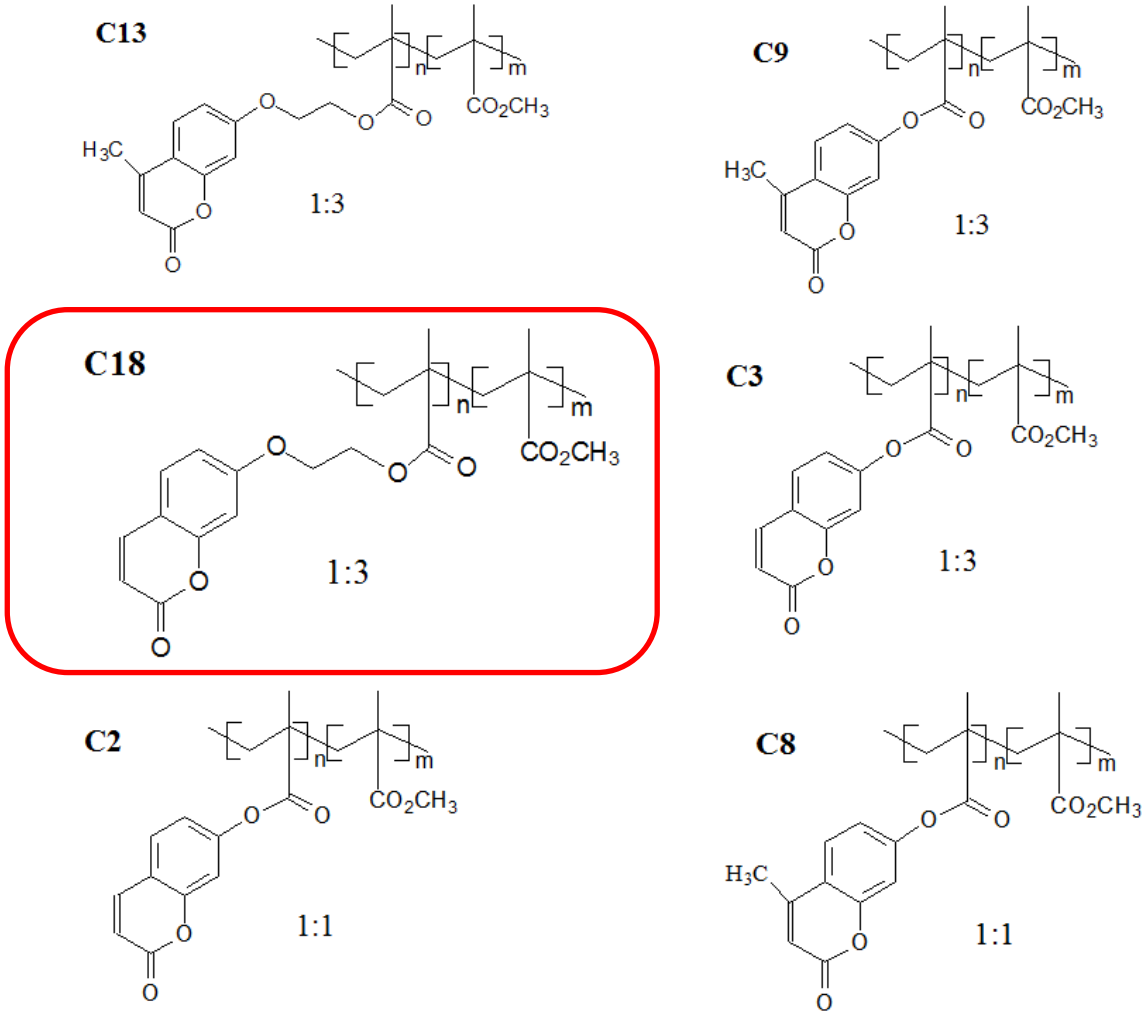
Reversible process

Photo-induced cross-linking of coumarins



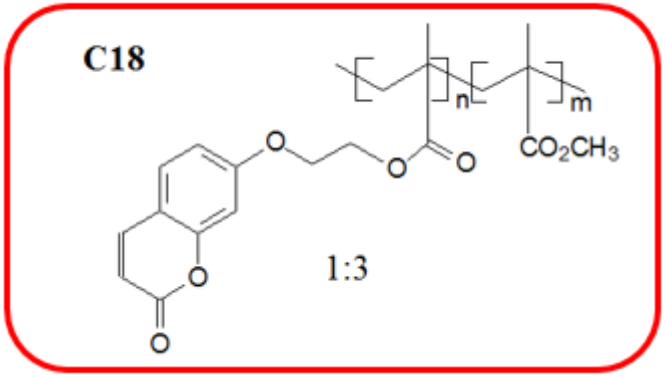
The ratio between monomer / dimer is controlled by the power of the laser
→ Modulation of the SHG response

Synthesis



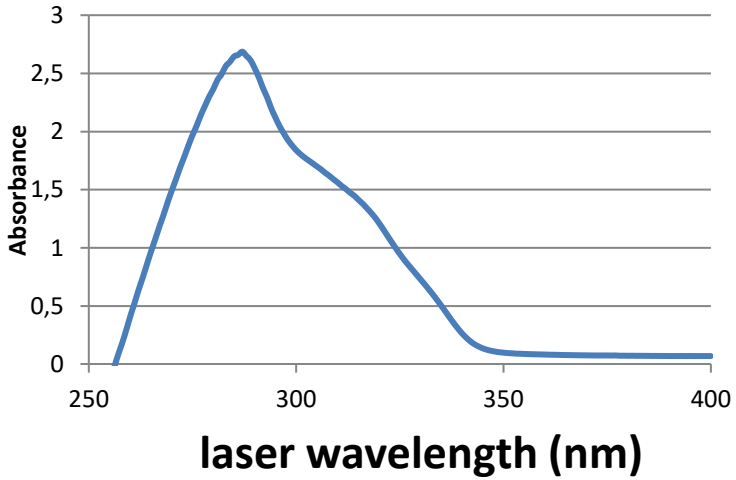
D. Gindre *et al* , submitted to Molecules (2016)

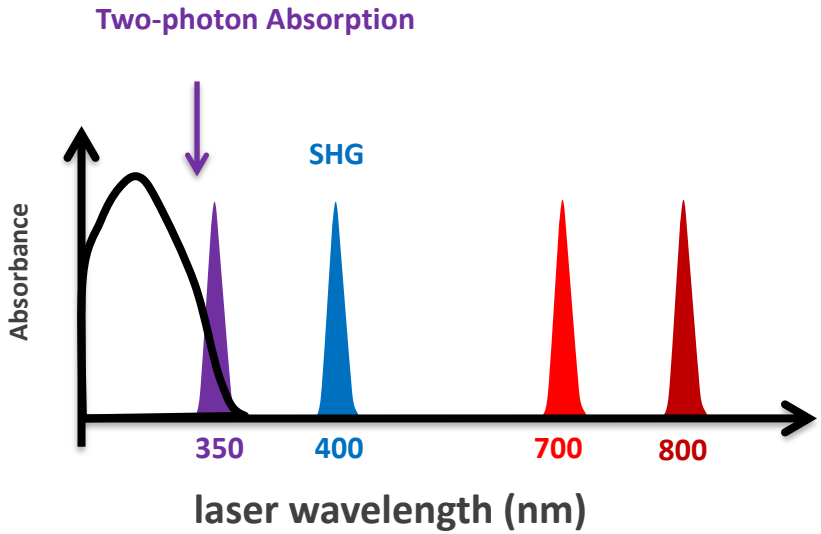
Absorption spectrum



READ

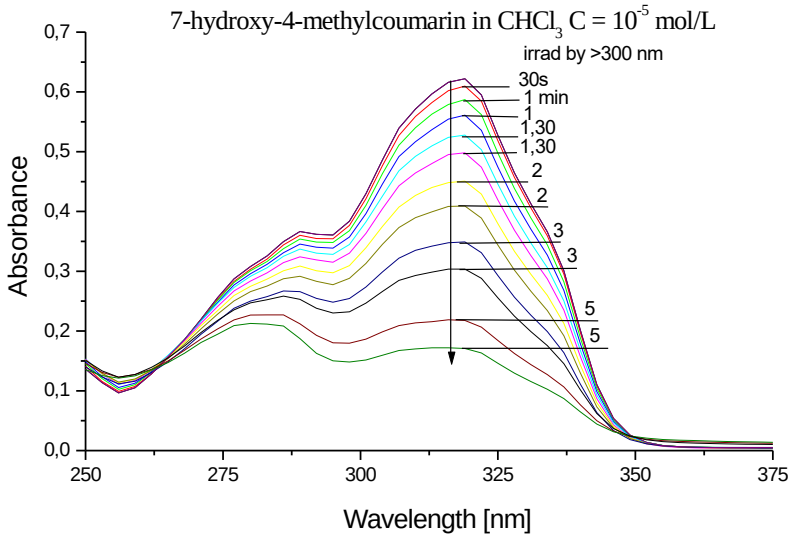
WRITE

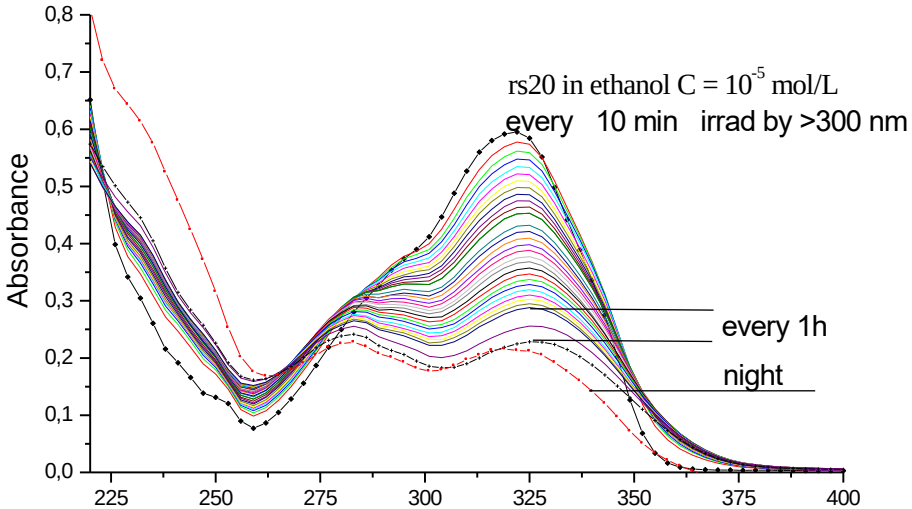


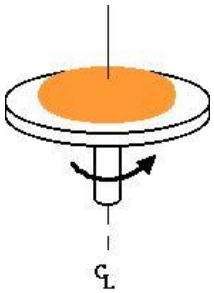


Chemistry study of coumarin based molecules

Photodimerisation in solution



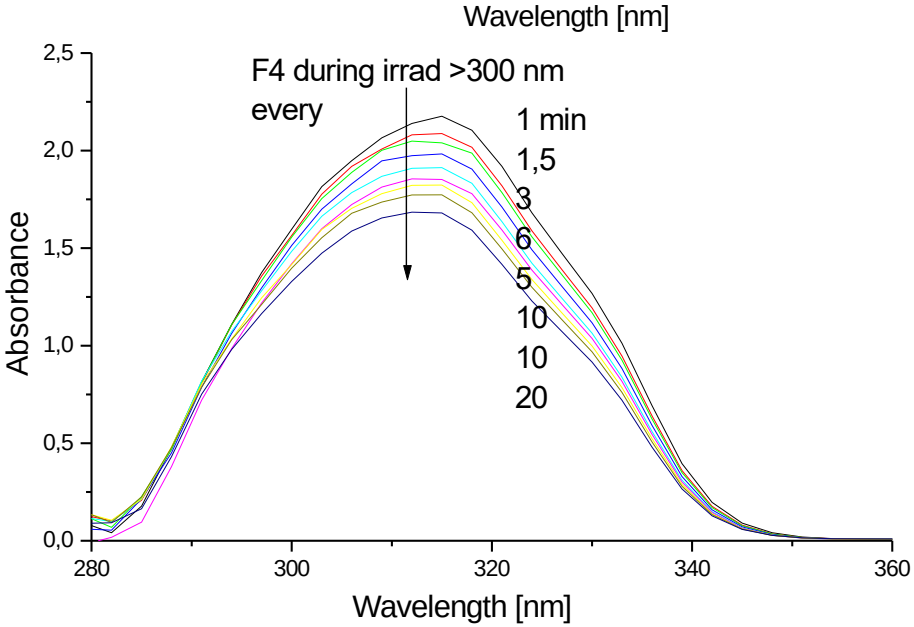




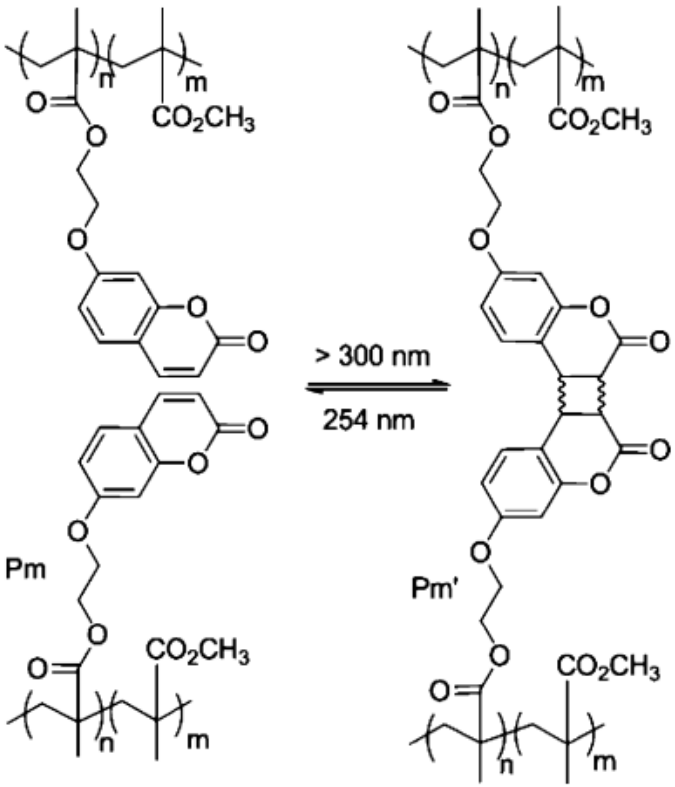
Spin coating

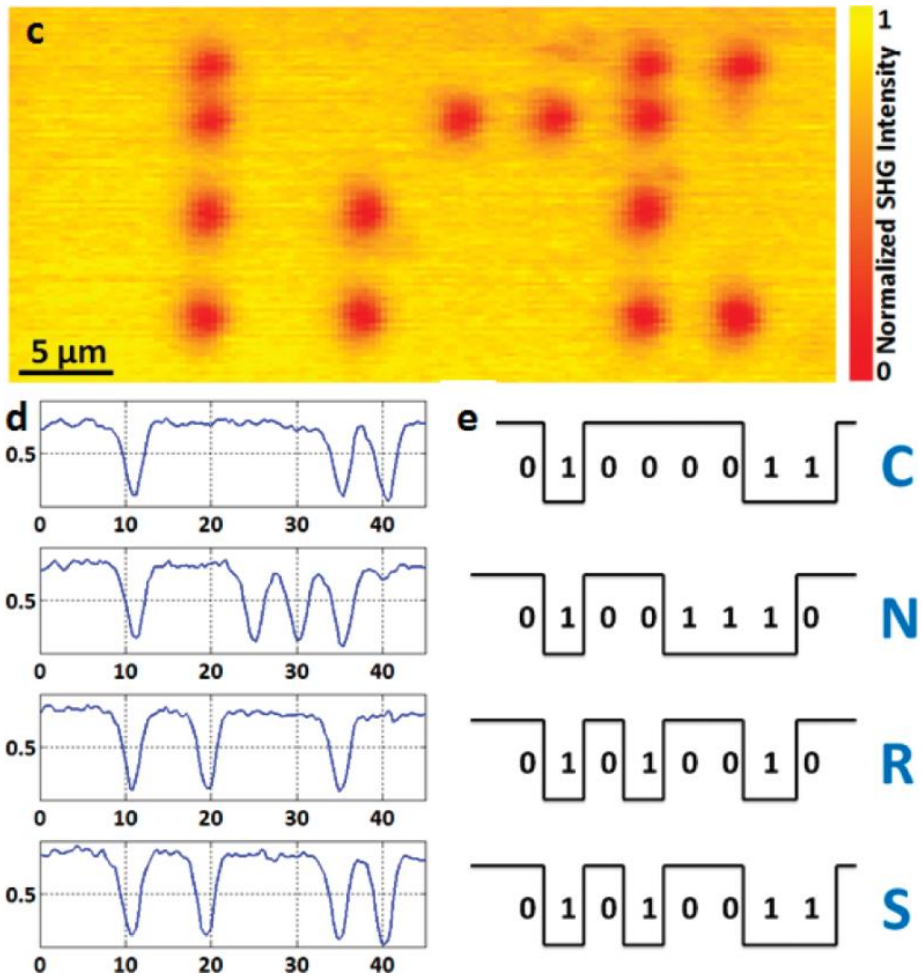
The spin-coating technique allows to make thin films with controlled thickness.

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



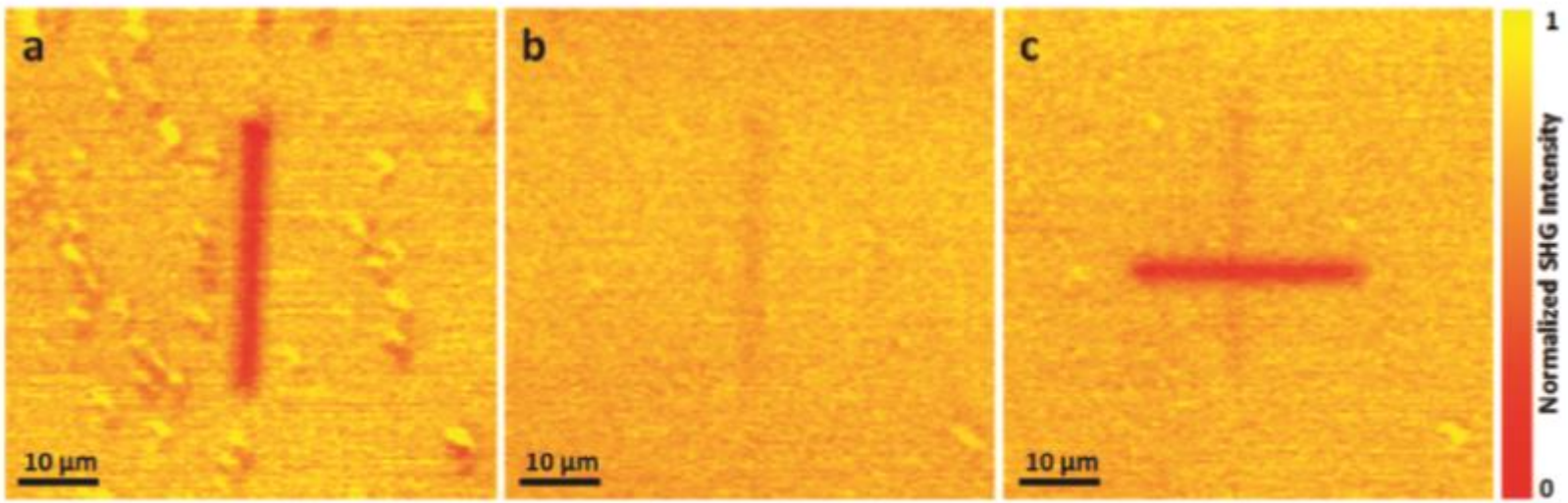
binary optical data storage





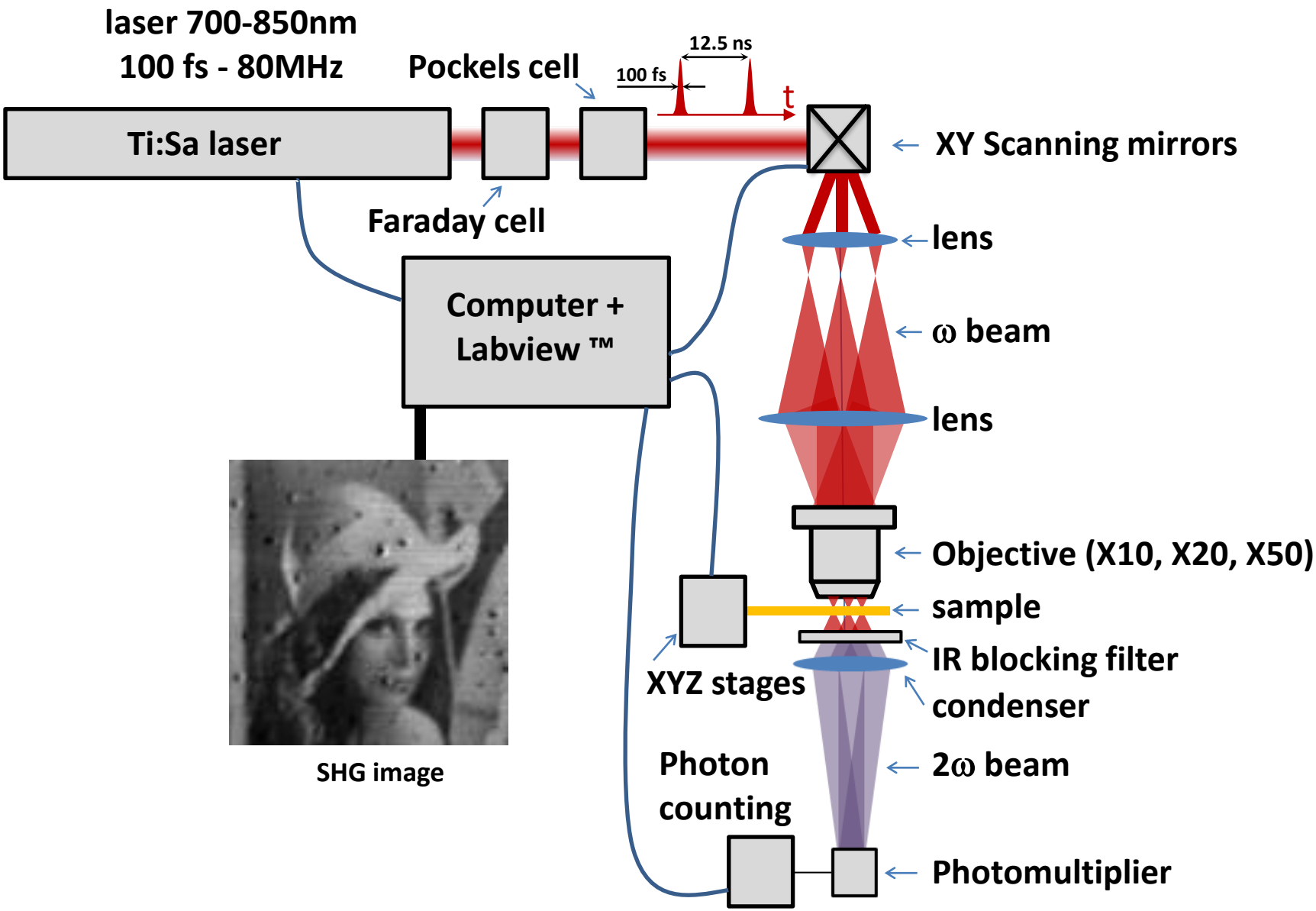
K. Iliopoulos et al, J. Am. Chem. Soc., 132, 14343 (2010)

Reversibility



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

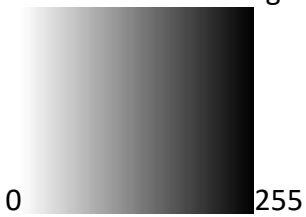
Multiphoton microscopy : setup



Principle of image storage

1. Calibration

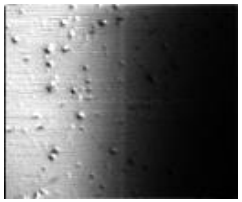
Reference 8-bit image



Writing laser power

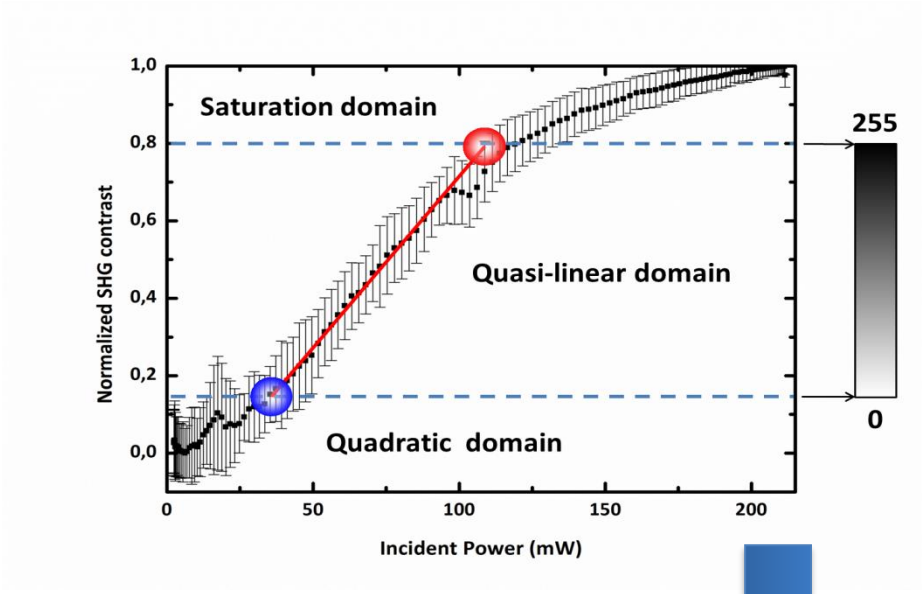
0 mW → 210 mW

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

100 mW

Black pixel

30 mW

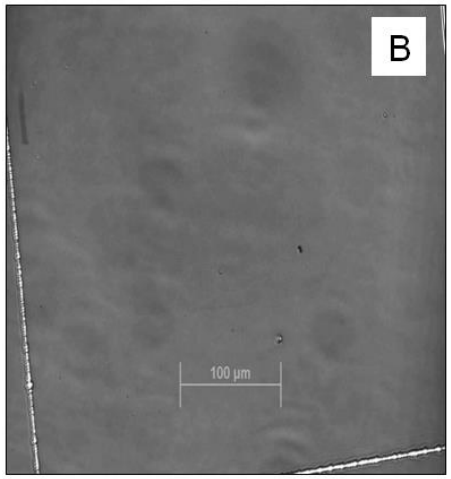
White pixel

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



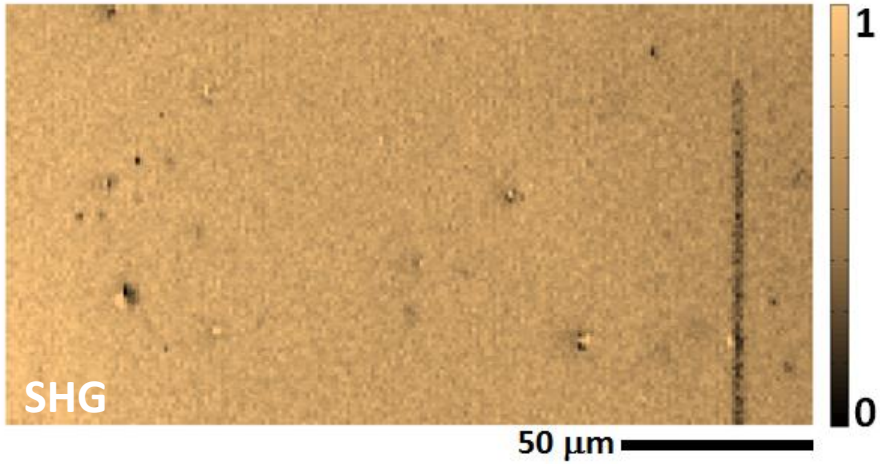
SHG imaging

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

Image storage by controlled dimerization

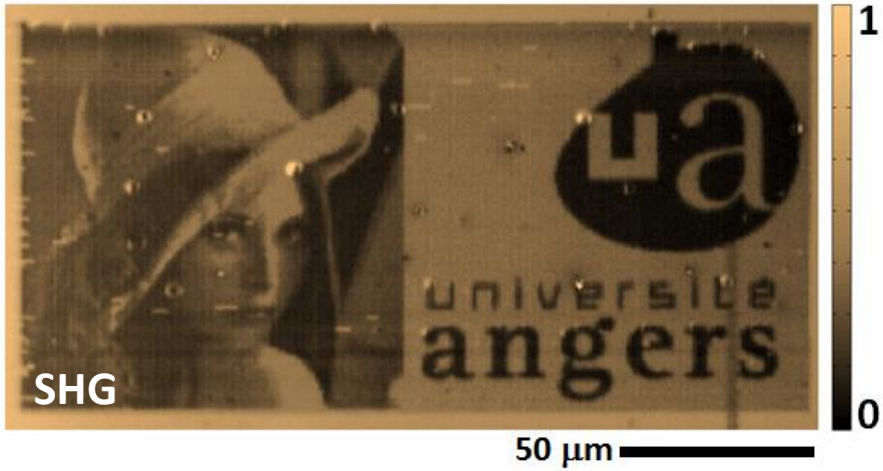
1 – **Calibration**

2 - **Fast SHG reading** of poled area
λ = 800 nm, P = 5 mW before writing



3 - **Image writing**
λ = 695 nm, P = 26 mW,
1 ms < Exp. Time < 1000 ms
I = Cste

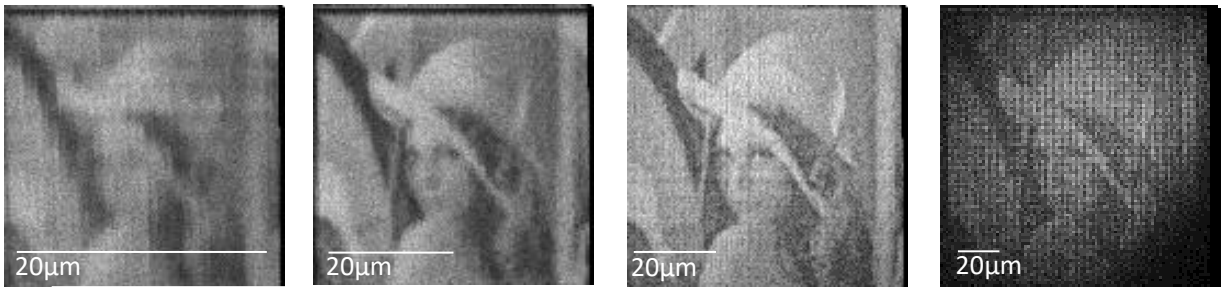
4 - **Slow SHG reading** of the same poled area λ = 800 nm, P = 5 mW



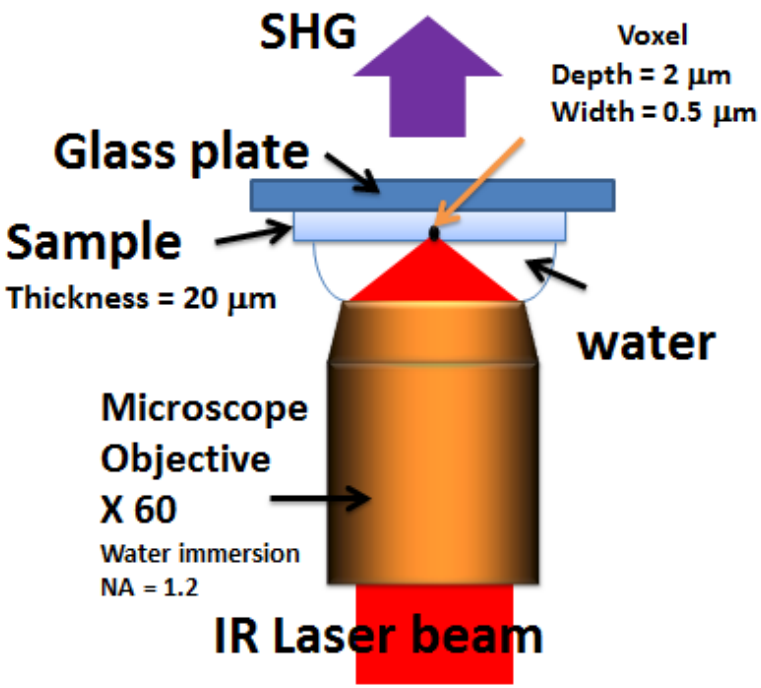
D. Gindre et al, Opt. Lett., 38, 4636 (2013)

Resolution optimization

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



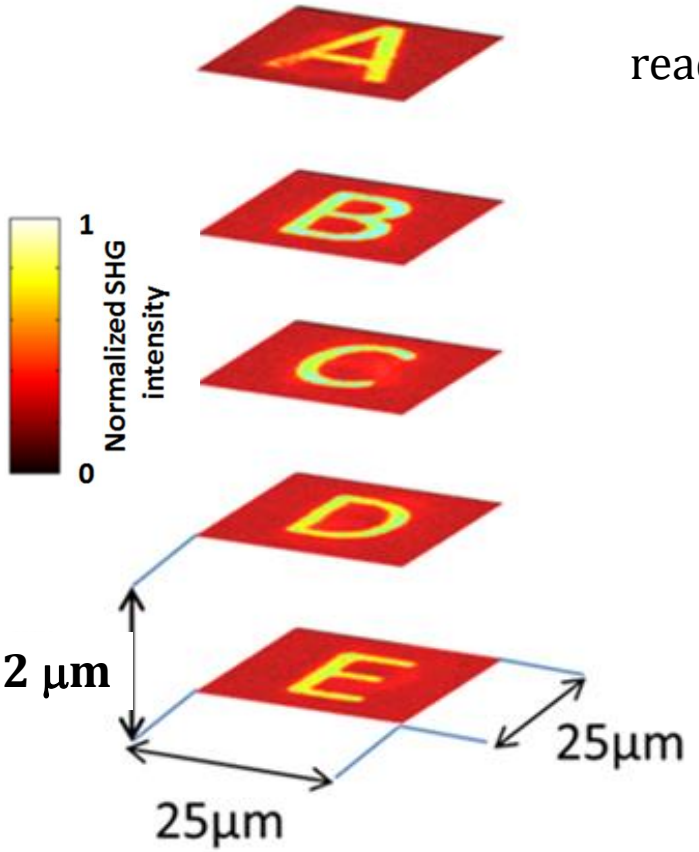
$$\delta_z = \frac{2n\lambda}{ON^2}$$

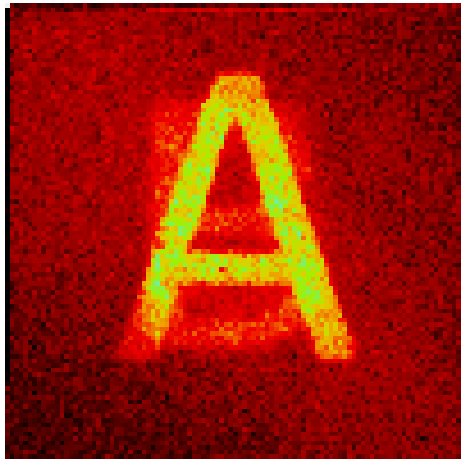


3D Binary storage

60 mW (700 nm) = white pixels
0 mW for the background
Space between letters :

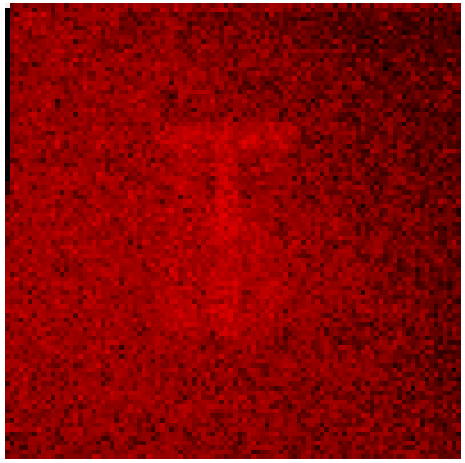
read-out at 800nm (power **10mW**)





100x100 pixels/image
Depth increment = 1 µm.
Pixel time = 200 µs

50 scans



100x100 pixels/image
Depth increment = 1 µm.
Pixel time = 200 µs

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 ⬇

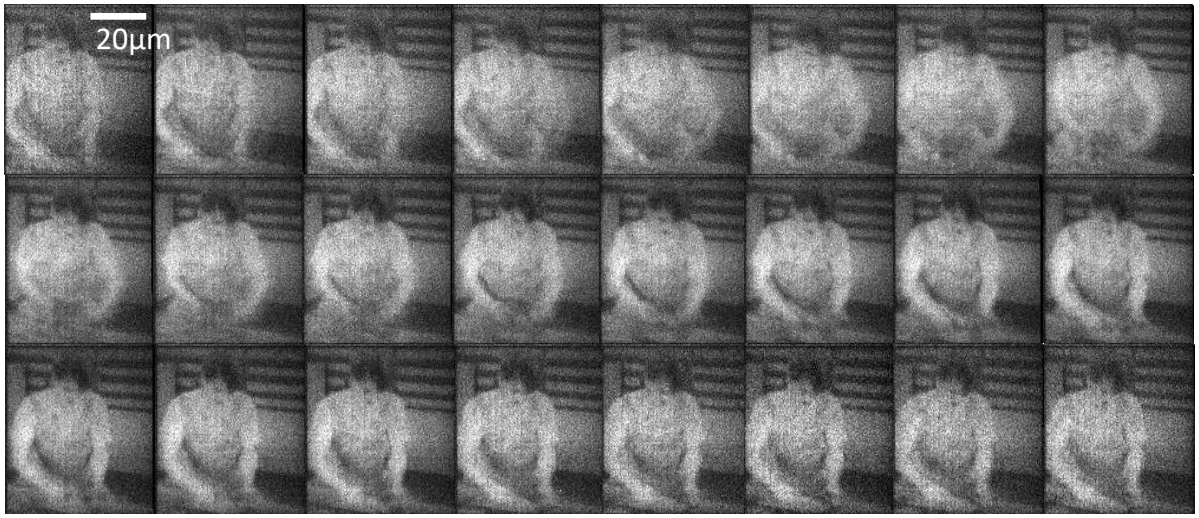
3D Image storage

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

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

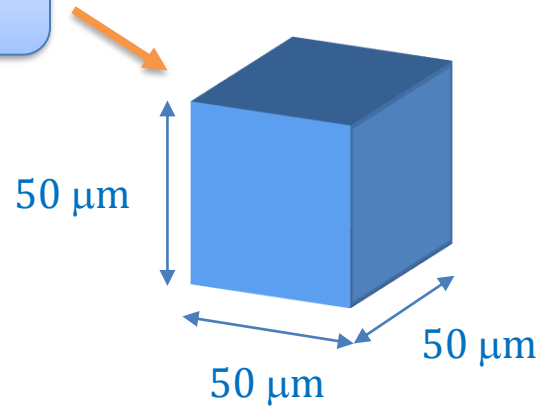
Space between images = **2 µm**

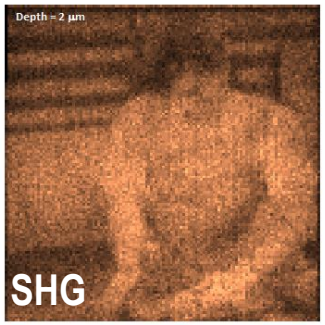
SHG images

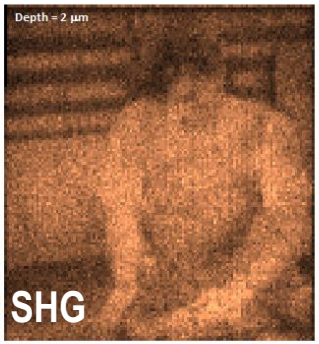


3D movie storage

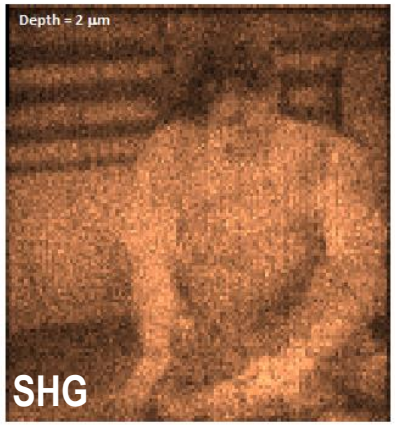
1 second of the movie
Modern Times







Poor quality bulk



Hidden tagging application

Invisible and Security TAG

Written with a focused laser beam

IR laser + scanning TPEF/SHG

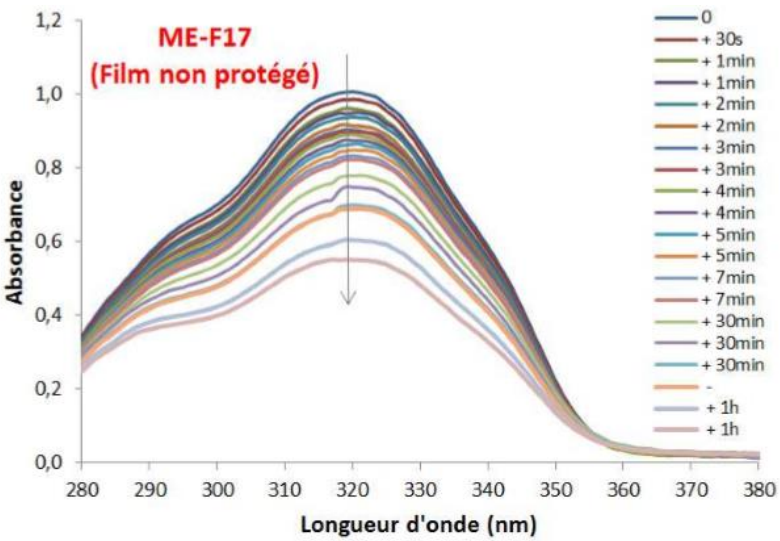
The tag is invisible without non linear optical measurements (laser + TPEF or SHG)

Hidden tagging application

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

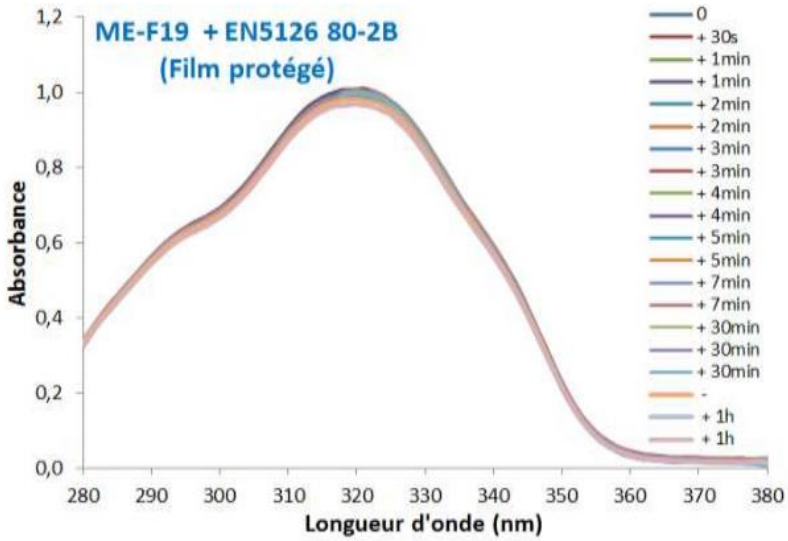
→ Protection of the premarked polymer **with stop UV film**
Formulation from acrylic resin ENCOR-5126 + Solasorb UV200 + Tinuvin P

Without protection



UV lamp
(150W)
319 nm

With UV protection



Conclusion

- 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-photons 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

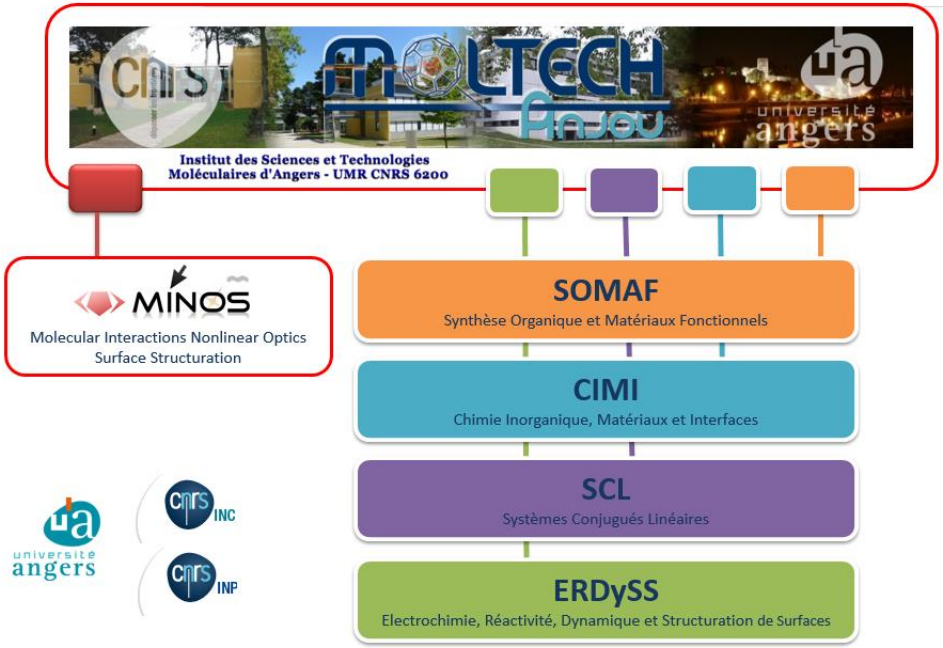
Bouchta Sahraoui
Pr MOLTECH-Anjou, NLO measurements

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