Towards the development of new optical Fibers

Younès Messaddeq

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The Optics & Photonics Building

- **Building 10.400 m² ($31 M)**
- **Equipment (15M$)**
  - Laboratory space: **6.900 m²** (class 10,000 clean rooms)
  - 45 offices for professors and researchers
  - Office space for 200 students

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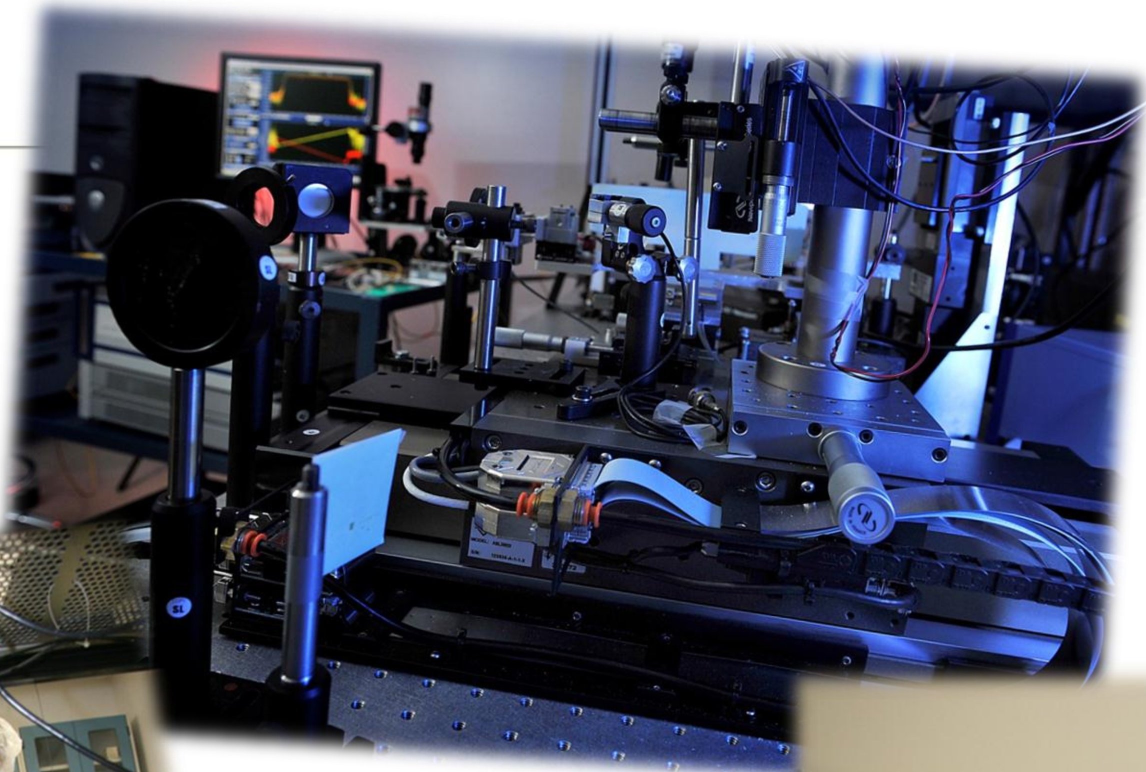

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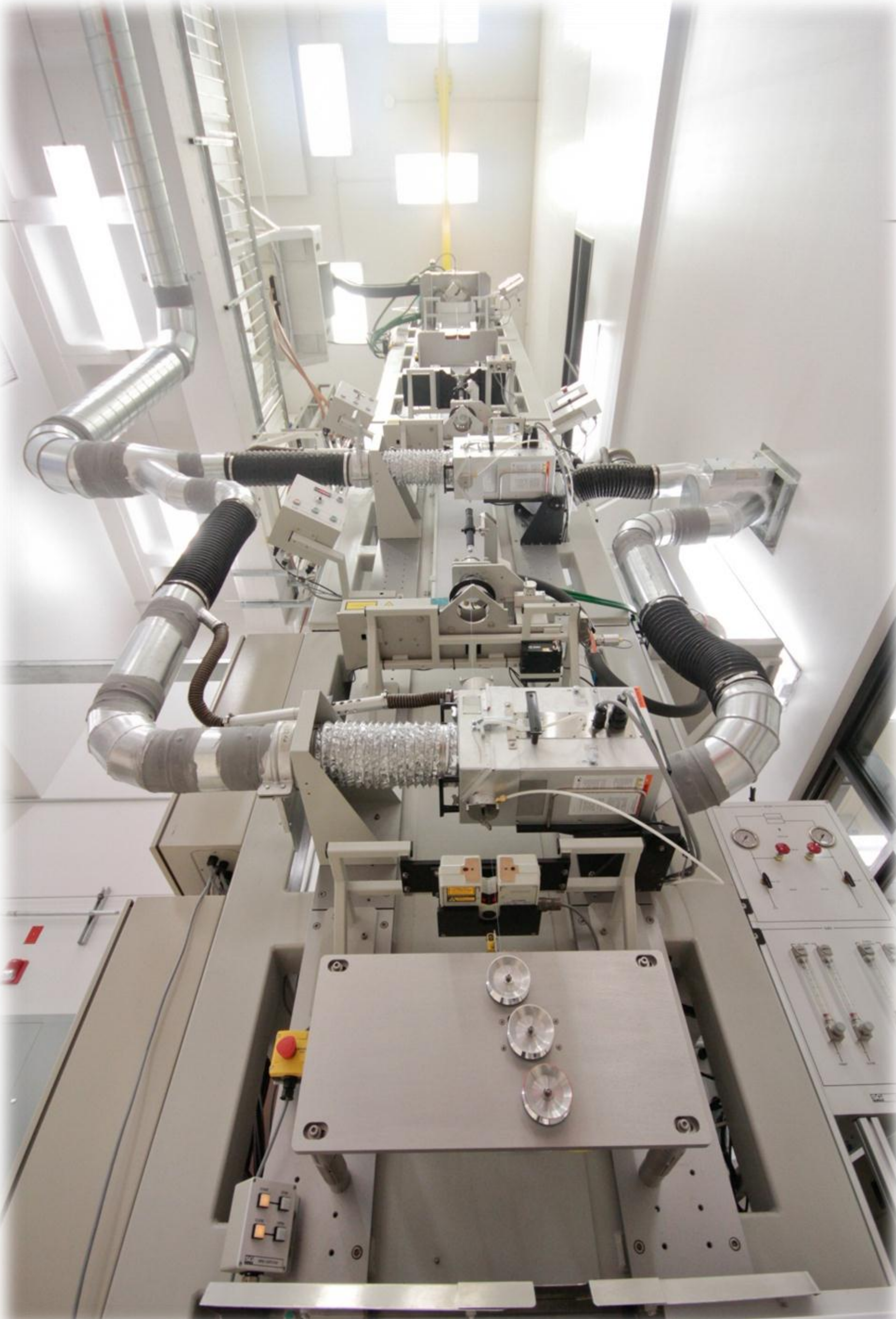


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NICOLAS
SG

Outline

- **Introduction**
- **Chalcogenide fibers**
  - Production of Highly pure glasses
  - Microstructural fibers
  - Waveguides using Fem. Laser
  - Self-organised periodic structure.
- **Fiber Laser**
- **Silica fibers**
  - Telecommunication
  - NPK Sensors
  - Health
- **Perspectives**

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Introduction

ITC

- Today, data exploration(unify theory, experiment and simulation);
- Increase Scientific Information Velocity;
- Huge increase in Science Productivity;

↓

- Can Internet unify all the literature and data?
- Managing petabyte(how to organize it? To share it?...)

Will be inadequate for 2025!

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Introduction

Earth and Environment

- **Pan-STARRS project** will capture 2.5PB of data each year;
- The large **Hardon Collider** will generate 50 to 100PB of data, with 20PB processed on a grids 100,000CPUs;
- The **climate** change ?
- How do we quantify and monitor total **forest biomass**?
- **Ocean science** need innovative technologies to see and sense, different processes.

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Introduction

Health &wellbeing

- Enhance medical care through improved diagnoses?
- New tools for neuroscience?
- New tools for chirurgy?
- Etc…….

Question:

How glass materials can contribute effectively to all these areas?

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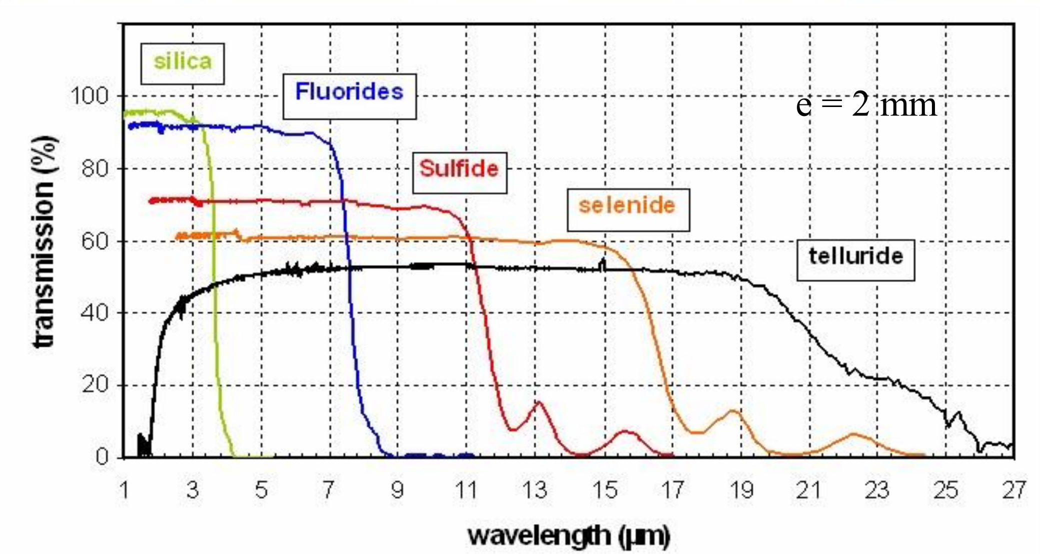
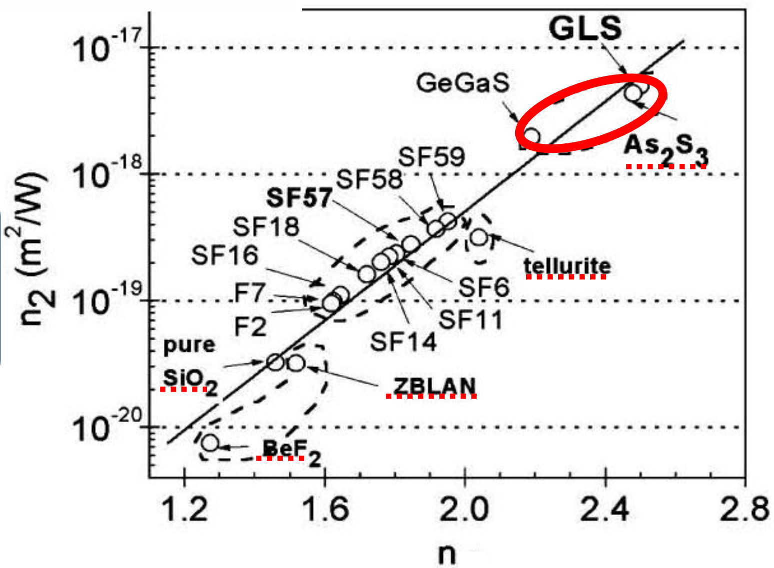
NON SILICA GLASSES : Interests



3 - 5 µm and 8 - 12 µm

High linear and non linear refractive index



X. Feng & al, J. Ligh. Tech. 23 (2005) 2046

<u>Phonon energies</u>

Oxides

Silicate (SiO_2): 1100 cm^{-1}

Fluorides

ZrF_4 : 560 cm^{-1}

Chalcogenides

As2S3= 350cm-1

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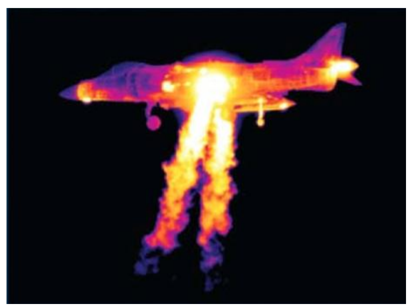
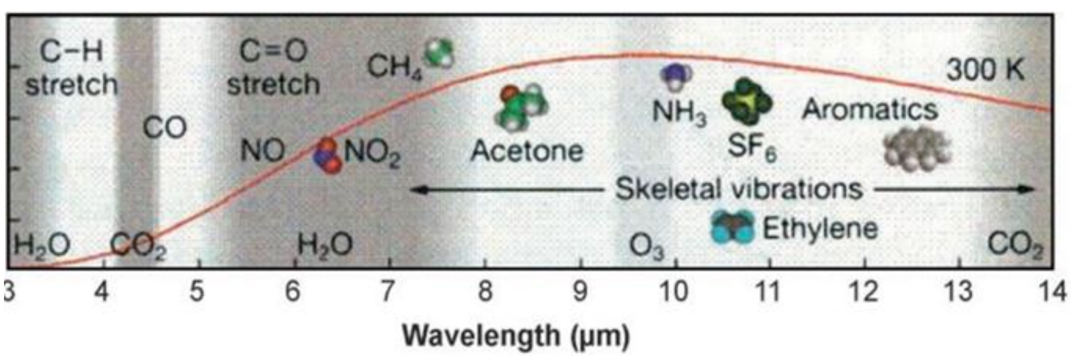
Applications for the infrared

Passive:
- Thermal imaging,
- Sensors for medicine, biology, environment (organic molecules with infrared chemical imprint)
- Pressure, temperature sensors





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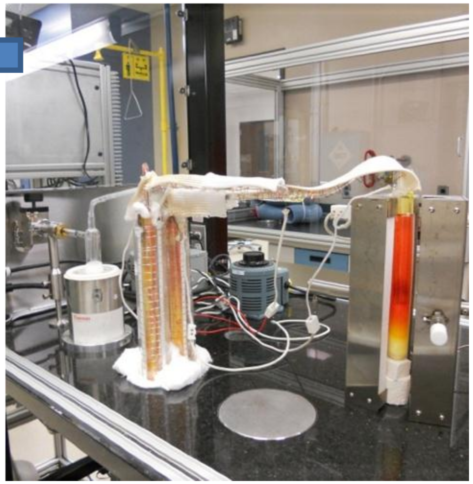
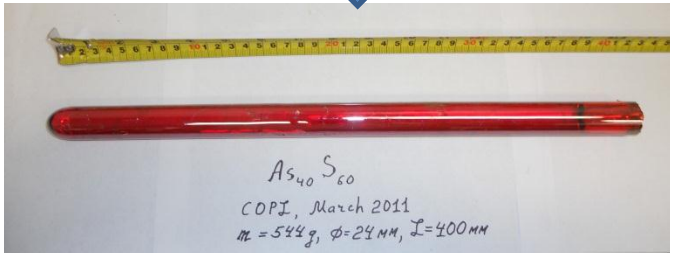
Production of H.Pure Chalcogenide glasses





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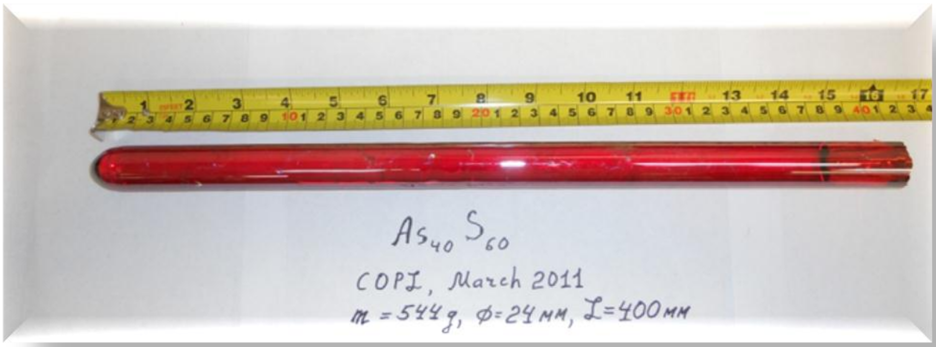
Production of H.Pure Chalcogenide glasses



As2Se3

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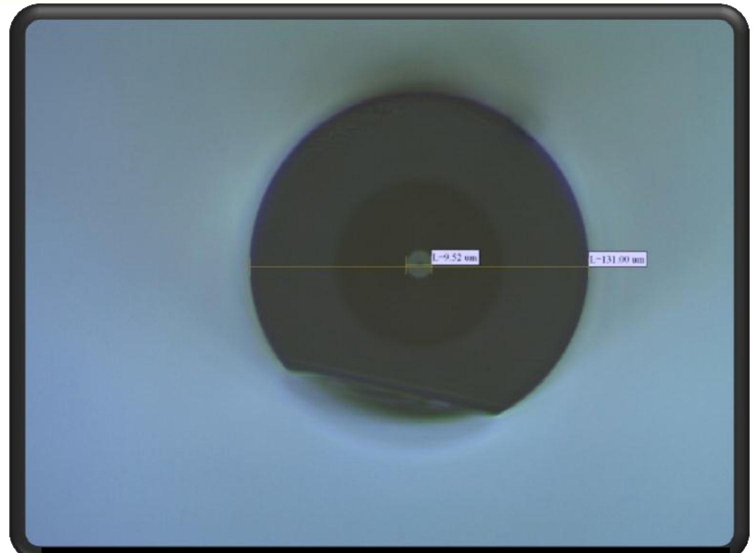
Chalcogenide Fibers



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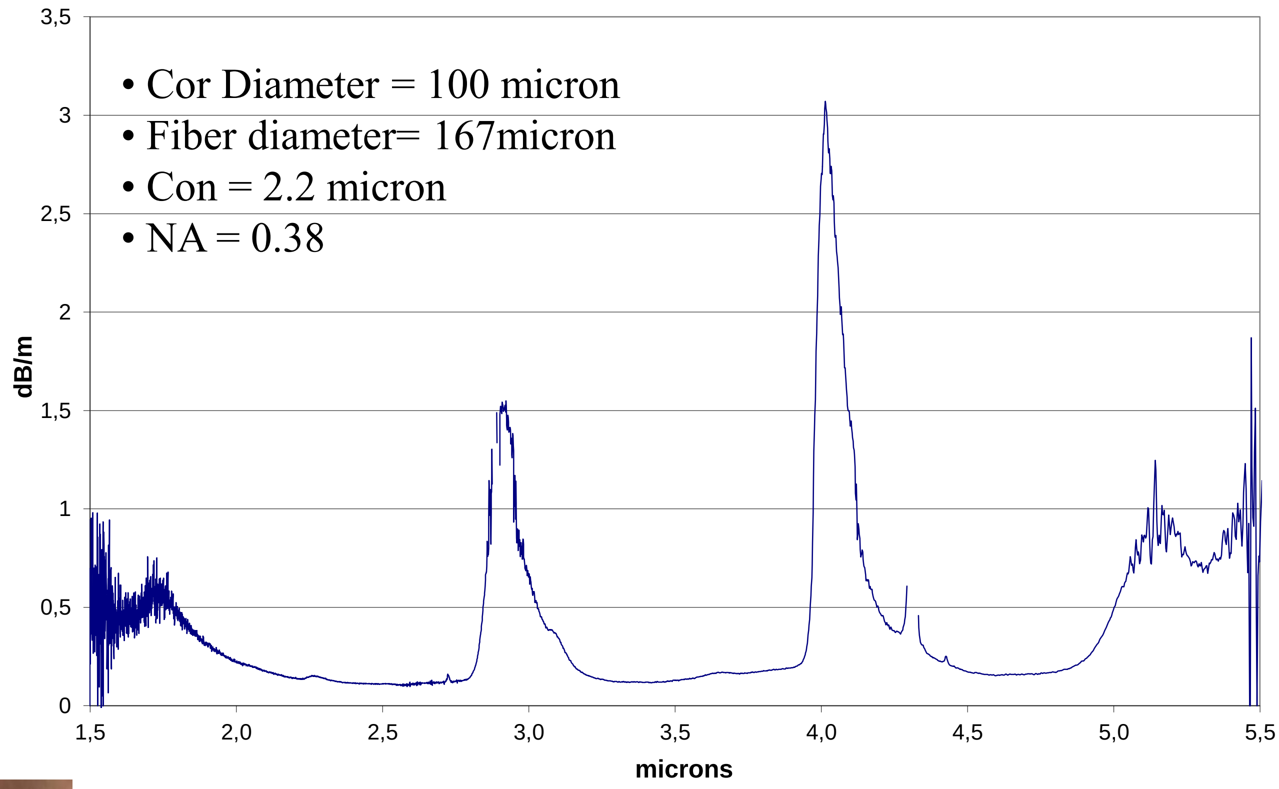
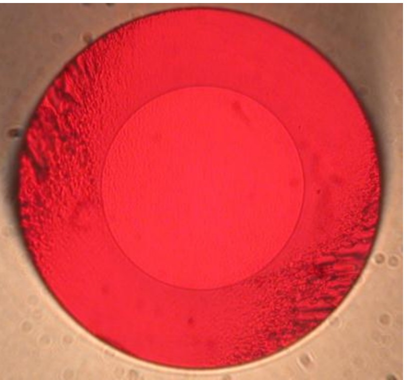
Multimode fibers As_2S_3

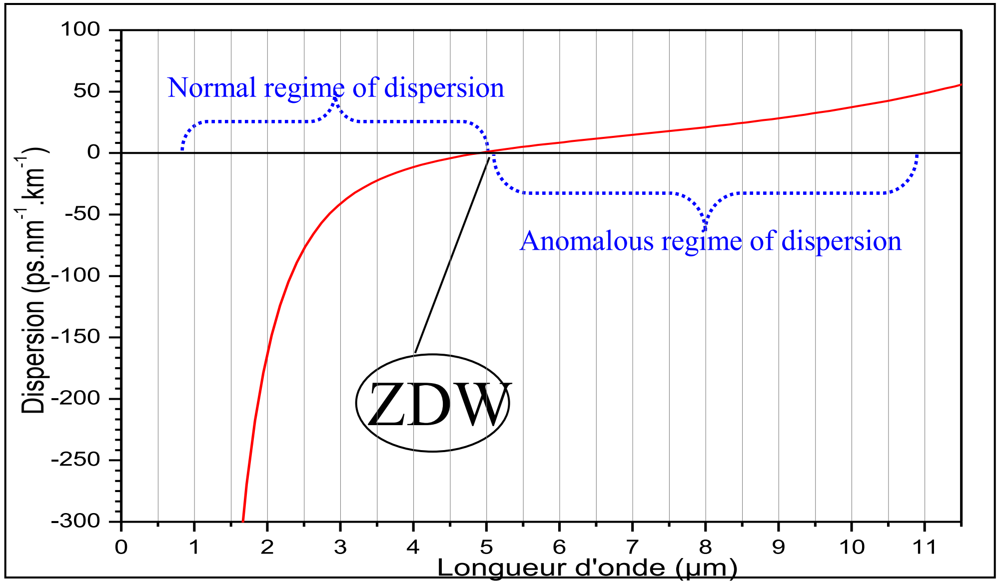




- Minimum d'atténuation = **0.1 dB/m @ 2.55 μm**
- Impuretés : OH **(> 1.5 dB/m @ 2.9 μm)**

  SH (**~ 3 dB/m @ 4.0 μm** ⇒ ~ **1.3 ppm en SH)**

Chalcogenides MOF : Material Dispersion



Material ZDW ≈ 5µm

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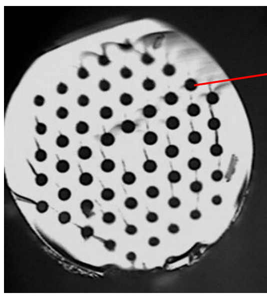
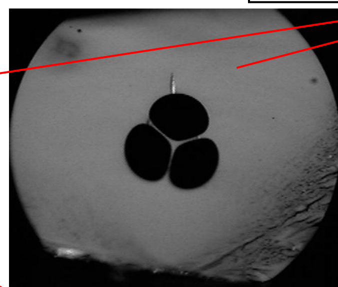
Chalcogenides MOF : Interests

$$\gamma = \frac{2\pi}{\lambda}\frac{n_2}{A_{eff}}$$





& Chalcogenide material

Nonlinearity exacerbate

ZDW management + Nonlinear effect generation

Supercontinuum generation

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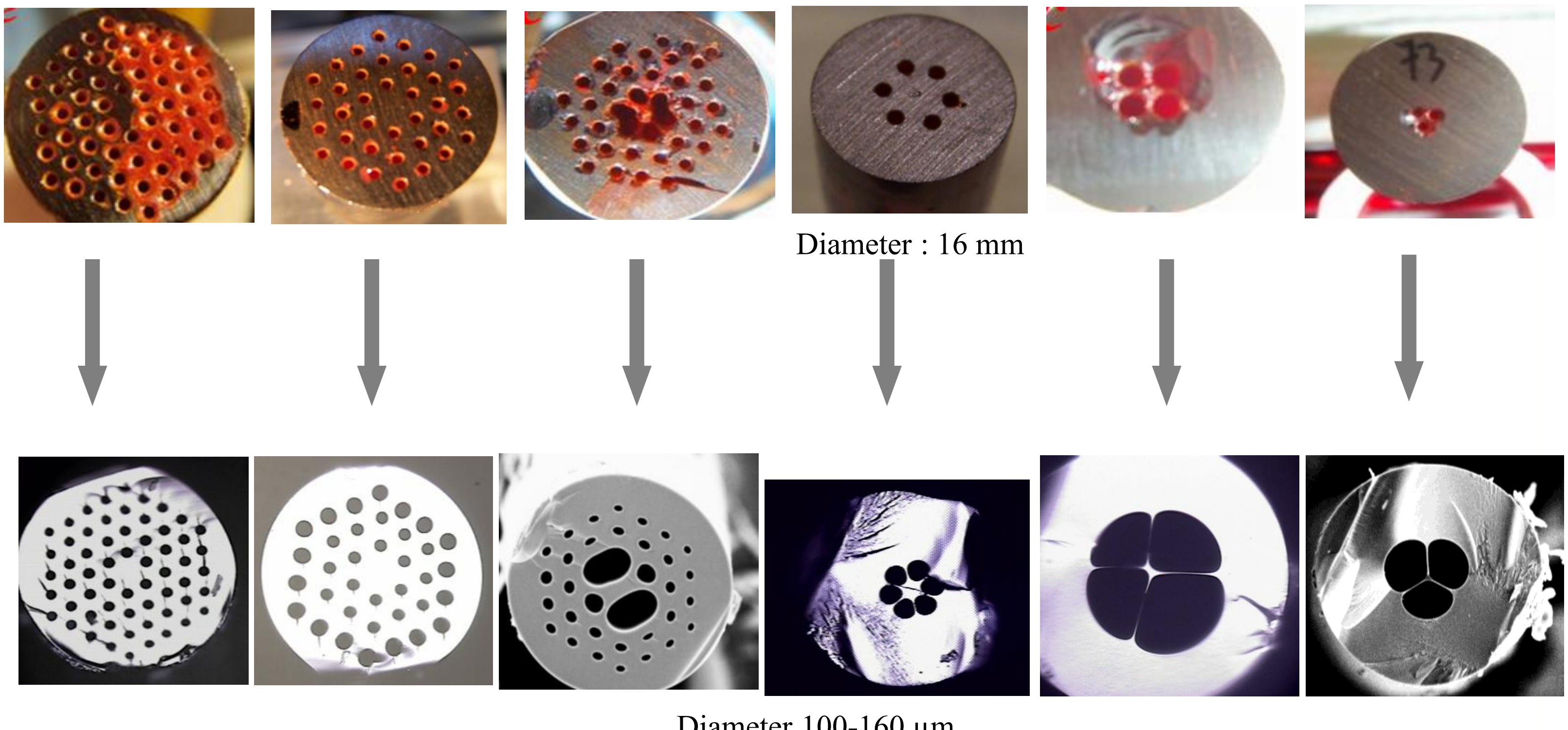
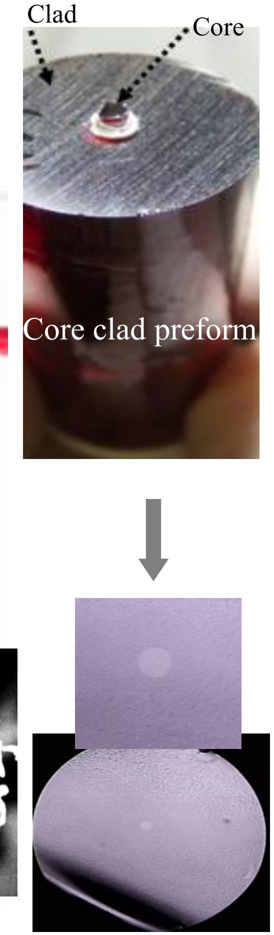
Chalcogenides MOF : fibers

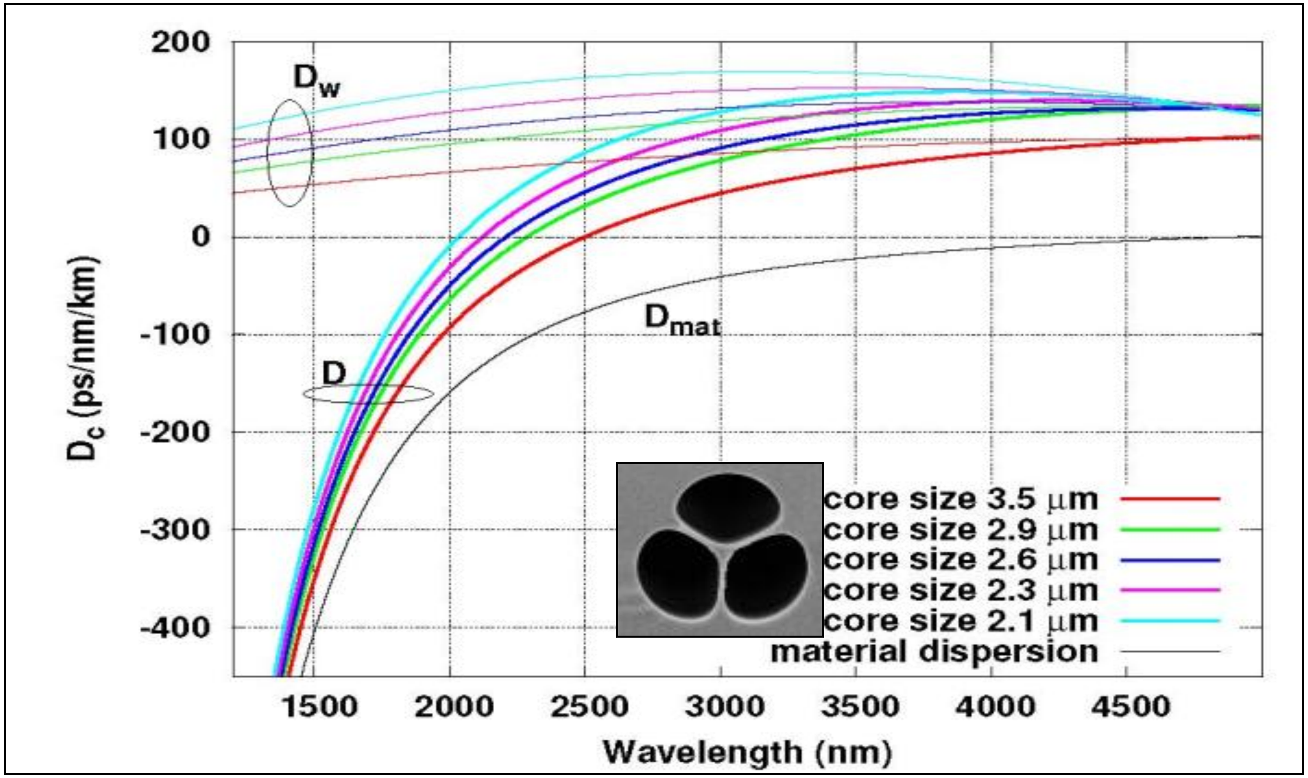
Preforms & corresponding fibers





Chalcogenides MOF : Material Dispersion

Suspended core MOF



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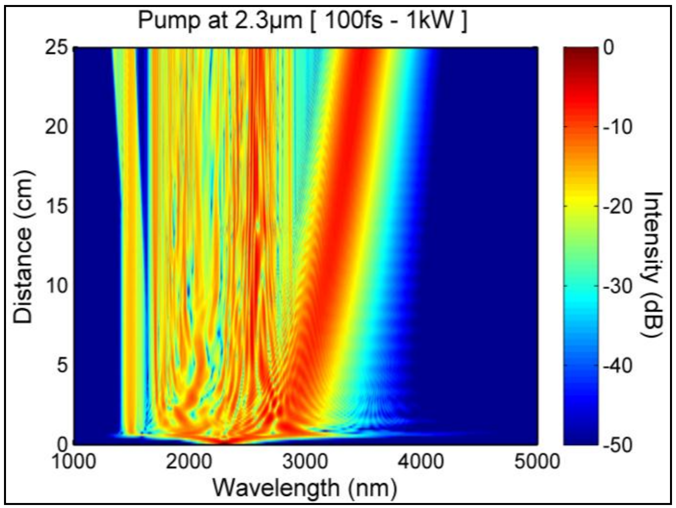
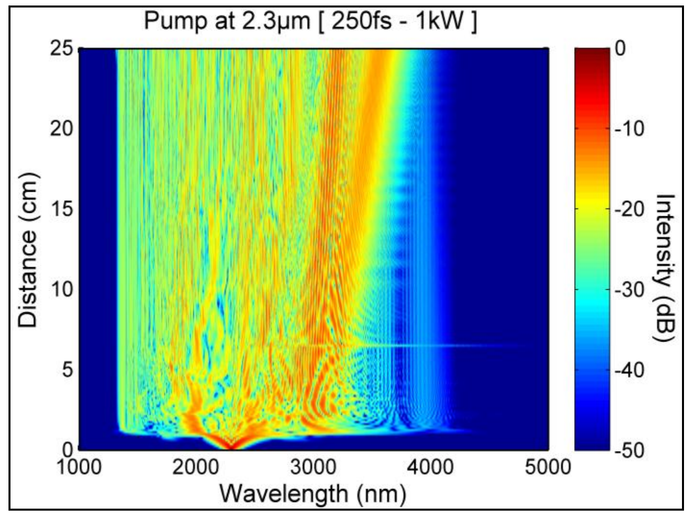
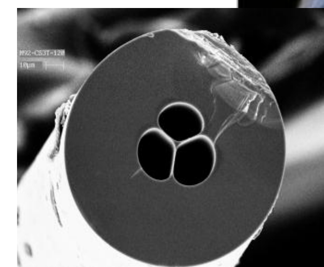
Joint Research with (Prof.F.Smektala, Dijon, France)

Supercontinuum in 3-5µm window Pumping MOF close to their anomalous dispersion regime







Core diameter : 2,6 µm
Length: 0-25 cm
Lossess @ 1550 nm = 0.7 dB/m
ZDW = 2.21 µm
Peak power : 1 kW
Pulses width: 100fs & 250 fs
λpompe : 2300 nm

<u>1-4 µm Supercontinuum couvering the atmospheric window 3-5 µm</u>

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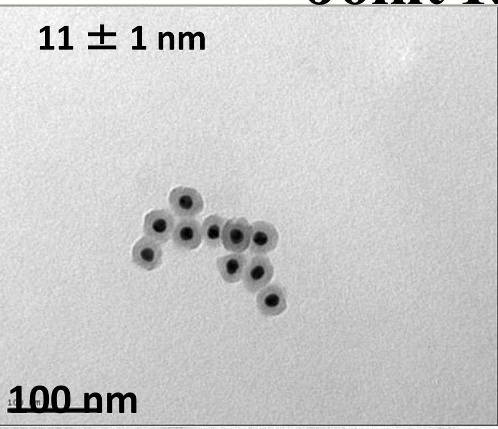
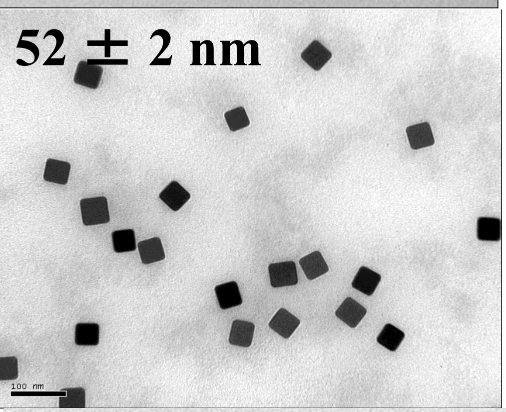
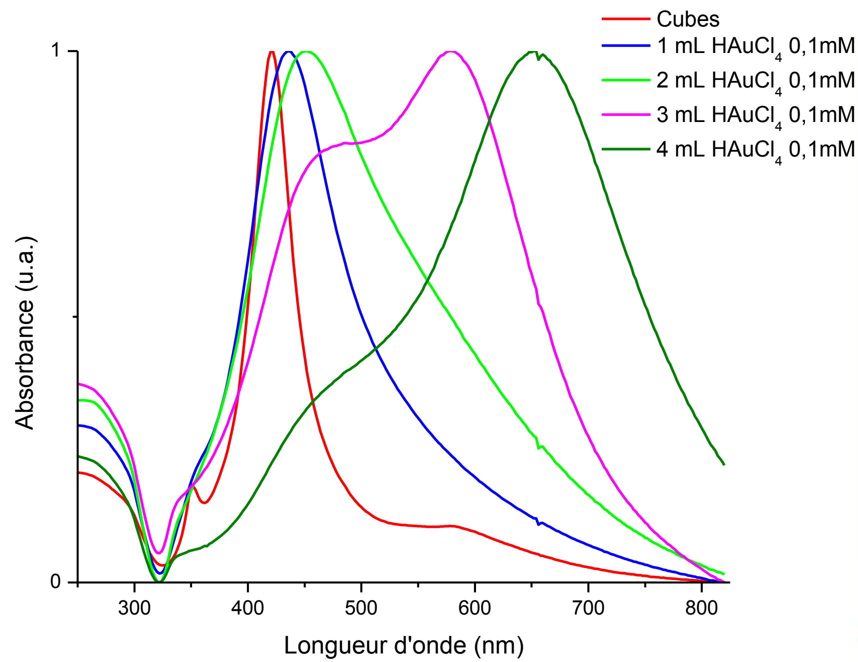
Nanopaticles Au ou Ag

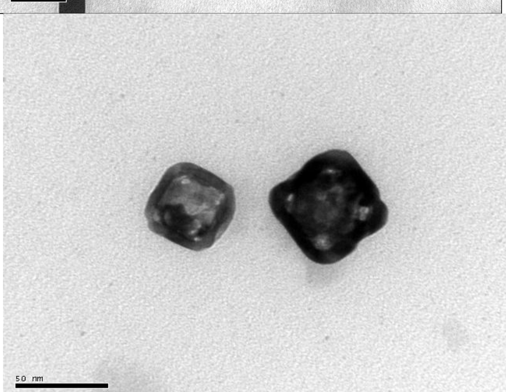
Joint Research with D.Boudreau (COPL).





Cubes





Cages

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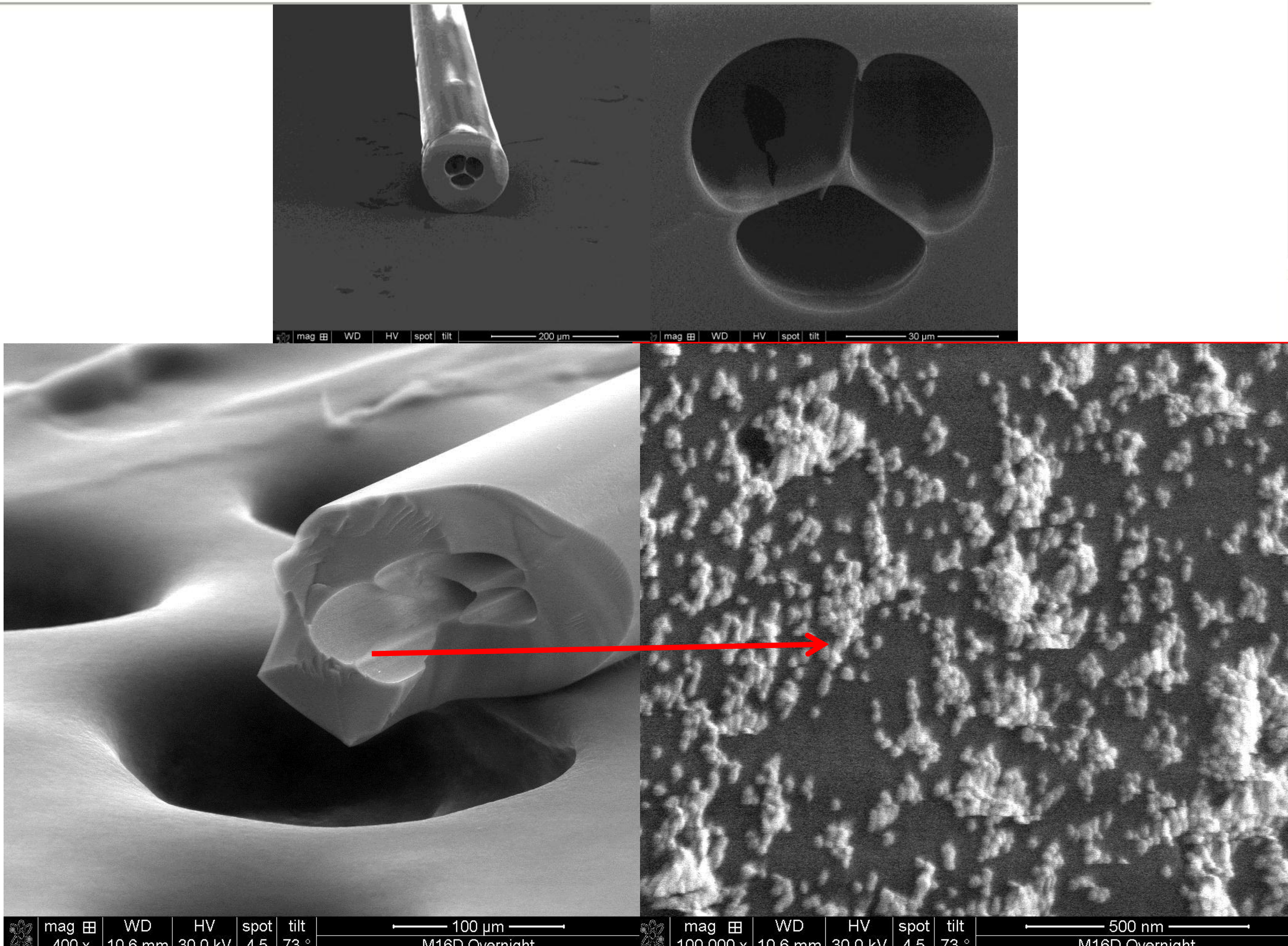
Multifunctionnal fibers



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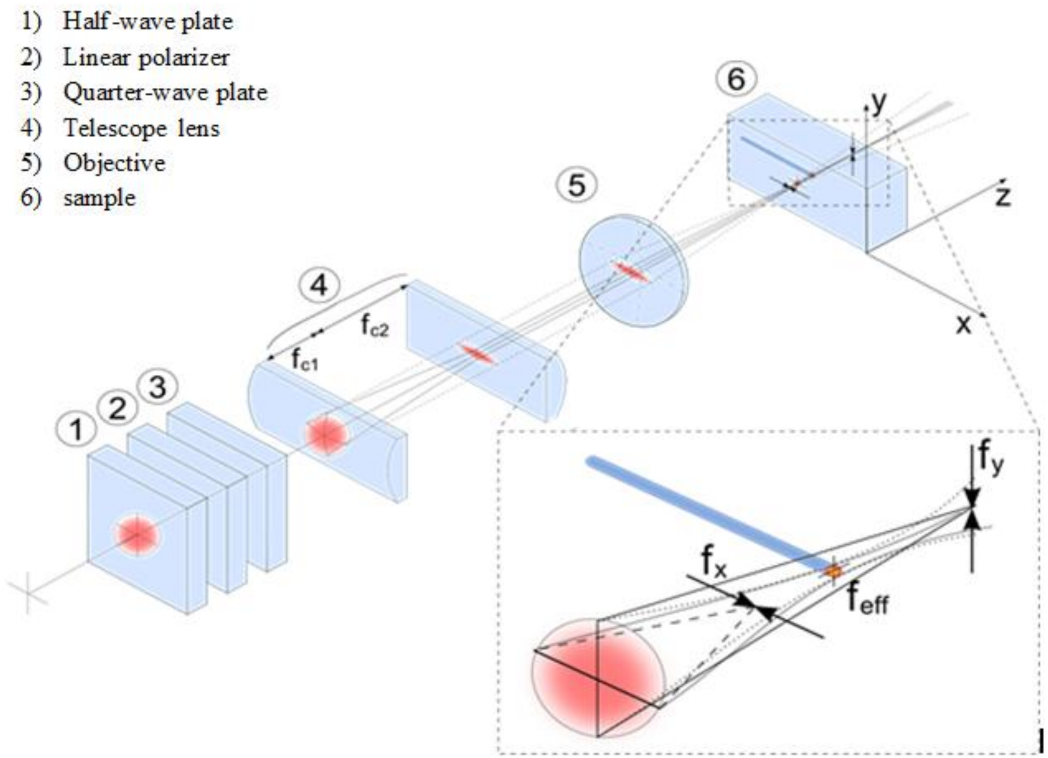
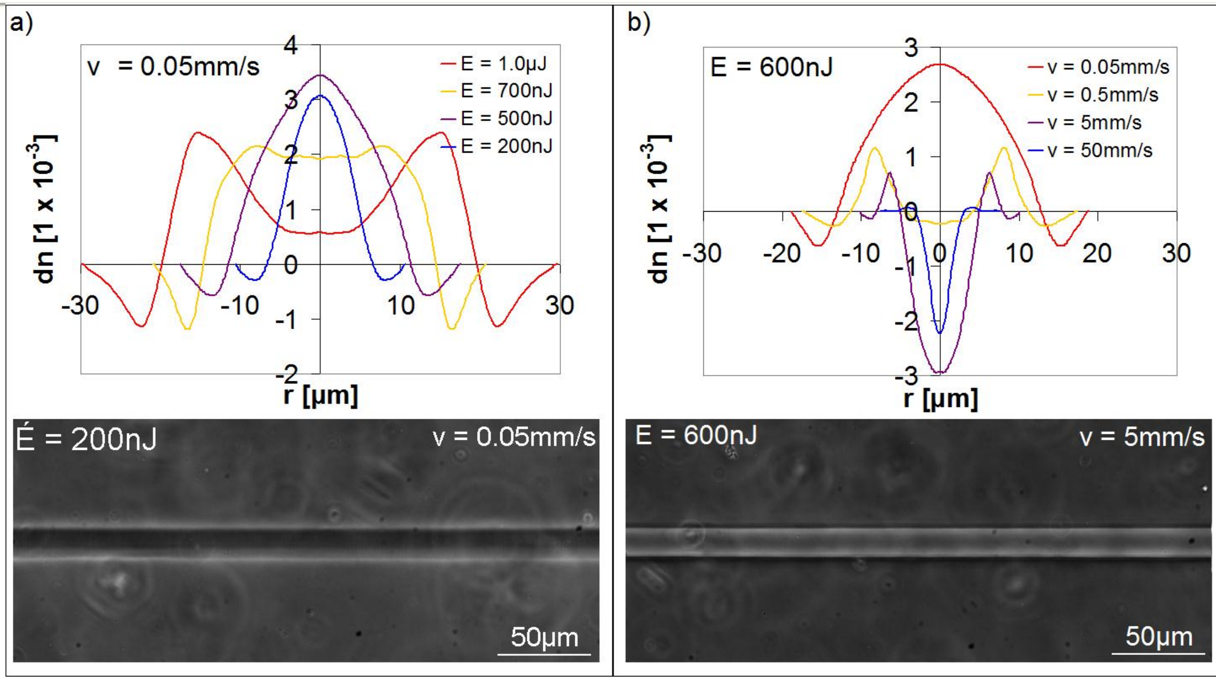
Production Mid-IR Waveguides
GeS Based Glasses

Join Research with Prof. R. Vallée (COPL)

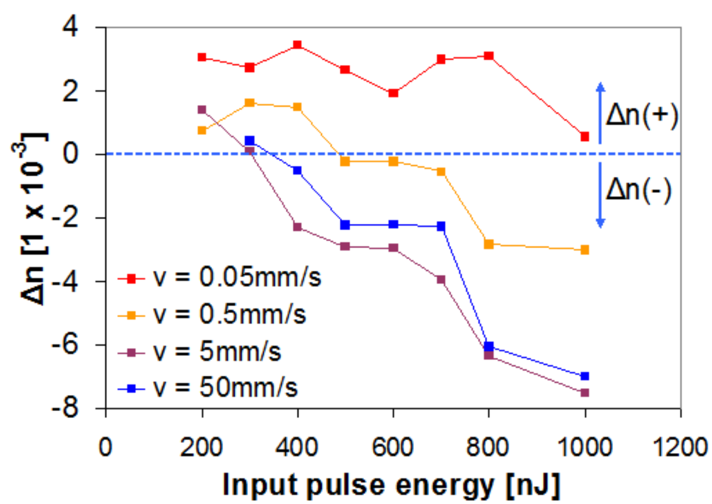


- Pulse duration :70 fs
- Wavelength : 800 nm
- Ep : 0.2μJ→ 2.0 μ J
- Frequency : 100 kHz
- Translation speed : 0.05mm/s, 0.5mm/s, 5mm/s, 50 mm/s

Production Mid-IR Waveguides
GeS Based Glasses



$$\Delta\varphi(x,y) = \frac{2\pi T(x,y)\Delta n(x,y)}{\lambda}$$



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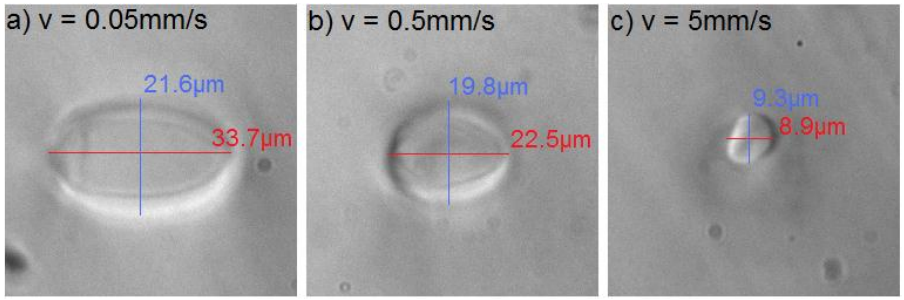
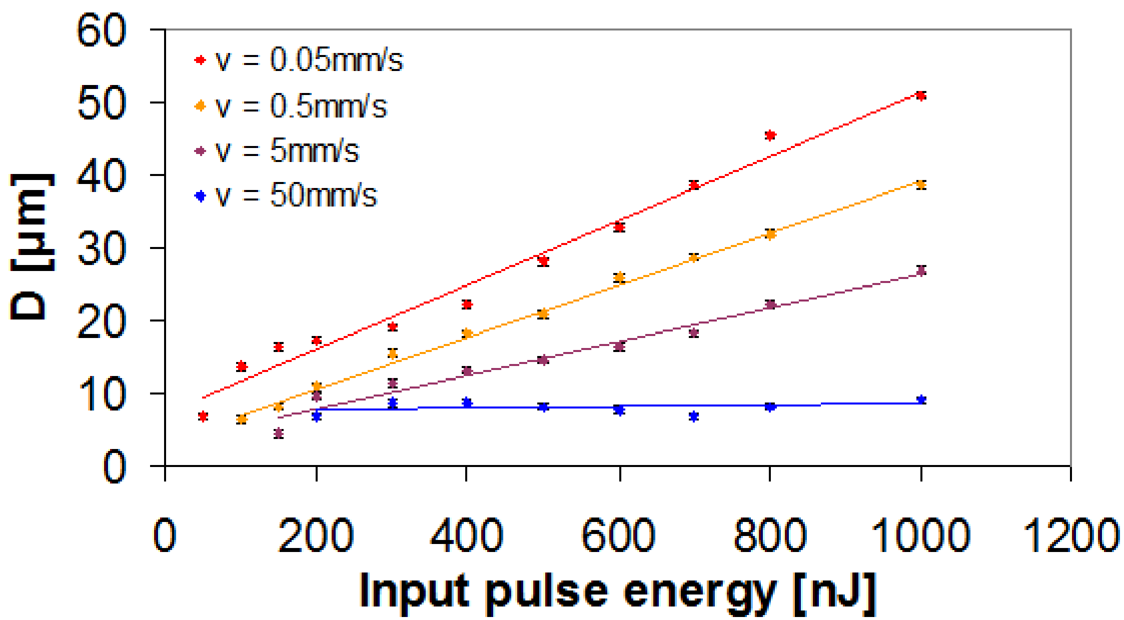
Production Mid-IR Waveguides
GeS based Glasses





S.H.Messaddeq, Opt express, 20(2)2826, 2012

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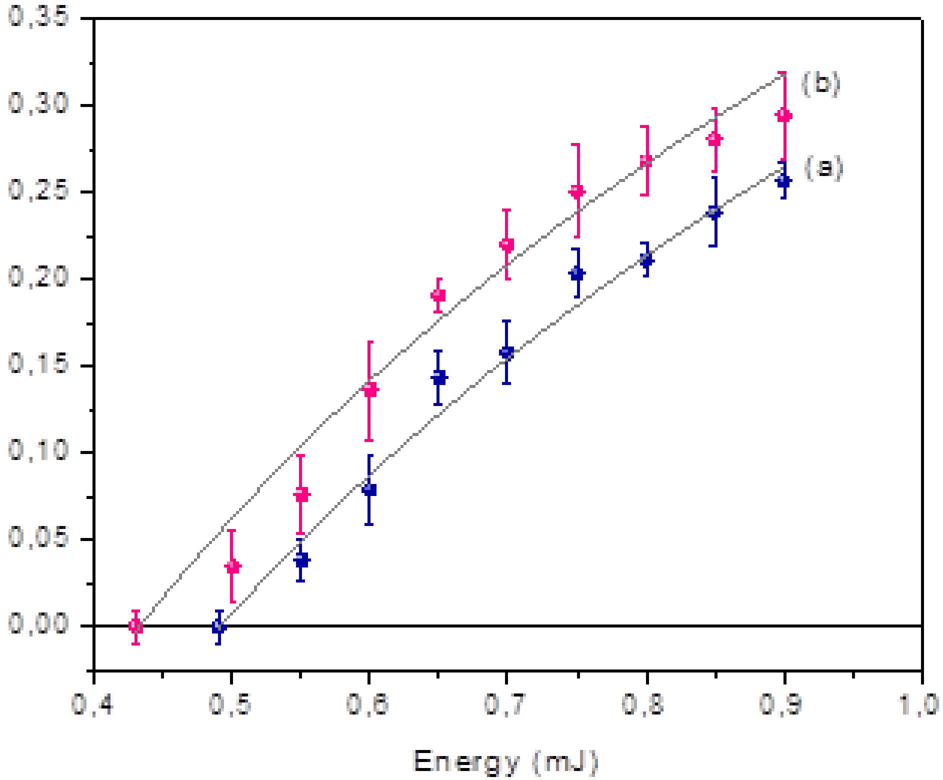
Interaction with Laser Femto $Ge_{25}Ga_1As_9S_{65}$

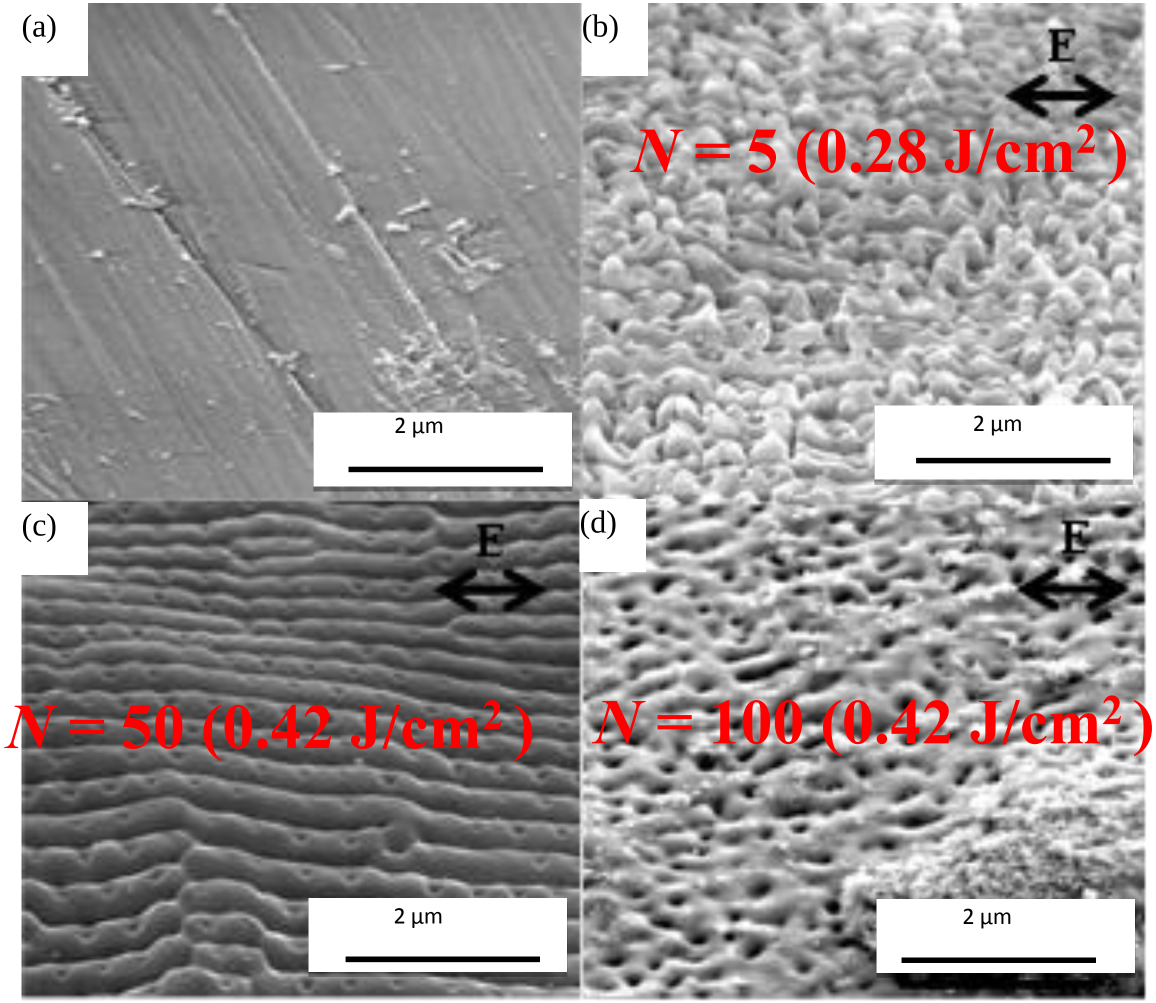
$$D^2 = 2w^2 \ln\left(\frac{E_{in}}{E_{th}}\right)$$

a) N=10 pulses
b) N=50 pulses



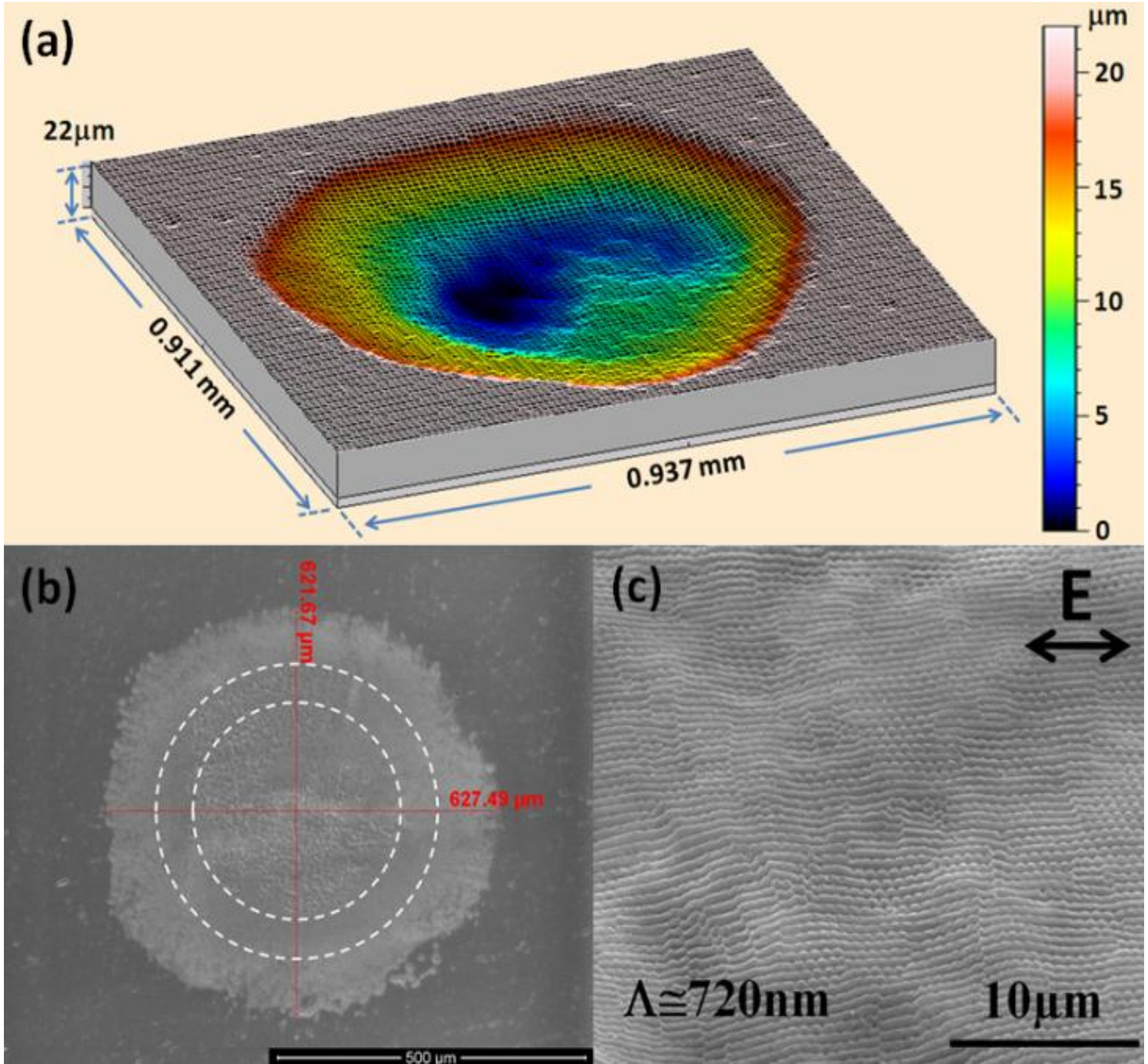
Squared diameter of the ablated craters as a function of the incident pulse energy

Interaction with Femto laser



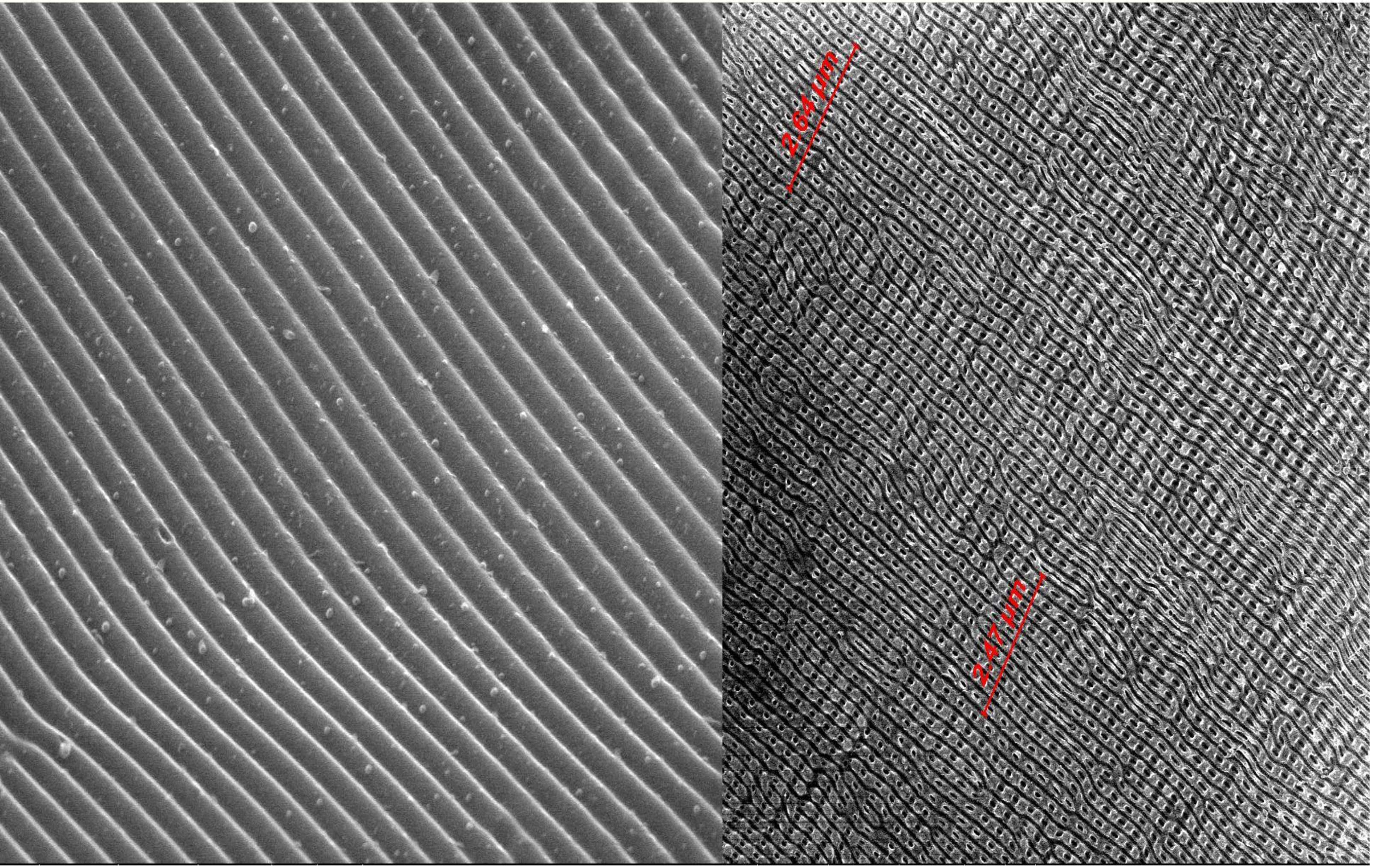
SEM image of an ablated region

N = 50 (0.42 J/cm²)



Interaction with Femto laser

E=0.2mJ, #pulses=500 **λ=400nm** **E=0.3mJ, #pulses=5**



The nanostructures could be formed with fluences between 0.36 & 1.06 J/cm²

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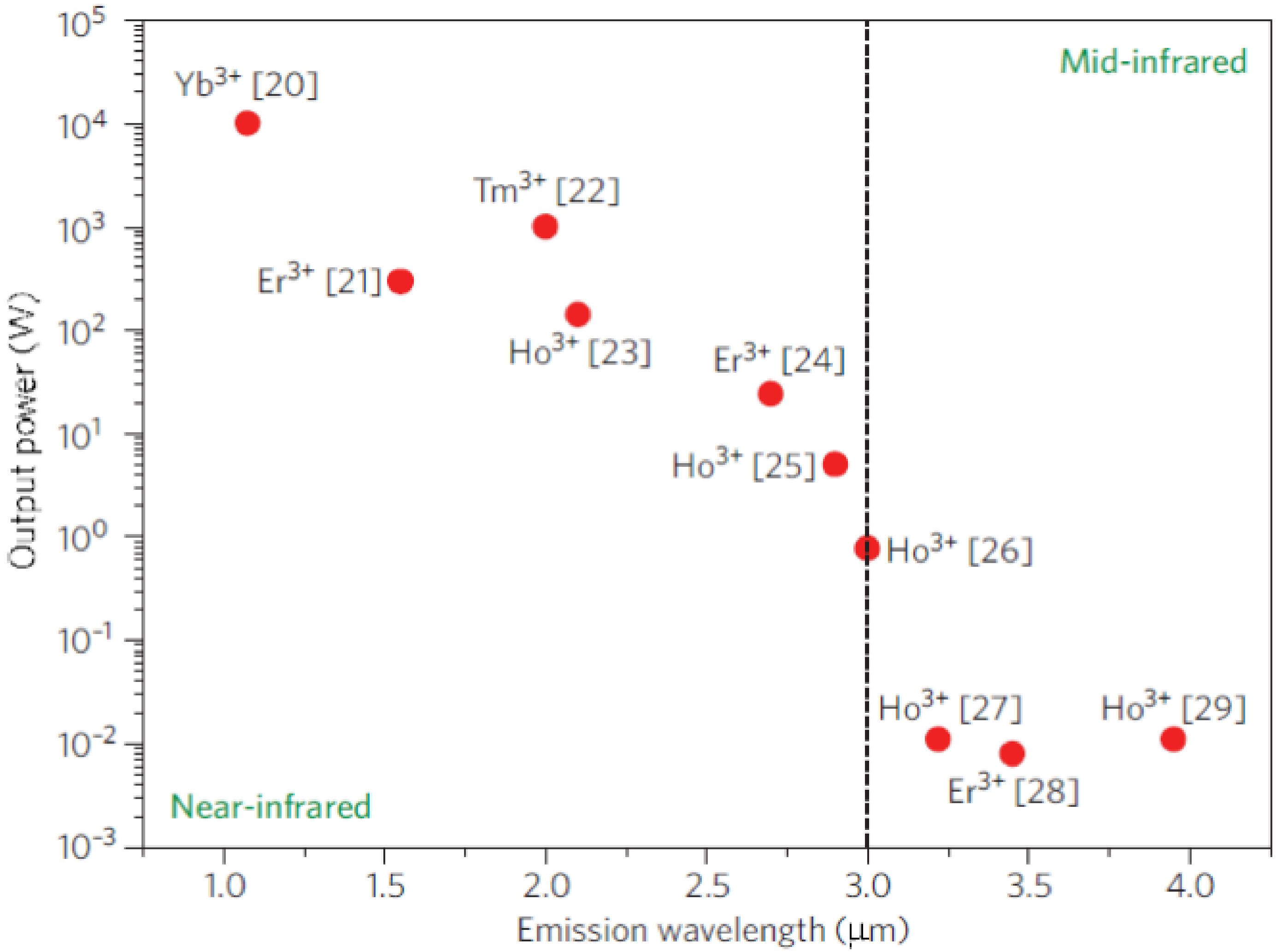
Fiber Laser

Fiber laser in Mid-Infrared



S.D.Jackson, Nature Photonics, 6,423 (2012)

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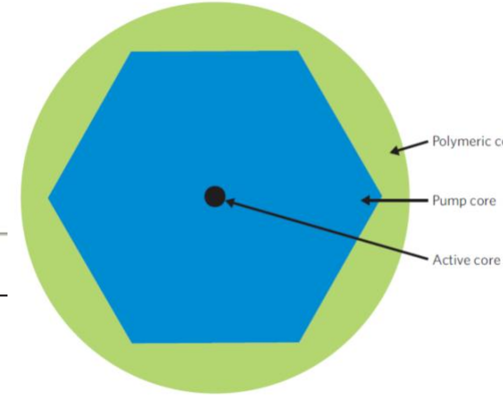
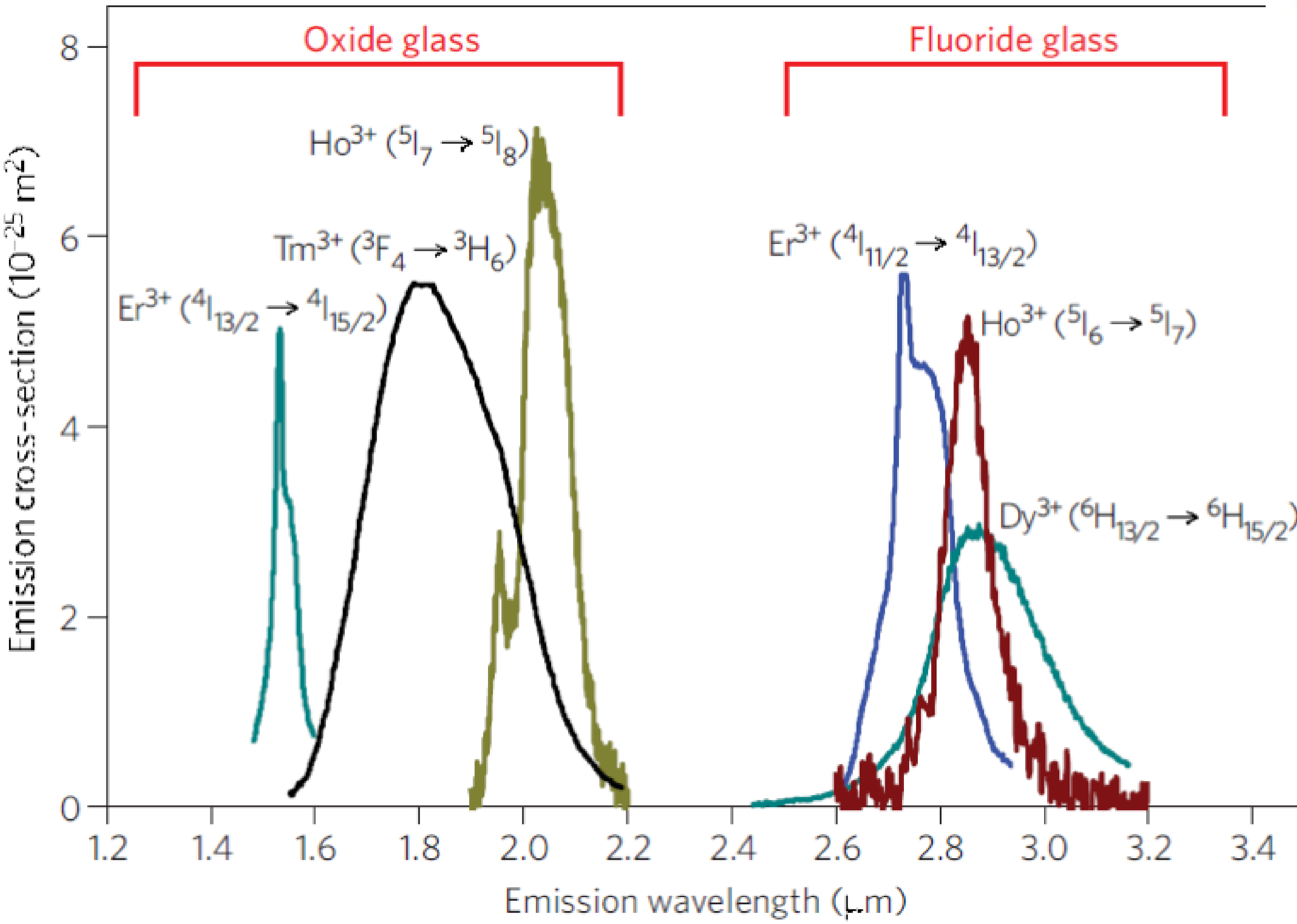
Fiber Lasers in the IR region





S.D.Jackson, Nature Photonics, 6,423 (2012)

Caracteristic of laser fiber

Dopant(s)	Host glass	Pump λ (μm)	Laser λ (μm)	Transition	Output power (W)	Slope efficiency (%)	Reference
Er^{3+}, Yb^{3+}	Silicate	0.975	1.5	$^4I_{13/2} \rightarrow {}^4I_{15/2}$	297	19	21
Tm^{3+}, Ho^{3+}	ZBLAN	0.792	1.94	$^3F_4 \rightarrow {}^3H_6$	20	49	33
Tm^{3+}	Silicate	0.793	2.05	$^3F_4 \rightarrow {}^3H_6$	1,050	53	22
Tm^{3+}, Ho^{3+}	Silicate	0.793	2.1	$^5I_7 \rightarrow {}^5I_8$	83	42	34
Ho^{3+}	Silicate	1.950	2.14	$^5I_7 \rightarrow {}^5I_8$	140	55	23
Tm^{3+}	ZBLAN	1.064	2.31	$^3H_4 \rightarrow {}^3H_5$	0.15	8	35
Er^{3+}	ZBLAN	0.975	2.8	$^4I_{11/2} \rightarrow {}^4I_{13/2}$	24	13	24
Ho^{3+}, Pr^{3+}	ZBLAN	1.1	2.86	$^5I_6 \rightarrow {}^5I_7$	2.5	29	25
Dy^{3+}	ZBLAN	1.1	2.9	$^6H_{13/2} \rightarrow {}^6H_{15/2}$	0.275	4.5	36
Ho^{3+}	ZBLAN	1.15	3.002	$^5I_6 \rightarrow {}^5I_7$	0.77	12.4	26
Ho^{3+}	ZBLAN	0.532	3.22	$^5S_2 \rightarrow {}^5F_5$	0.011	2.8	27
Er^{3+}	ZBLAN	0.653	3.45	$^4F_{9/2} \rightarrow {}^4I_{9/2}$	0.008	3	28
Ho^{3+}	ZBLAN	0.89	3.95	$^5I_5 \rightarrow {}^5I_6$	0.011	3.7	29

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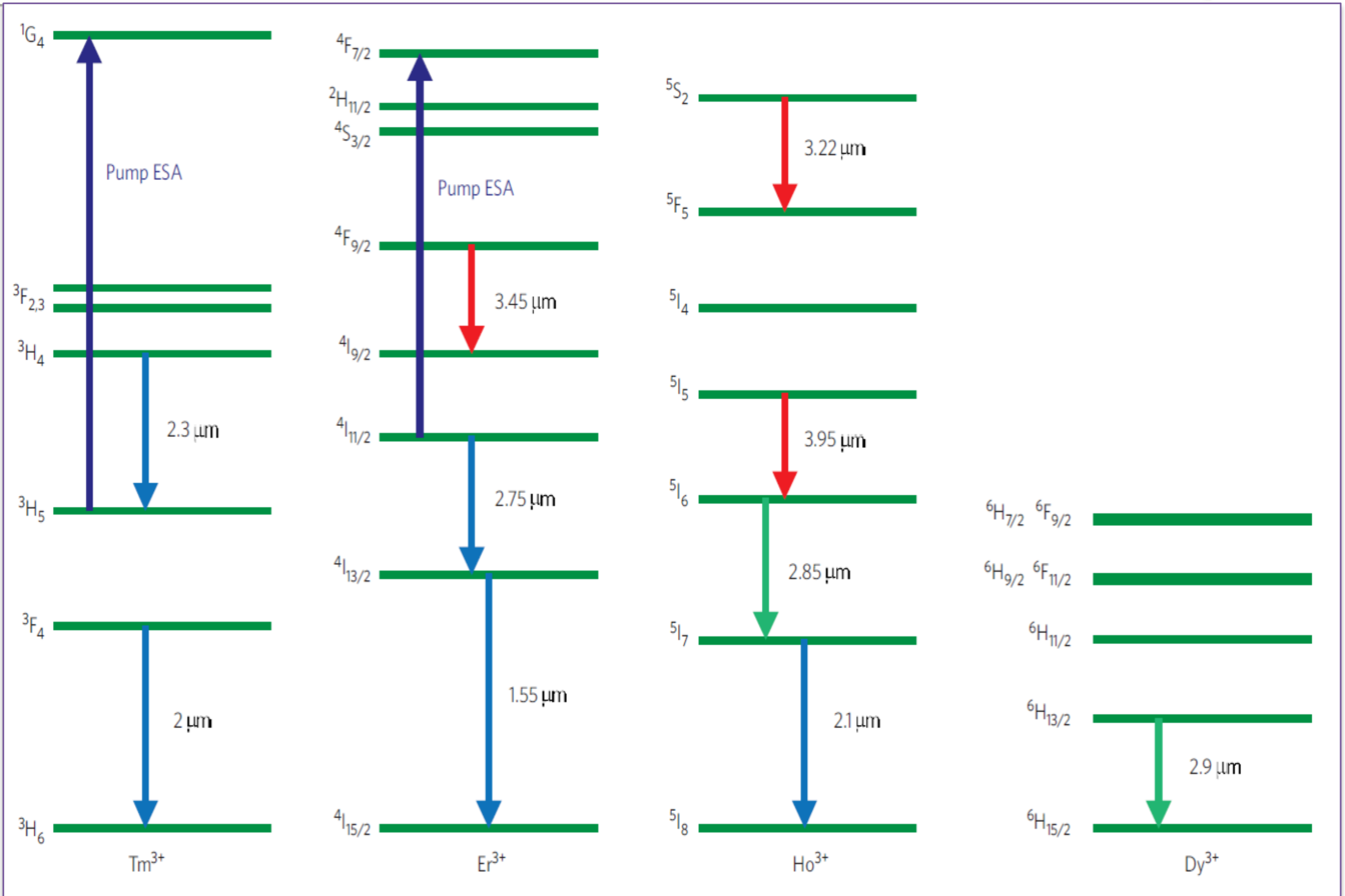

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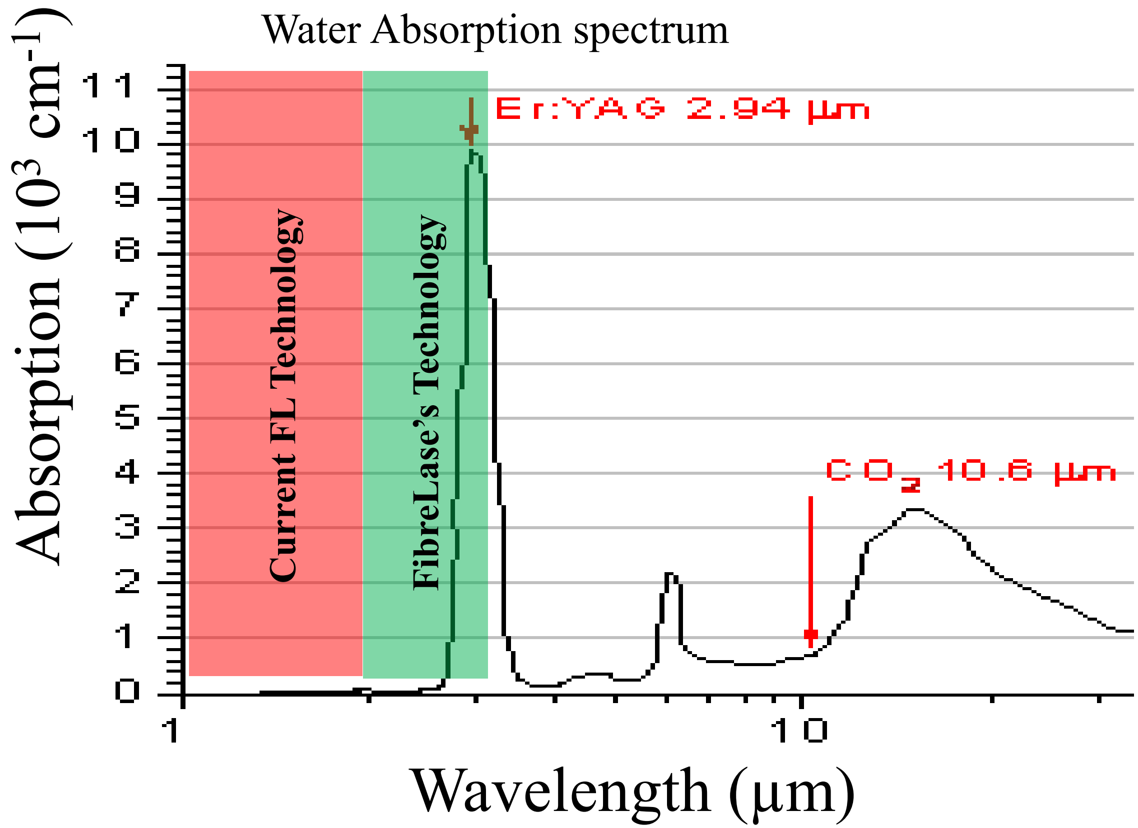
- ➢ Mid-IR radiation (especially at 2.94 µm) is ideal for <u>ablation</u> and <u>cutting</u> of biological tissues

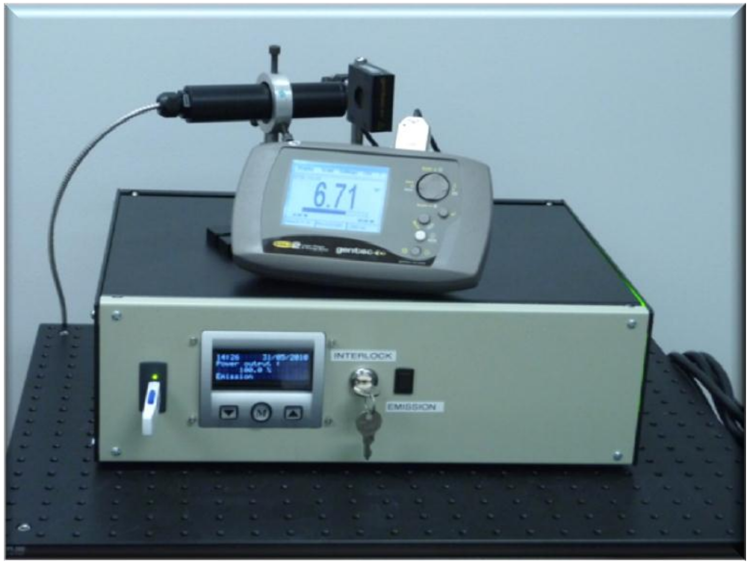


D. Faucher &al., Opt. Lett. **34**, 3313 (2009)

- **Current Medical laser systems rely on old laser technology which is:**
  - Expensive: high acquisition cost
  - Unreliable: high maintenance cost
  - Cumbersome and Inefficient

- **Fiber lasers have proven superior in terms of:**
  - Cost (acquisition and operation)
  - Ruggedness & Reliability
  - Size & Weight
  - Beam quality

- **FibreLase's technology in fluoride glass optical fibers unleashes the development of a new breed of Mid-IR fiber lasers ($\lambda > 2$ µm) for biomedical applications**



Prototype: 7 W @ 2940 nm

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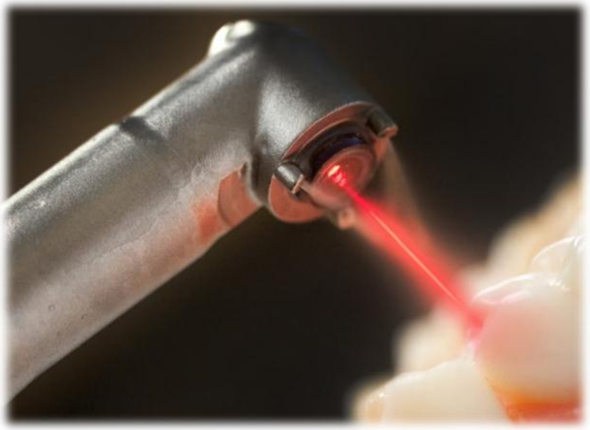
Lasers are increasingly used in medical procedures

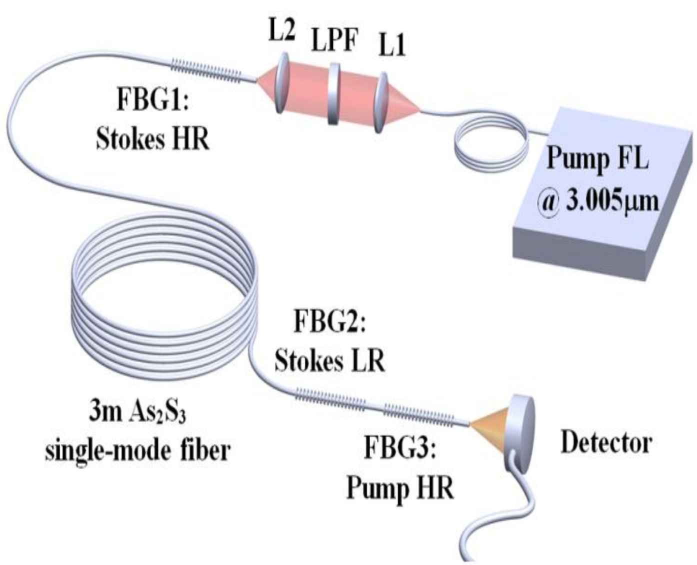
- Laser micro-surgery

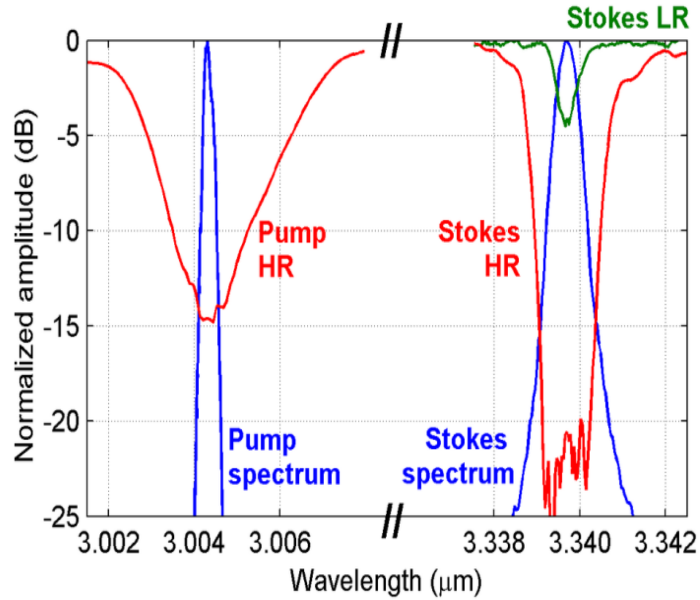
- Dental cavity removal

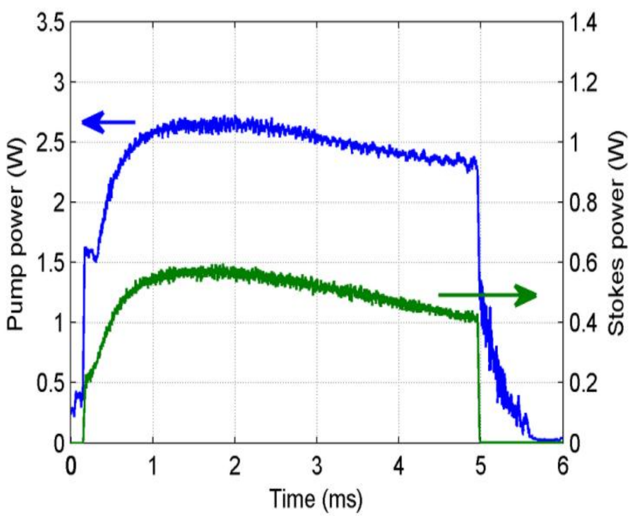


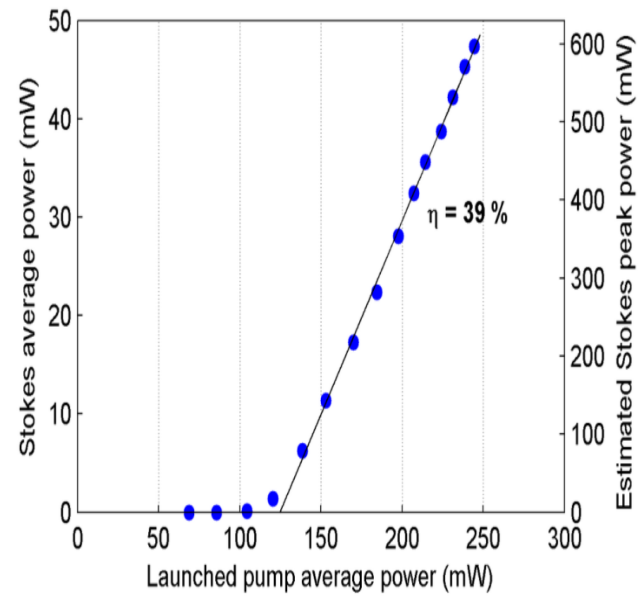
- Fractional Laser Resurfacing

Mid-infrared chalcogenide glass Raman fiber laser









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M.Bernier &al., Opt.Lett, 38, 127, 2013

Silica Fiber

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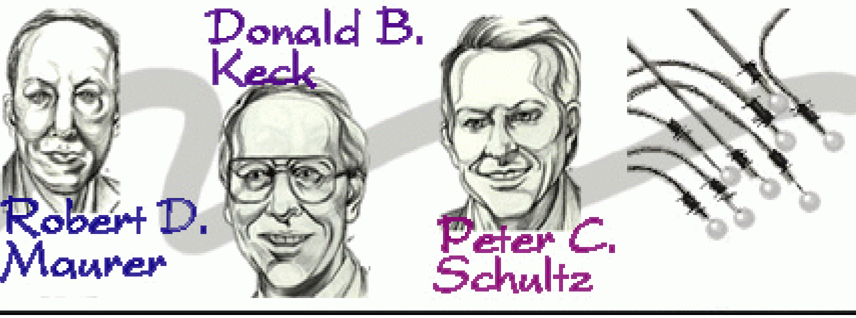
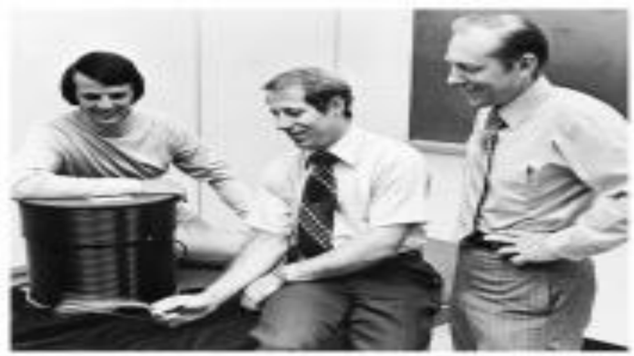
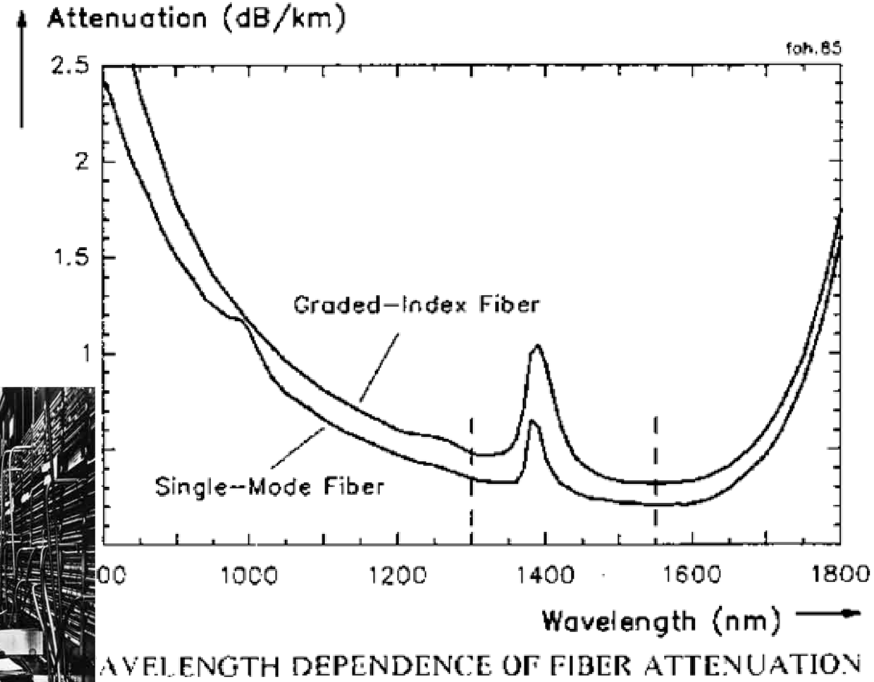
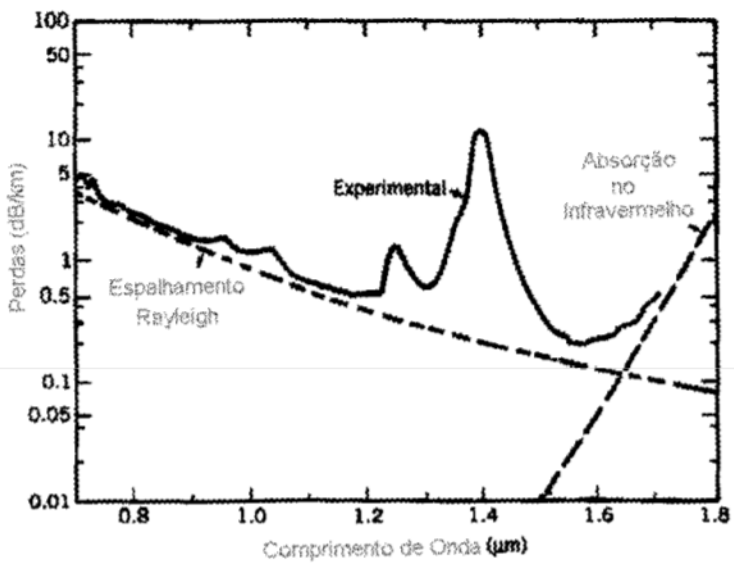




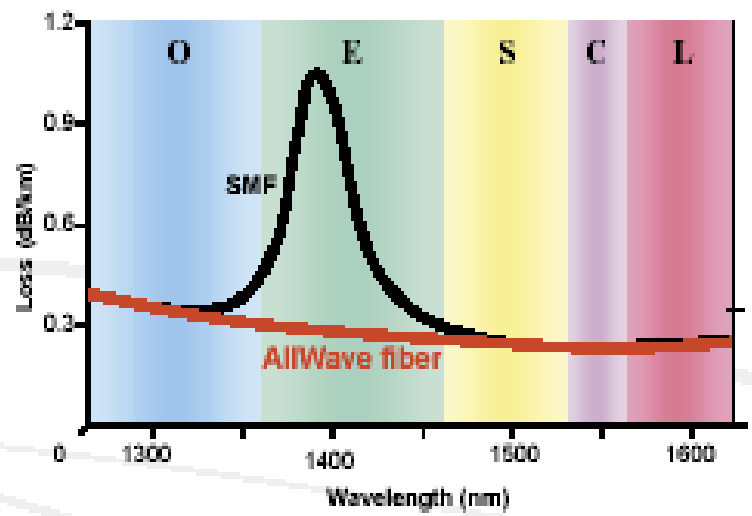


Decade 70



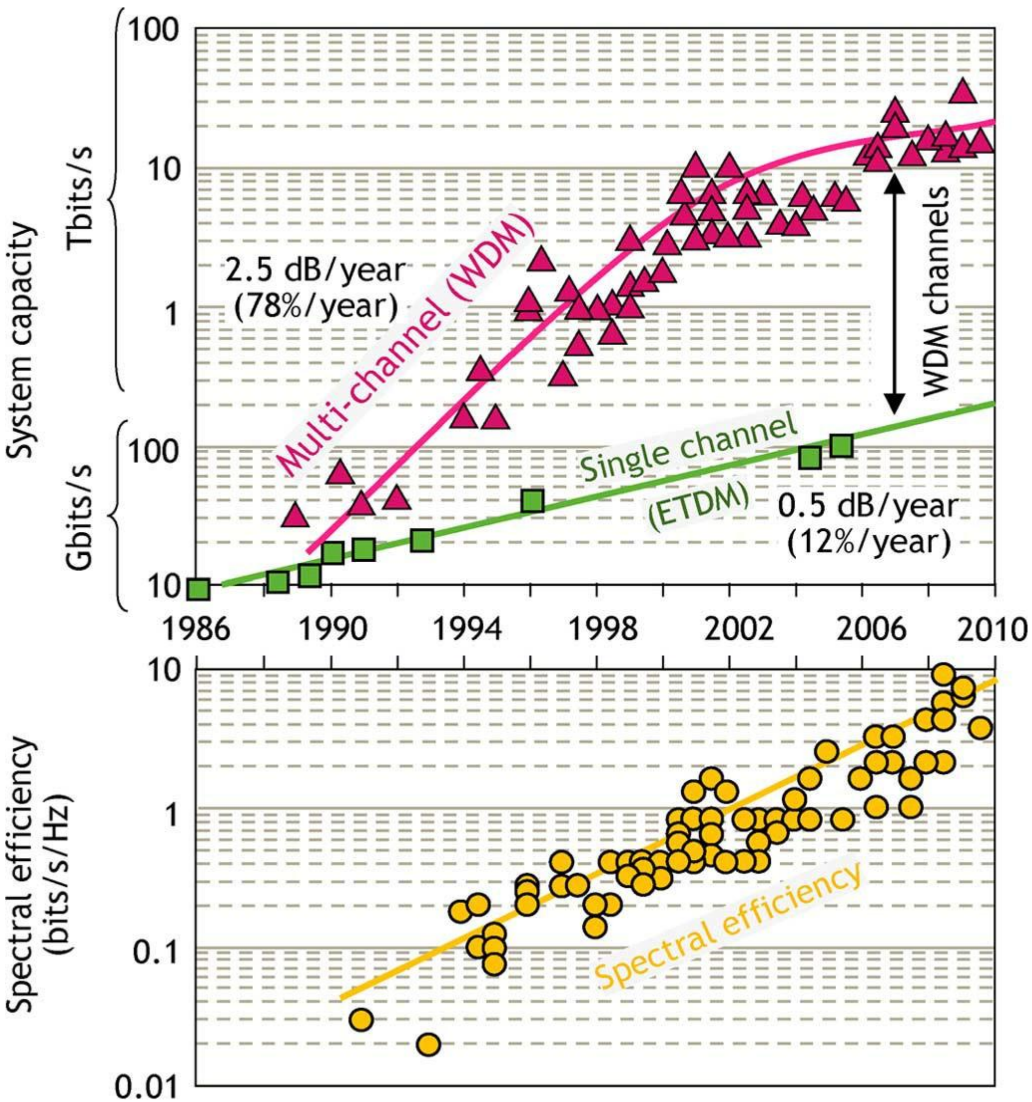
Decade 80

Figure 1. Comparison of Spectral Attenuation of AllWave Fiber and Conventional Single Mode Fiber



XXI Centry

Evolution of Record Capacity in Optical Fibers



R.-J. Essiambre &al., *J. Lightwave Technol.* 28, 662 (2010)

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Strategie for development

Linear Transmission:

- Increasse Aeff
- Bending losses?

k.Mukasa, IEICE Trans Comm, 94, 2011

Spectral Bandwidth:

- Microstructured/hollow core
- Need for amplifiers

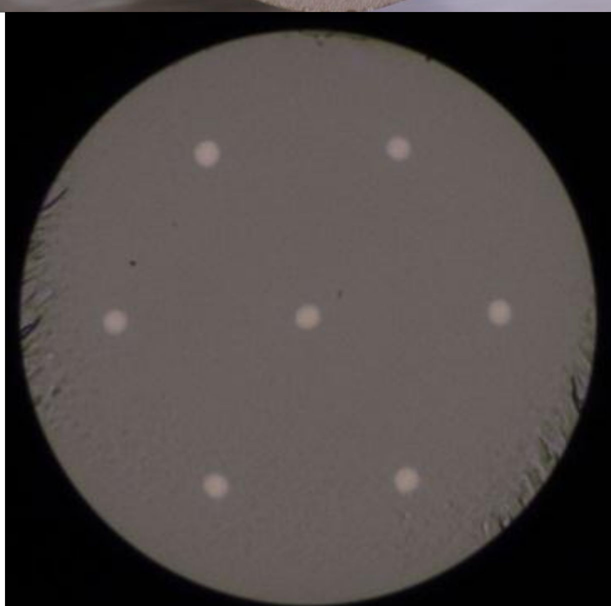
Y.Mimura, ECOC conference, 2012

Spatial multiplexing

- Multicore
- Multimode (Few modes, Few modes groups)
- Multicore + multimode

M.Salsi, ECOC, 2012

Multicore and multimode fibers for spatial division multiplexing



- Uniform Gain;
- Large Aeff
- Low Cross Talk
- Low Noise Figure
- Low Macro-bending
- Adaptability to radiation

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Electro-optical fibers

Core diameter: **3.6±0.4μm**
Numerical Aperture: **0.27±0.01**
Cladding outside diameter: **250±50μm**
Holes diameter: **75±15μm**

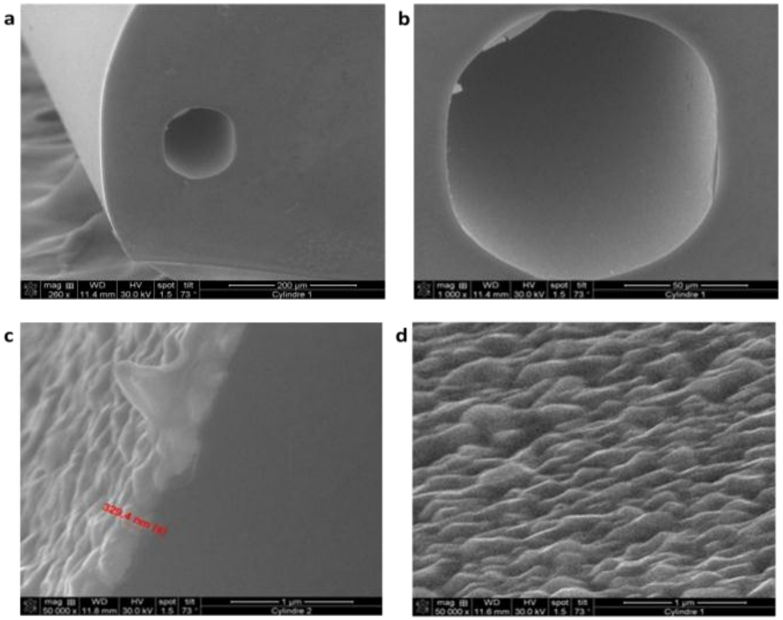
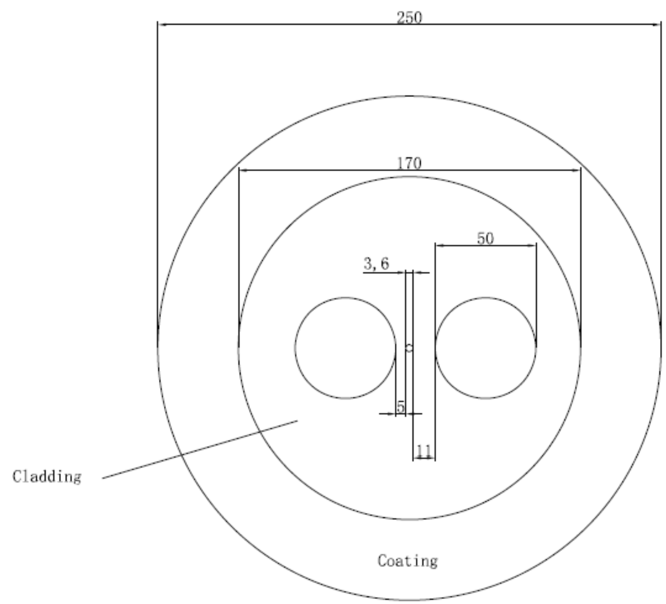
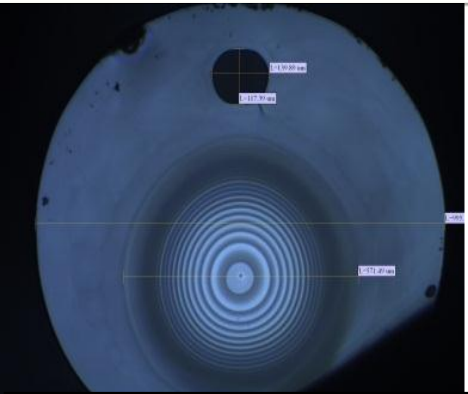


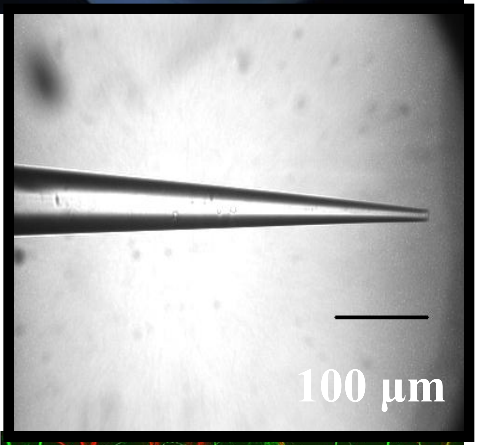
Fig 3. a,b,c,d) Images SEM, à différent grossissment, de la fibre dans laquelle un dépôt métallique a été réalisée.

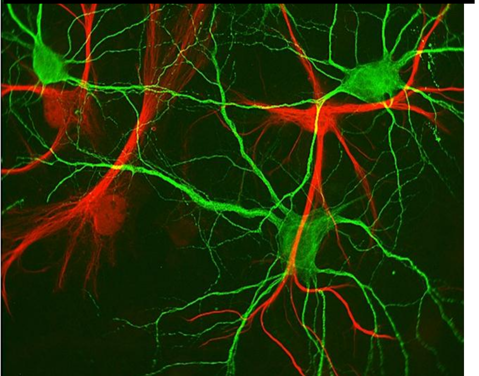
Twin-hole Fiber Intersection

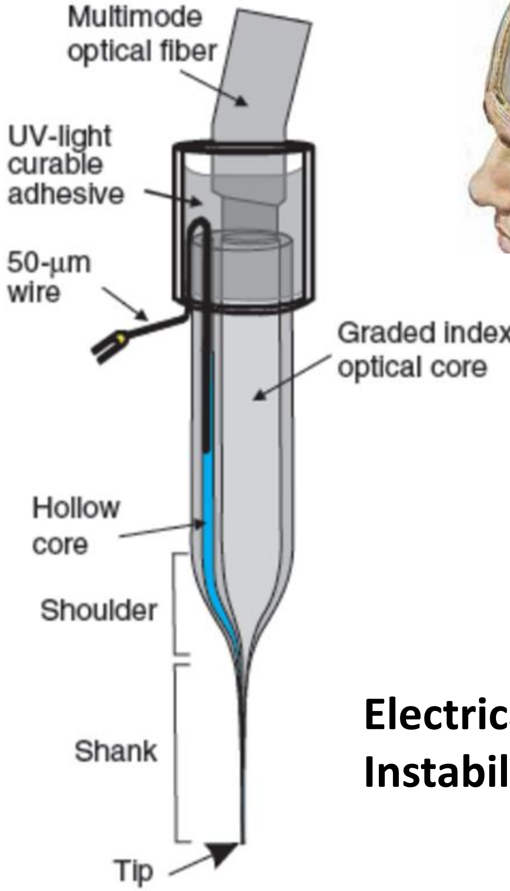


Special Fibers for Life Science









Electrical Resistance : 6-26 MΩ
Instability of the driver medium

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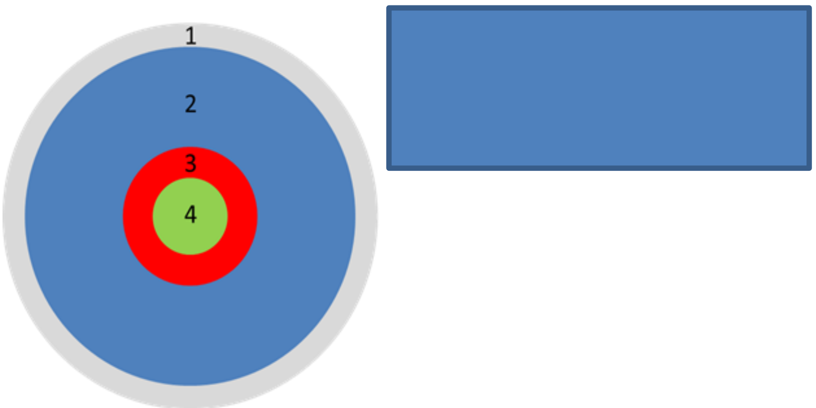
Y.Lechasseur, Nature Method,v8,4,319 (2011)

Alternative Design of Optical Fiber



- Conductivity: σ (RT)> 10^{-3} S /cm;
- ≥ 70% transmittance in the visible (400 nm -700 nm);
- Viscosity of the components are similar to T fiber drawing;
- Thermal expansion Coefficients CTE2 ≈ CTE3 ≈ CTE4;
- Mechanical &chemical stability.

LEDEMI, Y; VIENS, J.F; GRAVEL, J.F; RIOUX, M; MESSADDEQ, Y, OPTOGENETIC FIBER, Patent n 61/661,028 , June 19, 2012.

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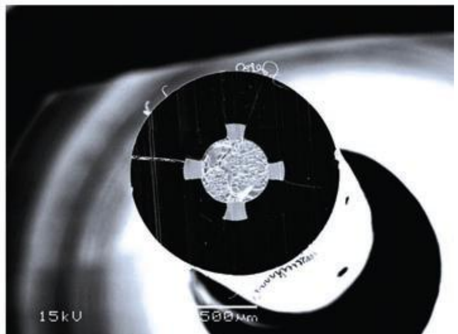
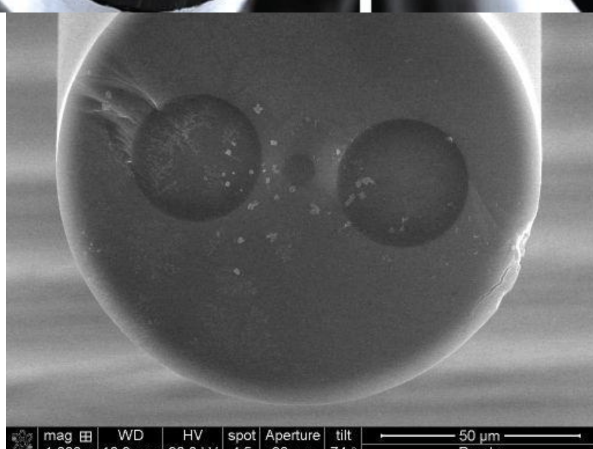
Multifonctionnel Fibers

RF textiles



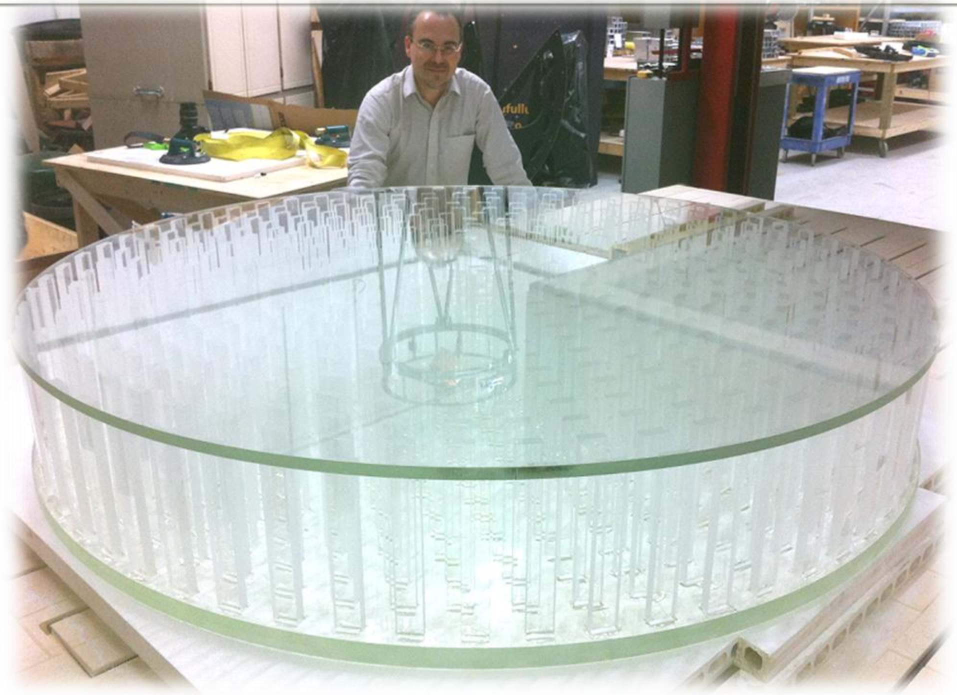


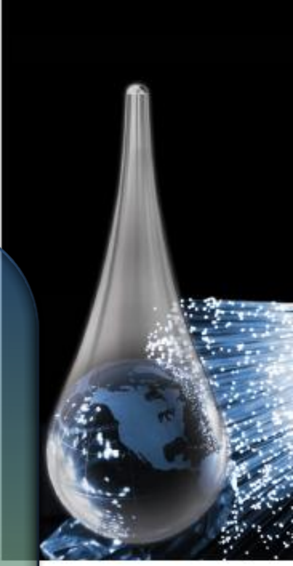
THz fibers

R.He &al., Nature photonics,6,174,2012

Perspectives

1.6 meter diameter lightweight mirror made of fused borosilicate





- High-res teledetection
- IR teledetection
- Border patrol
- Long-distance surveillance
- Airborne surveillance
- Drone optics
- Arrayed detection
- Mining prospection
- Forest prospection
- Environment monitoring
- Astrophysics

· **HIGH-RESOLUTION**: Large aperture parabolic mirrors from 0.5 to 2.5m.
· **HIGH-SENSITIVITY:** Fast focal ratios down to F/1.5 for NETD detectivity.
· **LIGHTWEIGHT:** Mirrors made of low-CTE glass materials with 75% lightweighting ratio for enhanced thermal stability and mobility.
· **LOW-COST**: Mold-less, low-temperature glass fusion process that provides 75% manufacturing cost reduction.
· **FLEXIBILITY**: Mirrors can be adapted to standard VIS, SWIR, MWIR and LWIR focal plane arrays.
· **ROBUST**: Survives 200C thermal shocks and 20g accelerations.

J.Viens, Y.Messaddeq, Moldless Lightwidth Mirror BLank Assembly, Patent 61/706,883 (2012).

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Long-range mobile teledetection

Prof. YOUNES MESSADDEQ

Project objectives:

This project develops large-aperture and light-weight optics for mobile, field-deployable, long-range infrared teledetection.

Our collaboration with the *Centre d'Excellence des Drones* (Alma, QC) aims at embarking long-range optics aboard drones for civilian prospection applications.

0.5-meter diameter LWIR camera prototype

- 25 km human detection distance
- 300 km aircraft detection distance
- 18 kg weight, foldable, field-deployable
- 5 Watts power consumption

Medium-altitude long-endurance drone

Alma, QC

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Long-range mobile teledetection

Prof. YOUNES MESSADDEQ

0.5-meter diameter LWIR camera prototype

- Human detection distance up to 25 km
- Incoming aircraft detection distance 300 km
- 18 kg weight, foldable, field-deployable
- 5 Watts power consumption

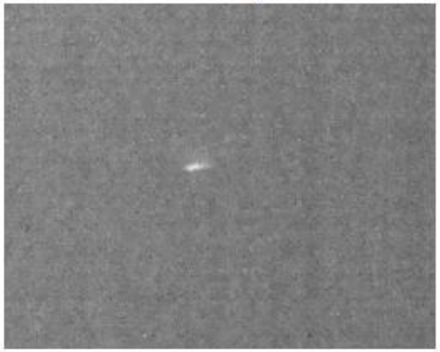
Pedestrian walking his dog 3 km distance

Raw Image

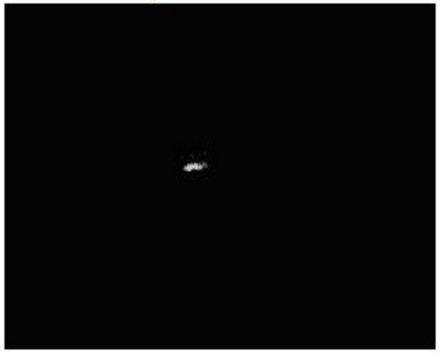
Background Substract

Incoming aircraft 300 km distance (0.7deg above horizon)

Raw Image



Background Substract



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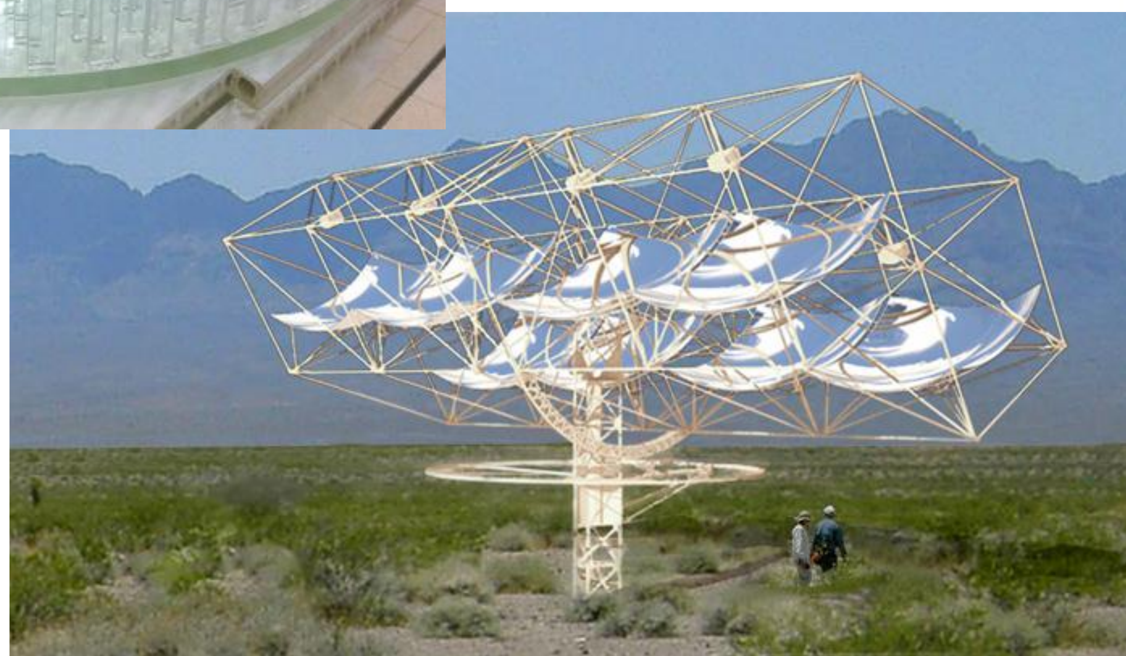
Large-aperture mirrors for concentrated solar energy

1.6 meter diameter lightweight mirror blank made of fused borosilicate



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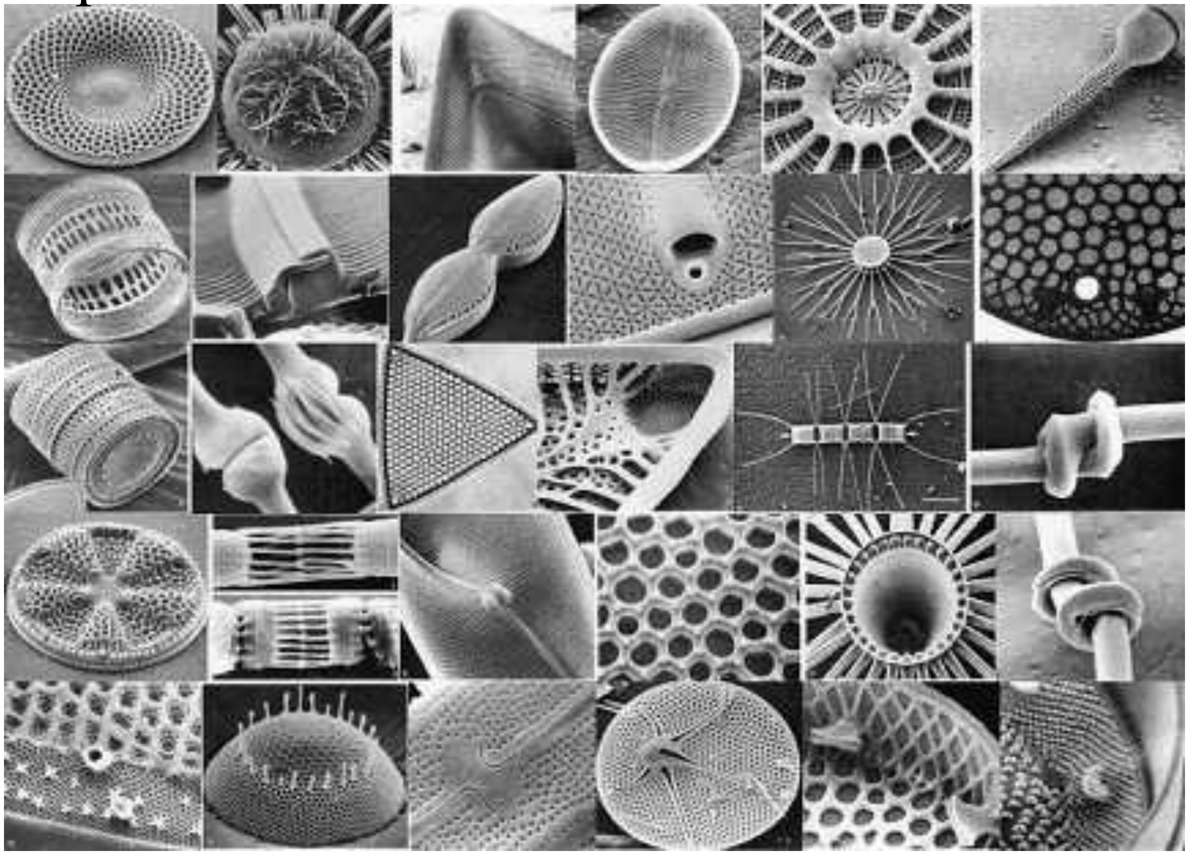
Diatoms

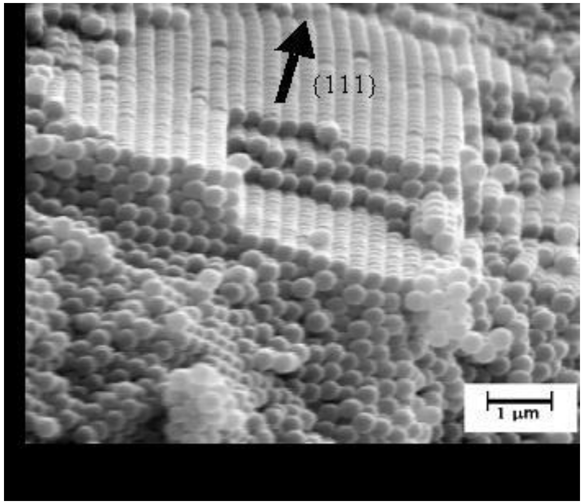
The diatoms are responsible for 20% of all the photosynthetic CO_2 consumption.

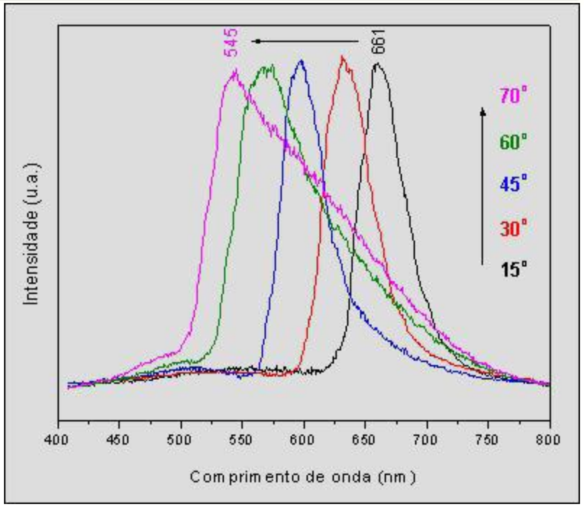


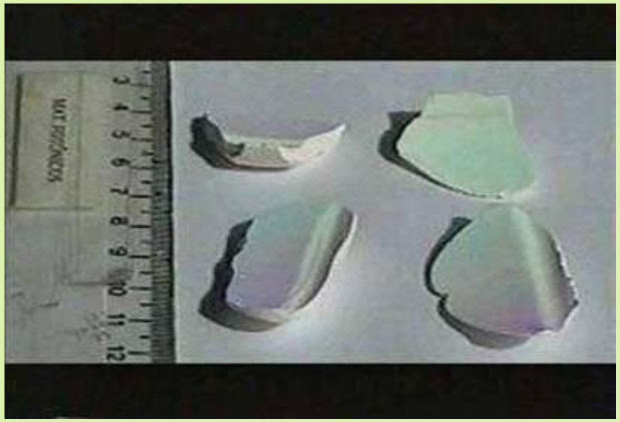
> 50.000 Species (5 µm to 5 mm)

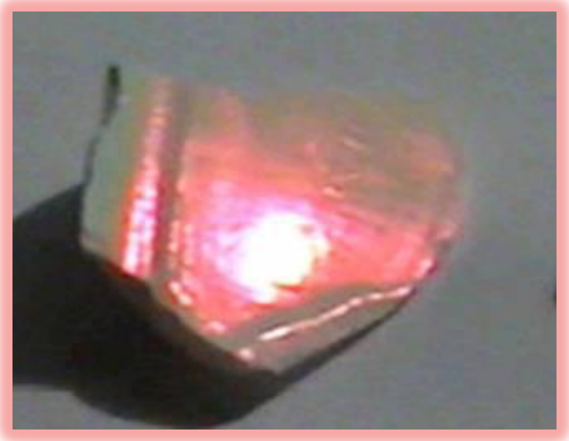
Glass Production > 10^{10} tons/year

Photonic Band -Gap









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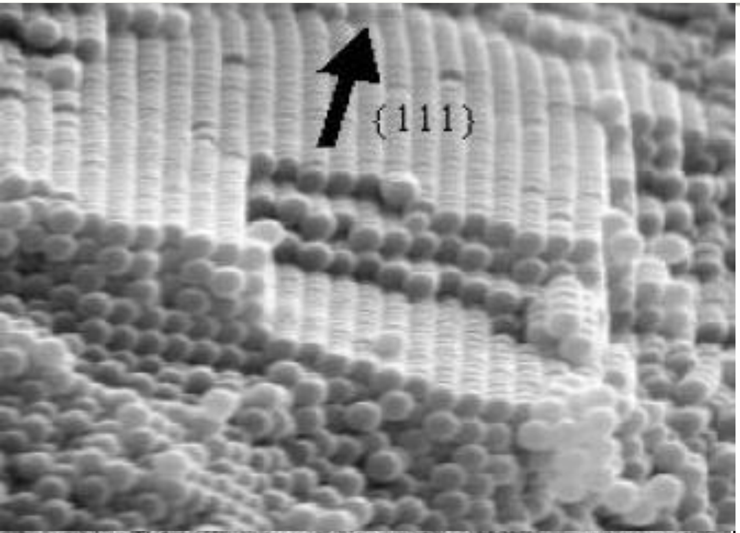
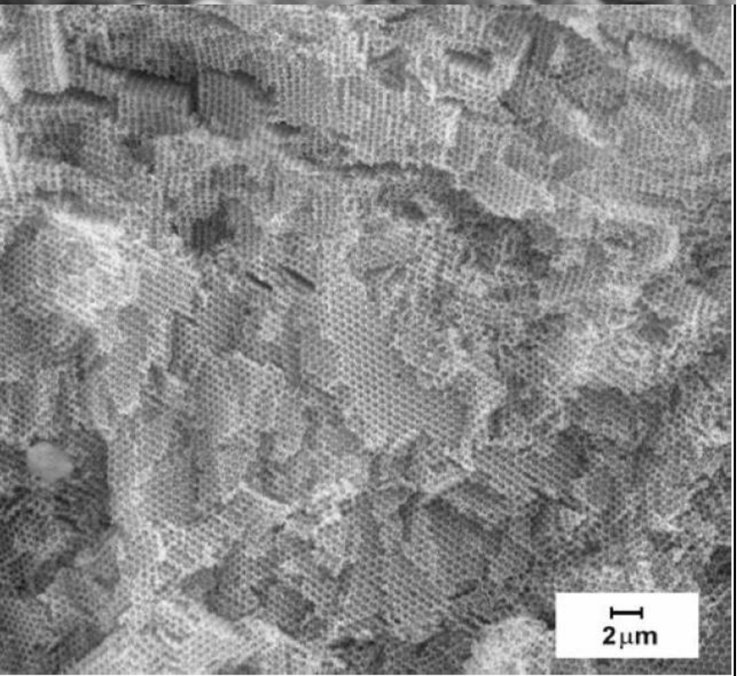
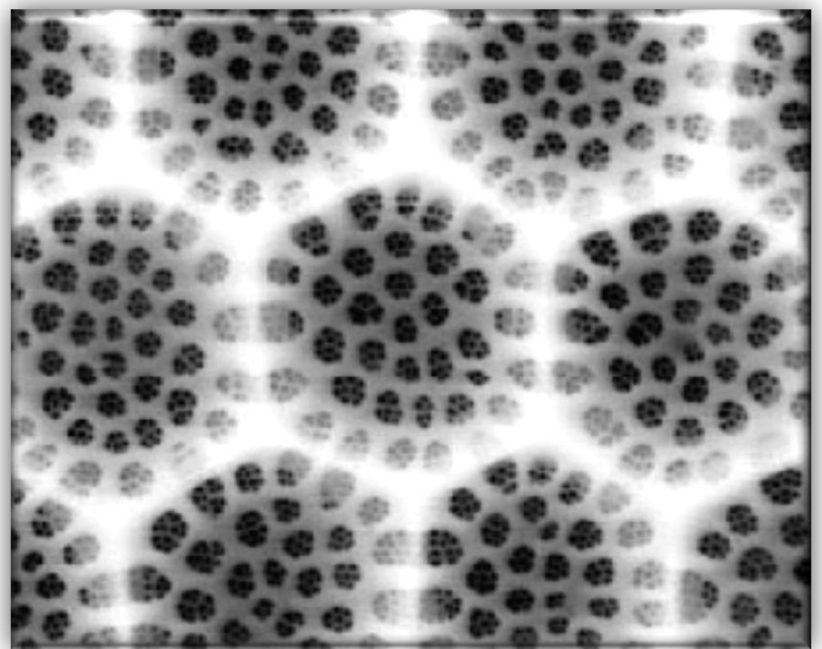
Y.Messaddeq e al. *J.Coll.InterfaceScience 291(2005)448*

Photonics band gap



Use of opals as molds in the preparation of materials with controlled porosity





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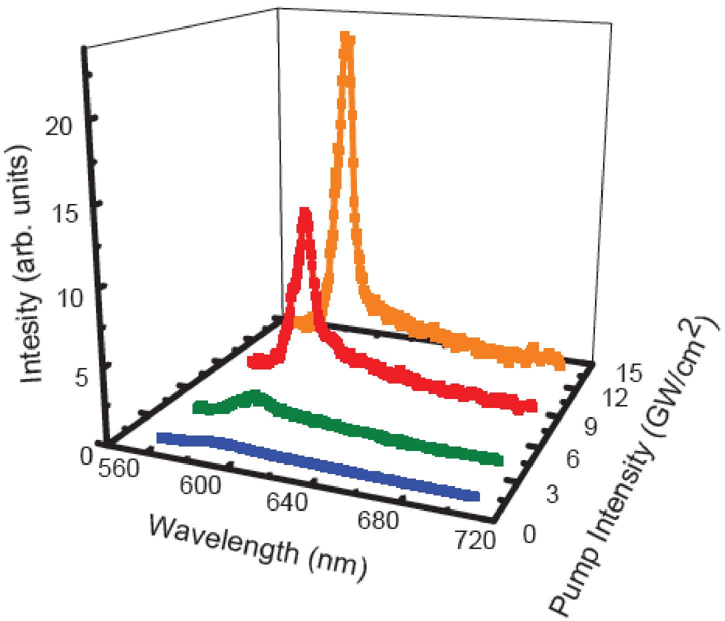
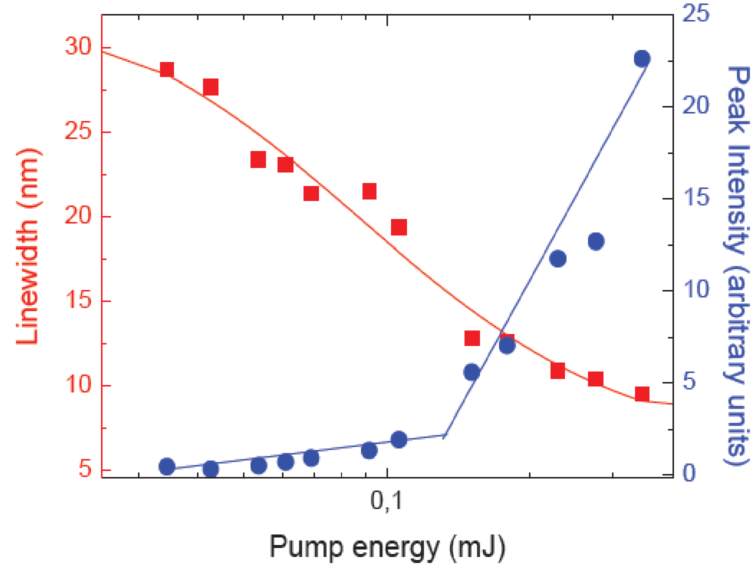
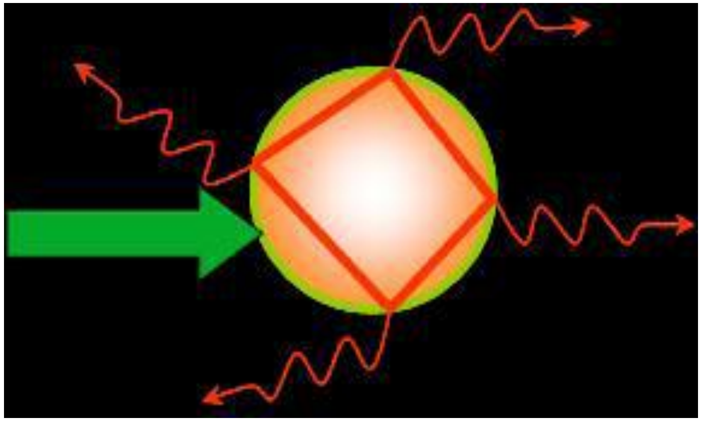
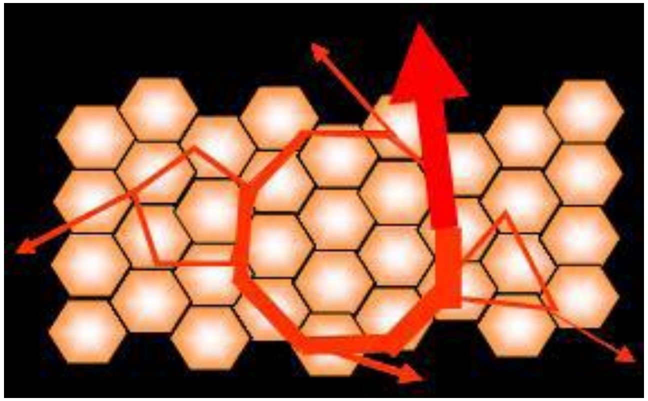
LASER Emission: Rodamin inside Inverse Opale









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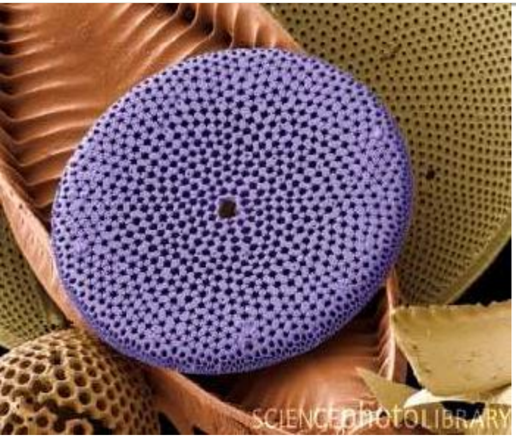
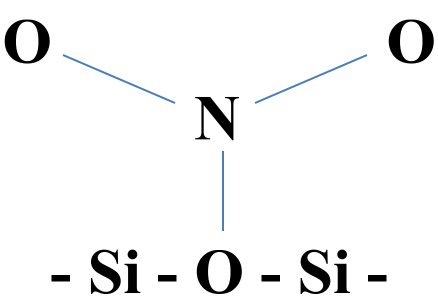
Y.Messaddeq, J. of Non-Crystalline Solids 351 (2005) 1846

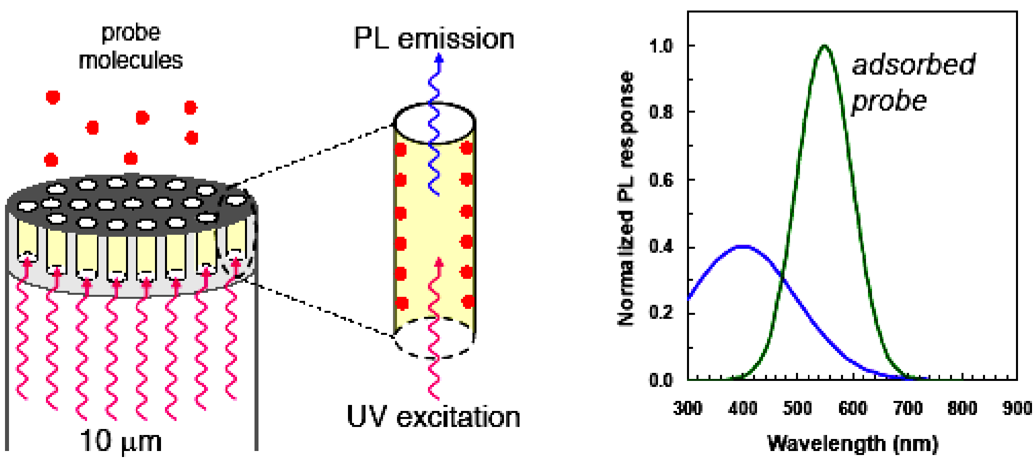
Marine diatoms as optical chemical sensors





Microsensor Device Development

(in cooperation with U.S. Department of Energy
Pacific Northwest National Laboratory)



Cyclotella frustule mounted onto tip of fiber optic cable

probe molecules adsorbed on surface uniquely change photoluminescent (PL) emission

Interfacing the nanostructured biosilica microshells of the diatom ***Coscinodiscus wailesii*** with biological matter.

De Stefano et al. ***Appl. Phys. Lett. 87 (2005) 233902***

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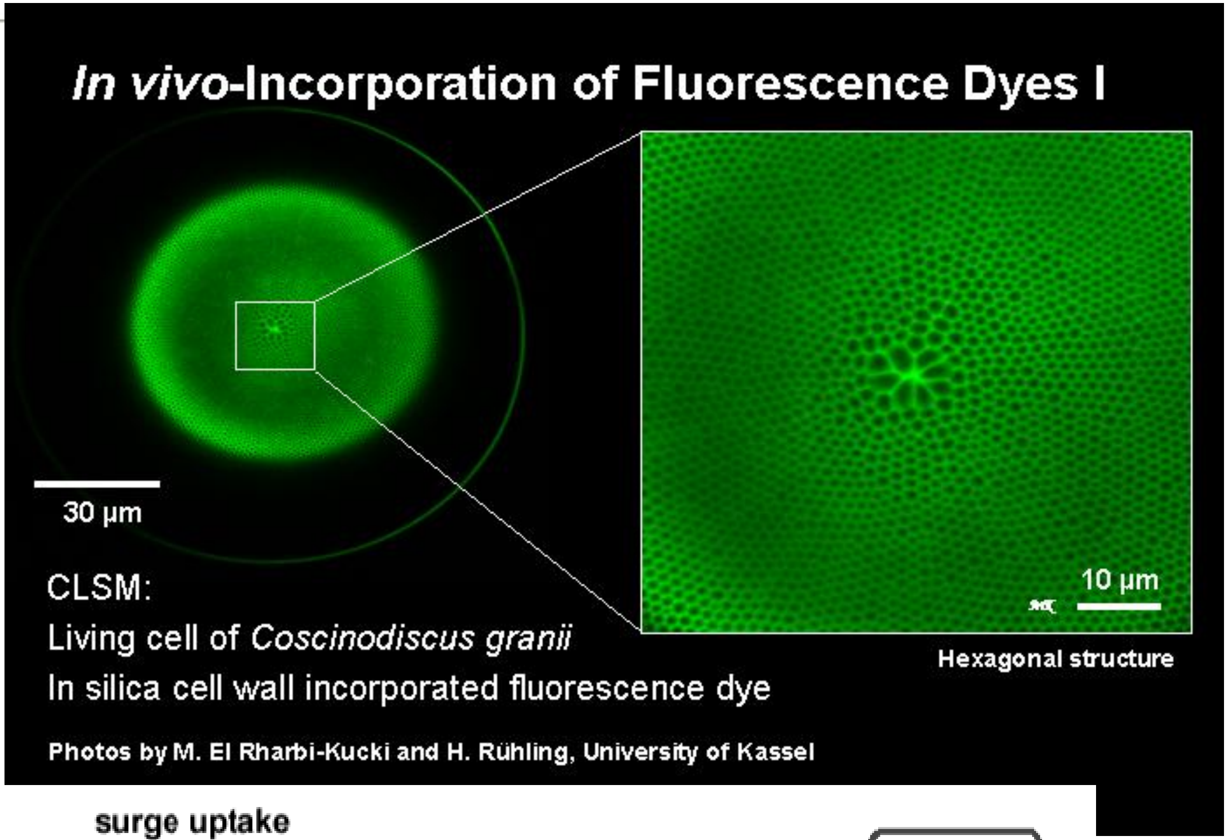
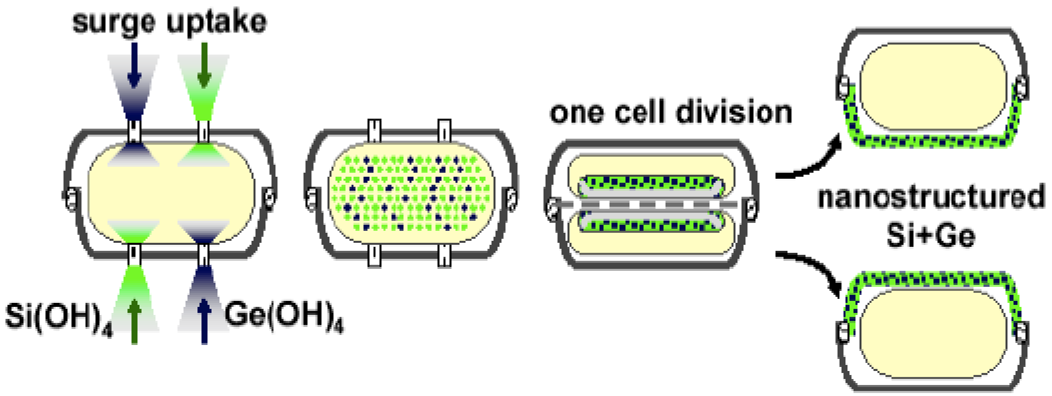
Nano-lasers



In vivo-Incorporation of Fluorescence Dyes I
30 µm
10 µm
CLSM:
Living cell of *Coscinodiscus granii*
In silica cell wall incorporated fluorescence dye
Hexagonal structure
Photos by M. El Rharbi-Kucki and H. Rühling, University of Kassel



surge uptake
$Si(OH)_4$
$Ge(OH)_4$
one cell division
nanostructured
Si+Ge

WWW.CERCP.CA

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Acknowledgements

Canada Excellence Research Chairs

Chaires d'excellence en recherche du Canada

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